Deep Dive City

Mumbai, India

City Characteristics

Mumbai is the capital of the Indian State of Maharashtra and the most populated city in the country. It is run by the municipal corporation of Greater Mumbai, also known as BMC. BMC has an exponentially increasing population of ca. 20 million inhabitants in 2021 compared to 12.5 million inhabitants in 2011[1]. It is spread over an area of 437.71 km², resulting in a population density of ca. 28,471 inhabitants per km²[2] in 2021. The surrounding Mumbai Metropolitan Region (MMR) is spread over an area of 6,328 km²[2] and has a total population of 24 million inhabitants[2]. It comprises 9 municipalities, 9 municipal councils and more than 1000 villages[3]. The population density in MMR is ca. 3,700 inhabitants per km²[2,4].

The geographical location of Mumbai facilitates this island city with several trading and business opportunities. It is located on the western coast of India on the bank of the Arabian Sea and consists of seven islands. The average altitude mostly ranges from 10-15 meters, except in the hilly northern part, where the altitude reaches up to 450 meters[5].

The climate of Mumbai is a tropical, wet and dry climate, which can be described as moderately hot with a high level of humidity. It has an average annual temperature of 27°C and an average annual precipitation of 2421mm [6]. The city's coastal nature and tropical location ensure lesser temperature fluctuations, but since 1973, an increase of 0.25°C has been noticed every decade. Some other climate risks include urban flooding, landslides, coastal risks like cyclones and rising sea levels and air pollution[7].

Mumbai is also India's commercial and entertainment capital, making it among the world's top fifteen centres for commerce in terms of global financial flows. It accounts for more than 6.16% of the country's GDP. It had a nominal GDP per capita of ca. US$ 10,600. Whereas the national average nominal GDP for India was US$ 2301.42 per capita in 2021[8].

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[1] TUMI E-Bus Mission, 'Factsheet - Mumbai'.

[2] Mumbai Municipal Corporation, C40 Cities, and Government of Maharashtra, 'Mumbai Climate Action Plan'.

[3] Mumbai Municipal corporation, 'Mumbai Metropolitan Region Development Authority - About MMR'.

[4] Mumbai Municipal Corporation, C40 Cities, and Government of Maharashtra, 'Mumbai Climate Action Plan'.

[5] Topographic-Map.com, 'Mumbai Topographic Map, Elevation, Terrain'.

[6] TUMI E-Bus Mission, 'Factsheet - Mumbai'.

[7] Mumbai Municipal Corporation, C40 Cities, and Government of Maharashtra, 'Mumbai Climate Action Plan'.

[8] World Bank, 'GDP Per Capita: India'.

Transport system

Residents of Mumbai make an average of 2.14 trips per day[9] and ca. 7.5 million people commute in and across the city, using public transport daily[10]. The transport system mostly relies on various forms of public transport (ca. 45% modal split) such as city buses, suburban rail, monorail, and metro, followed by active forms of transport like walking and biking, which collectively account for 33% of the modal split. Furthermore, private vehicles like cars and two-wheelers take up to 15% of the modal split, leaving the rest 7% for intermediate public transport options such as autorickshaws and taxis[11].

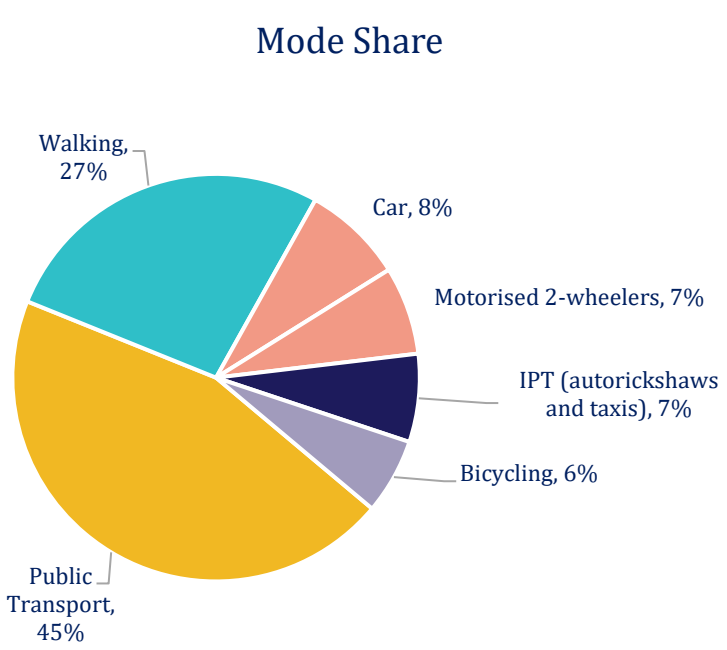


Figure 1: Modal Split. Source: TUMI e-bus mission factsheet Mumbai 2022

There are 6 main public transport authorities in Mumbai. The Mumbai Suburban Railways (49% modal share) being the most widely used option, operates a fleet of over 152 trains on three main lines[12]. Next, the Brihanmumbai Electric Supply and Transport (BEST) bus service (30% modal share) operates a network of 4128 buses on 507 routes and covers ca. 210 km distance per bus per day. The Mumbai metro operates 36 metro trains (5% modal share) on three different routes and the Mumbai monorail (1% modal share) operates 8 trains on 1 monorail line[13]. Additionally, as a form of intermediate public transport and to facilitate last-mile mobility (15% modal share), Mumbai offers a widespread network of 246,458 registered rickshaws

[9] Mumbai Municipal corporation, 'Mumbai Metropolitan Region Development Authority - About MMR'.
[10] Indian Railways, 'Western Railway'.
[11] TUMI E-Bus Mission, 'Factsheet - Mumbai'.
[12] Indian Railways, 'Western Railway'.
[13] Mumbai Municipal corporation, 'Mumbai Metropolitan Region Development Authority - About MMR'.

and 58,000 registered taxis. The average fleet age is 10 years old, and at least 85% of the fleet is utilized and occupied daily[14].

The Brihanmumbai Municipal Corporation (BMC) owns the BEST bus service. Most of the BEST buses are run on CNG and Diesel, but to achieve the emission targets, the first BEST electric bus was introduced in 2017. By 2022, BEST had successfully added 400 electric buses to its fleet[15].

Climate and air pollution targets

Mumbai has set an ambitious target of achieving at least 10% electric vehicle (EV) penetration in the city by 2025[16] and 96% penetration by 2050[17]. The city also aims to reduce local emissions from public transport and adopt sustainable bus operations by ensuring electrification of 50% of its fleet by 2024 and 100% electrification by 2027 along with fleet augmentation to 10,000 public buses[18].

Table 1: % Emission reduction targets (ambitious scenario), compared to 2019 levels. Source: Mumbai Climate Action Plan 2022

% Reduction of overall greenhouse gas emissions, compared to 2019 levels in Mumbai	
2030	27.1%
2040	43,8%
2050	71.5%

Table 2: Mumbai's public transport mode share and electrification plan. Source: Mumbai Climate Action Plan 2022

Target	2030	2040	2050
% Mode share of public transport	73%	78%	85%
% Electrification of passenger automobiles	35%	70%	96%
% Electrification of light-duty freight	29%	70%	100%

[14] Mumbai Municipal corporation.

[15] BES&T Undertaking, 'EBus'.

[16] TUMI E-Bus Mission, 'Factsheet - Mumbai'.

[17] Mumbai Municipal Corporation, C40 Cities, and Government of Maharashtra, 'Mumbai Climate Action Plan'.

[18] TUMI E-Bus Mission, 'Factsheet - Mumbai'.

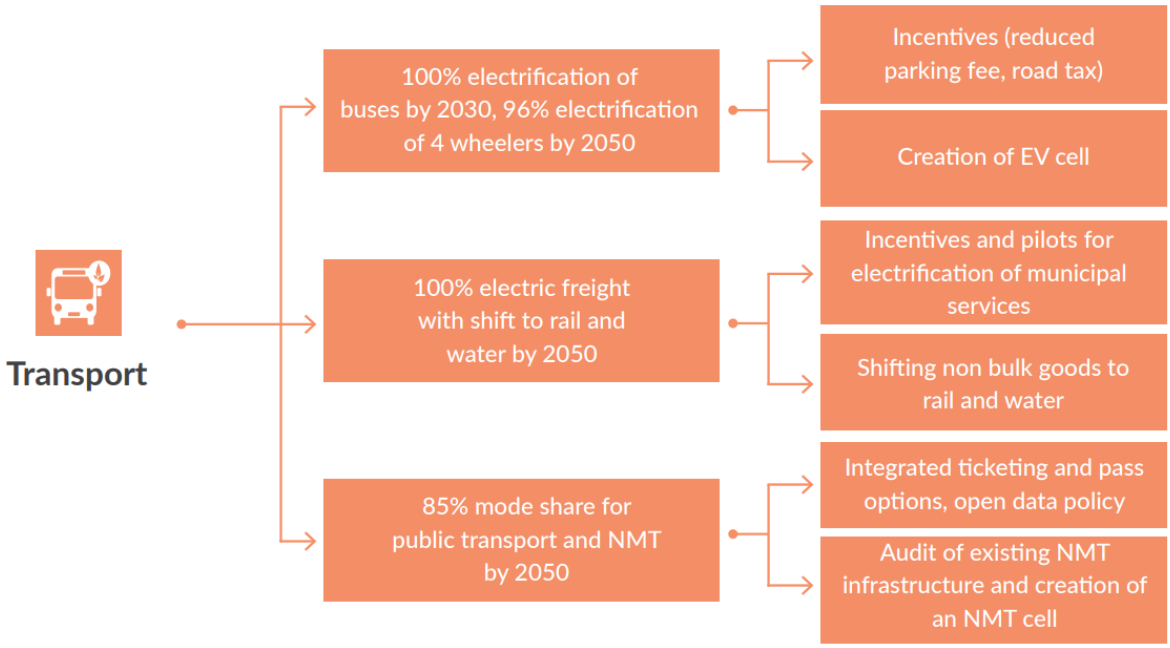


Figure 2: Mumbai City's target to action plan, Source: Mumbai Climate Action Plan 2022

Targets and policies related to the procurement of e-buses

Mumbai City has developed the Mumbai Climate Action Plan (MCAP) with tangible goals to decarbonise the transport sector. The aim is to increase the public transportation share via e-bus deployment and improved bus services[19].

Table 3: Targets for electric bus adaptation. Source: TUMI e-bus mission 2022

Targets for electric bus adaptation in Mumbai	
2023	Target to procure 2,100 e-buses (1900 single-decker + 200 double-decker e-buses)
2024	50% electrification
2027	100% electrification

By 2022, 400 e-buses were operating in Mumbai[20]. The city plans to have more than 2000 e-buses by the end of 2024[21]. In 2021, the Environment & Climate Change Minister of the Maharashtra state announced that BEST would operate 10,000 clean buses by the end of 2027, which would more than double the current bus fleet size of ca. 4,000 buses[22].

[19] Mumbai Municipal Corporation, C40 Cities, and Government of Maharashtra, 'Mumbai Climate Action Plan'.
[20] BES&T Undertaking, 'EBus'.
[21] Mumbai Municipal Corporation, C40 Cities, and Government of Maharashtra, 'Mumbai Climate Action Plan'.
[22] Sen, 'In Two Years, Mumbai Will Have Two Electric Buses for Every Km of Road'.

National-level support programmes for procuring e-vehicles have supported the diffusion of e-buses in Mumbai, including the Faster Adoption and Manufacturing of Electric and hybrid vehicles in India I and II (FAME I, FAME II) and the National Clean Air Programme (NCAP)[23]. Procurement and planned projects by BEST Mumbai under those programmes comprise:

Table 4 Procured e-buses and planned procurement in Mumbai under FAME I & II and NCAP. Source: TUMI E-Bus Mission, 2022

Scheme	Result
FAME I	40 BYD Olectra e-buses
	20 e-buses - 9 m Non-Air conditioned (Non-A/C), + 6 (City funding) operational
	20 e-buses - 9 m Air conditioned (A/C)
FAME II	340 A/C e-buses: of which 200 9 m, and 140 12 m
	Issued tender for 2,100 e-buses and plans to transition their fleet in 1.5 years (2023);
	Plan to replace 898 ICE buses at their end of operation life with e-buses.
NCAP	20 A/C double-decker e-buses (2022/2023)
	Plan to use the remaining 69% of funds from NCAP by 2027.

[23] TUMI E-Bus Mission, 'Factsheet - Mumbai'.

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	9.620	0	13.120	19.960
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., 2.100 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 28% and constant transmission & distribution losses of 20%.

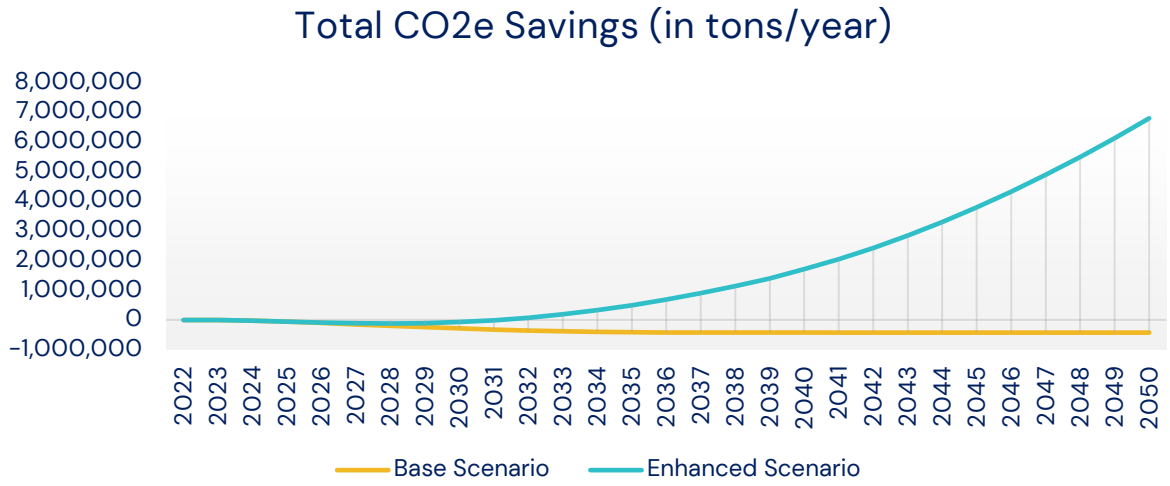
In the **enhanced scenario**, a key assumption was that the entire bus fleet is electrified by 2050 unless the city defined an earlier target for full electrification. Unless that city had no

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 a fleet size of 19.960 vehicles in 2050, this would mean that the city needs to procure 50.150 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 clean energy at 75% and that projected transmission and distribution losses will be gradually reduced to 10% by 2050.

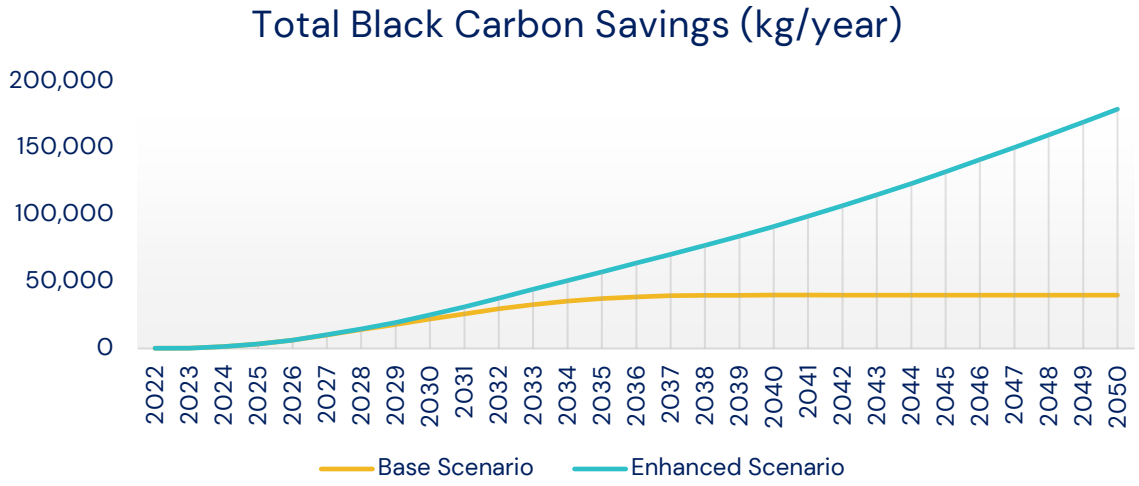
The tool estimates the cumulative savings for emissions and energy consumption by shifting to e-bus. Conventional urban buses are predominantly fuelled by diesel engines, emitting black carbon (BC), a harmful and carcinogenic particle. Other emissions that are analysed are the most crucial air pollutants 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)	22	40	25	179
CH_4 (tons)	69	124	80	562
CO (tons)	468	838	538	3.899
CO_2 (kilo tons)	-290	-432	-77	6.770
CO_2e (kilo tons)	-288	-428	-74	6.789
N_2O (tons)	0	1	2	55
NMVOC (tons)	58	106	69	576
NO_x (tons)	-1.464	-2.520	-1.411	-2.364
PM_{10} (tons)	221	393	256	1.902
$PM2_{.5}$ (tons)	124	221	143	1.047
SO_x (tons)	-166	-289	-171	-679
TSP (tons)	339	601	392	2.877
Energy consumption (MWh)	3.280.000	5.870.000	3.790.000	28.050.000
Energy consumption (TOE)	280.000	500.000	330.000	2.410.000

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.

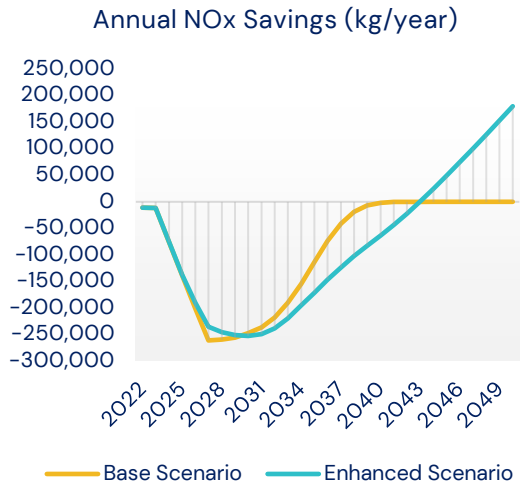


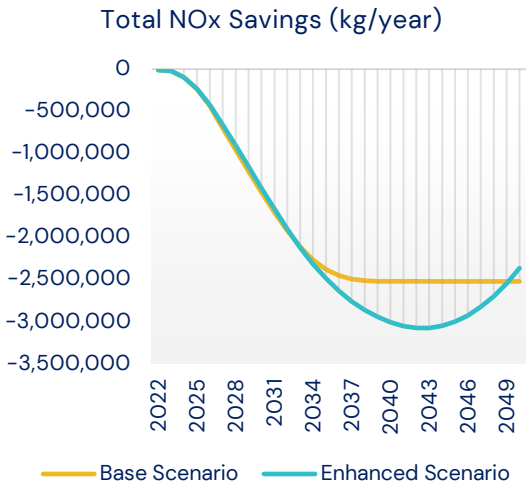
In the base scenario, by shifting to e-buses, the emissions will increase up to 428 ktCO2e by 2050, mainly due to the electricity generated from an electricity grid that is still dominated by fossil fuels (72%) and has high transmission and distribution losses (20%). In the enhanced scenario, the city will reduce about 6.770 $ktCO_2e$ up to 2050. The benefits from switching to e-buses are realised in GHG emissions mainly due to the increase in the number of buses compared and massive improvements in the energy mix.

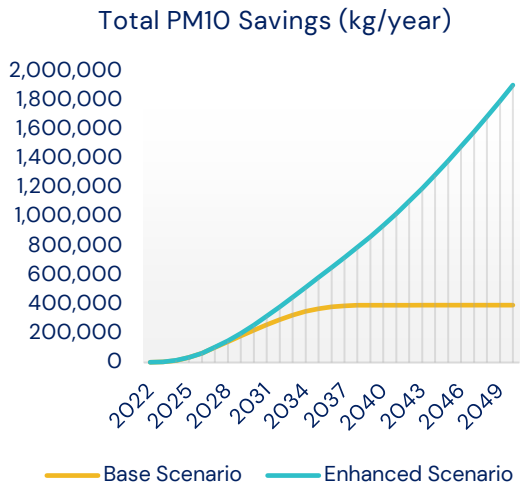


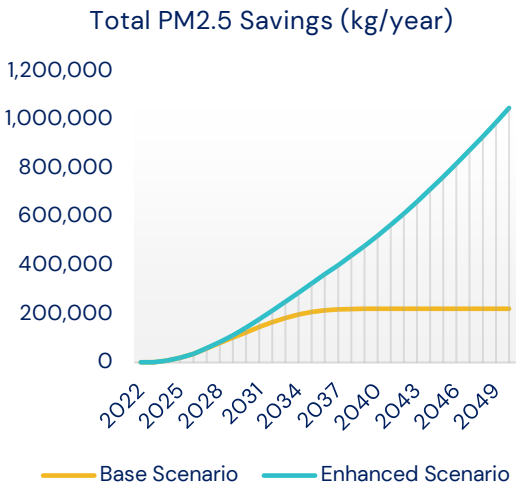
Electric buses decrease greenhouse gas emissions and improve air quality in the local area. The transition towards e-buses is expected to save the city a significant amount of black carbon, with an estimated 22 tons in 2030 and 40 tons by 2050 in the base scenario. Furthermore, the base scenario also predicts a significant reduction of tons of particulate matter saved by 2050. In the enhanced scenario, the reductions in black carbon and particulate matter by 2050 are 179 tons and 2.949 tons, respectively. The savings from the enhanced scenario are more than four 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 NO_x 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. The table above shows that the SOx emissions are increasing, the reason for this increase in the base scenario is that in addition to cleaning the grid if sulfur emission abatement technologies are also implemented and improved in the coal generation plants, the SOx emissions can be reduced. We have not incorporated the effect of such technologies on SOx emissions in this iteration of the tool.









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[24]. 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[25].

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[26]. 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.

[24] Climate Action Tracker, 'India'.

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

[26] Climate Action Tracker, 'India'.

List of Abbreviations

BC	Black Carbon
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
N_2O	Nitrous Dioxide
NMVOC	Non-Methane Volatile Organic Compound
NO_x	Nitrogen Oxides
PM	Particulate Matter
SO_x	Sulphur Oxides
T&D Losses	Transmission and Distribution Losses
TSP	Total Suspended Article

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