UITP ADVANCING PUBLIC TRANSPORT

WORKING PAPER

FLEET WIDE TRANSITION TO ZERO EMISSION BUSES

A ROADMAP FOR THE CITY OF BENGALURU

AUGUST | 2023

1. NEED FOR A FLEET WIDE TRANSITION ROADMAP

Indian cities have been witnessing concentrated economic activity leading to a rapid growth in population and their travel needs. Bus based public transport is the mainstay of urban mobility in India, providing dignified, affordable, and safe mobility services for citizens to access economic opportunities, educational institutions, commercial centres and other activities. Over the past two decades, however, bus service volumes and quality haven't kept pace with increasing travel demands and users' aspirations. Lack of adequate public transport combined with increasing disposable incomes with users has led to most cities witnessing an exponential increase in personal vehicle ownership and usage. Despite this and a steady increase in rail based public transport, buses continue to achieve a mode share of more than 30% of vehicular trips in most cities they operate. Their prominence in providing affordable and well-connected services to Indian cities and rural areas has become even more pronounced in the wake of the Coronavirus pandemic and the downturn in the economy which led to reduced disposable income of users thereby limiting their access to more expensive private vehicles and other commercial mobility services like taxis and auto-rickshaws.

In addition to the overall service backlogs, bus agencies have significant proportion of old fleet with Bharat Stage (BS) I, BS II and BS III emission standards which cause disproportionately high air pollution compared to their share of the total vehicular fleet. Government of India (GoI)'s adoption of BS VI standard vehicles and fuels from April 2020 and the increasing availability of electric bus technologies at affordable prices, bus agencies have the opportunity to transition to cleaner vehicle technologies. Indian cities are also amongst the most polluted in the world and the transport sector is a major contributor to air-pollution. Therefore, the combination of increasing public transport usage in cities and transitioning their fleets to soot-free (BS VI) and zero emission (electric) buses provides the best opportunity to address the mobility and air-quality challenges faced by Indian cities. This transition also comes with significant technological and financial challenges which are new for Indian cities given their limited experience with BS VI and electric buses. The current paper presents a roadmap for the city of Bengaluru, with the aim to support the city's transition to a better and cleaner bus system while also providing a reference for other Indian cities aiming for a similar transition.

2. INTRODUCTION TO THE FLEET WIDE TRANSITION PLAN FOR BENGALURU

Bengaluru (formerly Bangalore) is India's fourth largest city by population and Gross Domestic Product (GDP). It is also home to India's largest urban bus fleet of 6,577 buses as of November 2022, operated by Bengaluru Metropolitan Transport Corporation (BMTC), the sole public bus agency in the city. BMTC and the Karnataka State Government has shown several intents over the years to decarbonise their fleet, phase out their BS-II and BS-III buses, and move towards greener modes of transport, which are in line with the strategies listed in the Bengaluru Comprehensive Mobility Plan 2020[1]. BMTC also plan to procure only electric buses from 2024 onwards[2]. Thus, ICCT and UITP have partnered with BMTC between August 2018 and May 2022 to provide technical assistance for the initial deployment of BS VI and electric buses in the cities and to develop a fleet-wide strategy towards the longer-term transition of the entire bus fleet to soot-free and zero emission buses.

This paper focuses on the fleet-wide strategy for BMTC with 2030 as the horizon year. The strategy includes the following key components:

i. **Fleet estimates and service overview**: Fleet size requirements of BMTC to achieve the urban mobility vision outlined by the Comprehensive Mobility Plan (CMP) of Bengaluru (2021)[1]. This is followed by an overview of the current service characteristics of BMTC.

ii. **Financial implications**: The Total Cost of Ownership (TCO) of the technology transition to BS VI and electric buses including the capital and operational expenditure requirements. Alternative business and financial models available for BMTC to minimize the TCO of technology transition.

iii. **Emission reduction benefits**: Quantifying the Green House Gas (GHG) emission reduction and air-quality improvement benefits of transitioning to zero-emission buses and their associated public health benefits.

iv. **Capacity building needs**: The institutional capacity building and skill development needs for BMTC to transition to zero emission buses.

The summary findings for each of these items is presented below while the detailed analytical approach adopted to derive these are presented as annexes.

UITP ICCT WORKING PAPERS

- August 2018: Strategies for deploying zero-emission bus fleets: development of real-world drive cycles to simulate zero-emission technologies along existing bus routes
- December 2022: Strategies for deploying zero-emission bus fleets: route-level energy consumption and driving range analysis

3. OVERVIEW OF CURRENT BMTC OPERATIONS

Table 1 provides a detailed overview of the BMTC fleet, infrastructure, service coverage and operations as of November 2022 that serves as the baseline in the report. Figure 1 provides an overview of the overall network spread of BMTC services in the Bengaluru Metropolitan area, which also includes the municipal limits of the Bruhat Bengaluru Mahanagara Palike (BBMP). BMTC's current services already provide network connectivity to 90% of residential areas and 82% of commercial areas in the city within a 250m access distance. However, the network density reduces progressively from the city centre to the municipal boundaries and the metropolitan area served by BMTC. As the population in these areas is projected to increase significantly over the next decade, BMTC's fleet expansion needs to be concentrated to serve this demand efficiently.

[1] https://dult.karnataka.gov.in/assets/front/pdf/Comprehensive_Mobility_Plan.pdf

[2] Bengaluru: BMTC to procure only electric vehicles from 2022 | Bengaluru News - Times of India (indiatimes.com)

CATEGORY	VARIABLE	VALUE
Fleet	BMTC Total Fleet size	6,577
	Non-AC	5,755
	AC	822
	Average age of buses in yrs or lakh-km (Total)	8.3 yrs or 5.22 lakhs
	Average age of buses in or km (AC)	10.9 yrs or 6.10 lakhs
	Average age of buses in yrs or km (Non-AC)	7.9 yrs or 5.10 lakhs
	Scheduled scrappage age (Non-AC buses)	11 years or 8 lakh-km (whichever is earlier)
	Scheduled scrappage age (AC buses)	15 years or 10 lakh-km (whichever is earlier)
	Average bus capacity	45 seating + 15 standing
Infrastructure	No. of depots	45
	No. of Traffic and Transport Management Centres (TTMCs) (major terminals)	10
	No. of bus stations (minor terminals)	45
	No. of workshops	1
Service coverage	Number of routes	1,876
	Average route length (in km)	25.8
	Total route-km (Sum of length of all routes)	49,183
Operations	Number of buses scheduled per day	5,705
	Effective-km (Revenue-km) of service per day	~1 million-km
	% Fleet utilisation (% fleet operated daily)	87%
	% Cancelled-km (km scheduled but not operated)	5%
	Vehicle utilisation (km/bus/day)	174
Demand	Daily ridership (in million)	3.5
	Occupancy Ratio (Load Factor)	67.70%
Human Resource (upto Feb 2022 provisional)	Staff Employed	29,491
	Class-I & II Officers	141
	Driver/Driver-cum-Conductor	19,612
	Conductors	4,212
	Traffic Supervisory	811
	Mechanical	3,237
	Administration	1,478
	Bus Staff Ratio	5.29

*1 Lakh = 100,000

Table 1: Overview of BMTC fleet size, infrastructure and operations (November 2022)

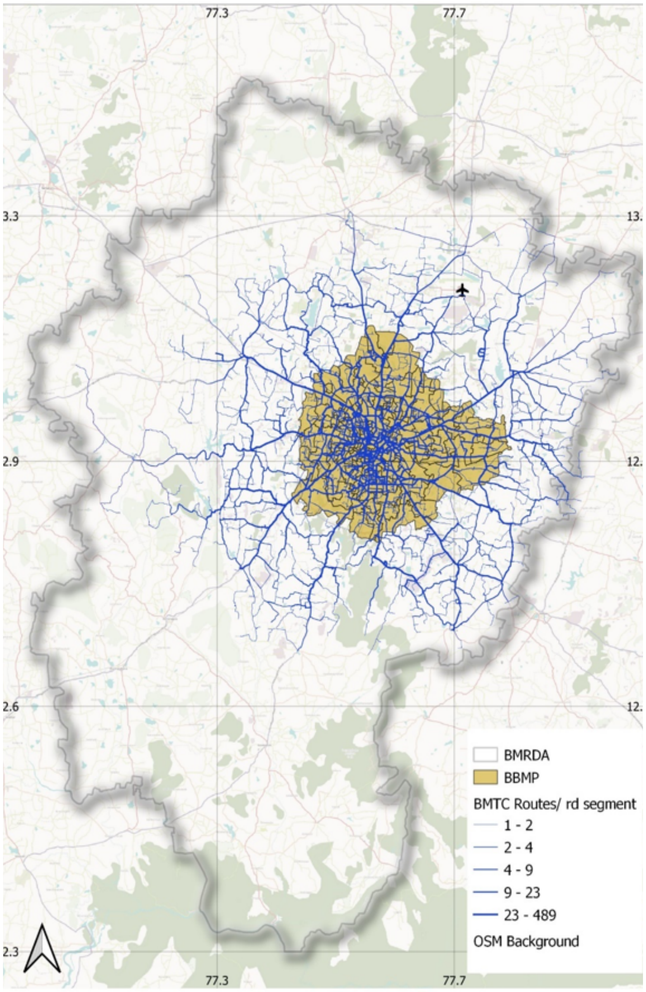

Figure 1: BMTC route network overlayed on Bengaluru's municipal and urban district boundaries

4. BMTC 2030 FLEET NEEDS AND PROCUREMENT TIMELINE

BMTC's fleet needs until 2030 have been estimated based on the projected travel demand increase in Bengaluru and the role of public transport in meeting this demand. The public transport demand is further split into rail based (metro and suburban rail) and bus-based demand based on the demand catered by available rail-based modes and the current plans for their expansion until 2030. The remaining public transport demand is estimated to be met by BMTC and the fleet needed for this is derived accordingly. The fleet needs have to be met by a combination of existing fleet and new fleet to be procured by BMTC, which includes procurement to replace the buses reaching their end of life in each year as well as fleet to be augmented to meet the increasing travel demand. The current age profile of BMTC fleet is used to estimate the number of replacement buses needed in each year while the remaining buses to be procured in each year are based on the service augmentation for the year. The total buses for replacement and augmentation are further split into the types of buses to be procured, i.e., Air-Conditioned (AC) Vs Non-AC, Standard sized (12m) Vs midi-sized (9m) based on the type of bus needed to serve the demand. The estimate doesn't include any buses shorter than 9m because there are more likely to be on-demand services around specific points of high-activity like metro or commercial space feeder service. This paper only focuses on the traditional fixed-route public transport service demand which requires procurement and operations by BMTC. The on-demand services are estimated to be taken up in partnership with private providers of the services and are beyond the scope of the current paper.

BMTC ELECTRIC BUS PROCUREMENT

- In 2022, BMTC decided to induct a total of 1,941 electric buses in 2023
- BMTC procured 300 e-buses under the FAME II scheme in 2021-22
- Another 921 buses were procured through the CESL 'Grand Challenge' aggregating demand across five cities, including Bengaluru

BMTC currently has 822 AC buses out of its 6,577 strong fleet, i.e., about 12.5%. It is estimated that there will be demand for more AC bus services in the future due to the ever-increasing service needs of customers. Based on these needs and the age profile of the AC and non-AC buses, it was estimated that 30% of the new fleet to be procured should be AC buses. These are estimated to be standard sized buses (12m) serving the trunk routes in the city.

As mentioned in Section 2, the augmented fleet in BMTC is likely to serve the Bengaluru metropolitan area outside the municipal limits given the extensive coverage within the city limits. It is likely that the demand in these areas as well as the road infrastructure available would be better served by smaller 9m buses which can provide higher frequency and require lower turning radius-rather than the standard 12m long buses. Additionally, the rapid expansion of the metro network also necessitates the need for more metro feeder services in the future which are better served by 9m buses compared to 12m buses. Therefore, based on the previously stated analysis, 40% of new buses to be procured are estimated to be 9m Non-AC buses while the remaining 30% are estimated to be 12m Non-AC buses. These are indicative fleet-mix recommendations and may be modified based on a more comprehensive demand assessment exercise.

Table 2 provides a summary of the simulation of the fleet procurement for each year until 2030 based on the demand assessed. This includes natural replacement and augmentation (additional new buses) needs as well as the timeline for different types of buses to be procured in each year. Annex 1 provides a detailed explanation of the fleet needs estimate based on travel demand needs for 2030. This approach was presented to the relevant decision makers during the CMP development process and the fleet needs estimated for a targeted public transport mode-share of 41% of motorized trips in Bengaluru by 2030 was agreed upon as the most suited option for BMTC. Accordingly, a fleet estimation of 16,582 was identified for 2030 and the same was included in the CMP as well. Within the procurement timeline, the buses to be inducted in 2023 was already decided in 2022 and accordingly the procurement of 1,941 buses is at various levels of approval and contracting. This included 1,101 12m Non-AC electric buses to be inducted through financial assistance from the Government of India's Faster Adoption and Manufacturing of Electric Vehicles (FAME)-II scheme. BMTC procured 300 e-buses under the scheme in 2021-22 out of which about 180 buses will be deployed in 2023. Another 921 buses were procured through the 'Grand Challenge' conducted under the scheme which aggregated demand across five cities, including Bengaluru. Another 840 BS VI (Euro VI equivalent) standard diesel buses are being procured on an outright purchase model through budgetary assistance from the Government of Karnataka (GoK). These 1,941 buses have already been contracted and are scheduled to be deployed in 2023. The timeline presented from 2024 onwards is according to the planned fleet upgradation to meet the 2030 fleet needs.

CATEGORY	TYPE OF BUSES	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total BMTC fleet		6,577	8,138	9,010	9,975	11,043	12,225	13,534	14,983	16,582
Annual scrappage	Total		380	651	769	97	612	759	567	19
	Non-AC		370	528	574	28	583	634	467	9
	AC		10	123	195	69	29	125	100	10
Augmentation			1,561	872	965	1,068	1,182	1,309	1,449	1,599
Fleet procurement	Total		1,941	1,903	1,734	1,165	1,794	2,068	2,016	1,618
	12m AC		0	570	520	349	538	620	604	485
	12m Non-AC		1,941	571	521	350	539	621	605	486
	9m Non-AC		0	762	694	466	718	828	807	648
Diesel and e-bus share in the procured buses	Electric-12m		1,101	571	521	350	539	621	605	486
	Electric-9m			762	694	466	718	828	807	648
	Diesel-12m		840							
	Electric-12m			570	520	349	538	620	604	485

Table 2: Estimated Fleet demand and procurement timeline

5. TECHNOLOGY SELECTION BASED ON TOTAL COST OF OWNERSHIP (TCO)

Even as BMTC is inducting 840 diesel buses and 1,101 e-buses in 2023, the technology and business model choice of procurement from 2024 onwards needs to be made based on sound financial analysis. All the electric buses are being inducted under the 'Gross-Cost Contract (GCC)' model wherein a private operator takes care of the capital, operations and maintenance of the buses and charging infrastructure in-lieu of monthly payments to be made by BMTC throughout the contract tenure of 12 years. The monthly payments are calculated based on the per-km fees determined at through bidding at the time of procurement and the actual km operated in each month, post deductions for any non-adherence to 'Service Level Agreements (SLAs). BMTC takes revenue collection as well as the provision of supporting infrastructure such as depots for parking and maintenance of buses and the power connection needed to charge the buses.

The results of the Grand Challenge by GoI have, for the first time, discovered per-km GCC fees which is lower than the per-km cost of operating diesel buses. In case of BMTC, the per-km fee was 34% lower than the per-km cost of operating diesel buses. While part of this cost saving was due to the subsidy provided by GoI, it is estimated that even without subsidy, the prices are 25% lower than per-km diesel bus costs. Therefore, e-buses now provide a cost advantage along with the energy savings and emission reduction benefits to BMTC.

The savings provided by e-buses are due to a combination of the savings accrued through the reduction in operating costs provided by e-buses as well as the savings through shift in business model of bus operations from in-house ownership and operation to GCC model. A TCO analysis is conducted to analyse this in further detail and guide the future procurement decisions of BMTC.

5.1 BUS AND FLEET LEVEL TCO ANALYSIS FOR BMTC

Analytical TCO models are designed to evaluate the life-cycle cost of ownership and operation of an electric bus and compare it against traditional bus offerings. A TCO analysis provides a more holistic assessment of the cost of owning and operating a bus, as it balances the higher upfront costs of e-bus technologies with the operational savings offered by the technology over its operational life cycle.

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Business models that involve multiple parties and a separation of bus ownership and operation require TCO evaluations that clearly identify the cost associated with each of the actors. The time-distributed cost component associated with bus ownership would be evaluated separately from cost derived from infrastructure ownership or from operational costs due to energy consumption or maintenance costs, as well as the financial costs brought by different kinds of actors.

The TCO can be modelled at the fleet-wide level or at the representative bus level. A fleetwide TCO model generates cost information for the average bus operating at average conditions. Such fleet-level analysis is useful for overall business planning and identifying systemic barriers for electrification, like strong fuel subsidies and high electricity prices that make the electric bus operational savings unfeasible over time. In this paper, we present both the bus-level TCO analysis-assuming operating conditions of a representative route of BMTC as well as a fleet-wide TCO which incorporates the fleet induction timeline presented above and the overall financial implication for BMTC.

The bus-level TCO provides the most detailed framework for exploring cost elements by individual routes. It is also the best tool to inform the cost aspects of the technical design, including bus battery sizing, battery performance over time, as well as charging infrastructure and strategy. The results from the bus-level TCO model such as the cost per-km, replacement ratio, technology and business model choices are used as input for the fleet-level TCO model. Both fleet-level and bus-level TCO analysis are useful as part of the decision-making process to transition to zero emission and cost-effective fleets.

BMTC has about more than 30,000 inhouse staff, who will continue on the rolls for a long term and will continue to operate and maintain diesel buses. Thus, the outright purchase model is still considered given it is best suited for them. For the electric buses, the Gross Cost Contract or the GCC contract is considered.

The results presented in this paper are based on the bus-level TCO model prepared by the ICCT and the fleet-level TCO model prepared by the UITP. The approach adopted for the bus-level TCO model is explained in Annex 2 while the fleet-level TCO model workings are explained in 'Financial planning for electric bus transition (UITP, 2022)[3]. The input values for the TCO analysis were based on prevailing market conditions established through extensive stakeholder consultations conducted during the course of this project.

5.2 RESULTS FOR BUS-LEVEL TCO ANALYSIS

The TCO model is applied to analyse the comparative TCO of 12m Non-AC diesel buses, which constitute more than 80% of BMTC fleet with alternative electric bus technology and business model choices. The electric bus technology choices evaluated are 12m AC buses, 12m Non-AC buses and 9m Non-AC buses-the three models proposed to be procured as per the fleet improvement strategy until 2030. The business model choices are to continue the in-house ownership and operations like the existing diesel buses with the existing STU staff, and Gross Cost Contract (GCC)-the model used for the recent e-bus tenders. No capital subsidy is assumed for the buses while incentives like lower Goods and Services tax (GST), subsidised electricity tariff are assumed to continue. Annex 2 provides details of all the assumptions for the TCO analysis.

Figure 2 presents the comparative TCO per km of all these choices over the 12-year life of the bus including the split of the cost between different items in Indian Rupees (INR) per km while Figure 3 presents the cost split in percentage. It is to be noted that these values include inflation (and are not discounted to derive their present value. Therefore, the TCO values seem to be on the higher side compared to the recently evaluated e-bus tenders. The following are the key observations from the TCO analysis:

- The cost structure of diesel and electric buses is fundamentally different. In the case of diesel buses the cost of fuel comes out to be INR 29.8 per-km which is 34% of the TCO while in case of e-buses, it ranges between INR 6.6-9.5 per-km or 8-11% of TCO. The capital and financing cost to STUs adds up to around INR 21.3 to 32.1 per km in case of e-buses while it is only INR 5.3

[3] https://www.uitp.org/publications/financial-planning-for-the-electric-bus-transition/

per km for diesel non-AC buses. This difference in cost structure is the essence of e-bus economics and cities need to take up adequate policy measures to balance these costs during the course of their transition to e-buses.

- GCC operations are cheaper than in-house operations across vehicle types primarily due to the lower staff costs prevalent in the private operations compared to staff hired by the Government. This practice is due to the salaries of private operators' drivers and mechanics being linked to the minimum wages declared by the Government for private sector labour which has traditionally been lower than Government wages. This practice will continue to be in place even in the future. Even though items like the need for insurance and the cost of financing add to the cost of GCC, the savings in staff cost compensate for these extra costs.
- The TCO per km of 12m AC e-buses is INR 5.4 per km more expensive compared to 12m Non-AC buses when operated in-house and INR 0.7 per km more expensive when operated through GCC. In contrast, the operating cost of diesel AC buses is 30% more compared to its equivalent Non-AC bus, primarily due to the high-diesel consumption of AC buses. Therefore, the recommendation to procure 30% of new buses as AC buses is likely to not cost BMTC significantly higher but will bring in more revenue as AC buses have up to INR 25 per-km of additional revenue currently and are likely to deliver improved revenues even in the future.
- The TCO per-km of 12m Non-AC e-buses is lower than a 12m Non-AC diesel buses across both technologies and business model choices. An in-house operated 12m Non-AC e-bus is estimated to have a TCO saving of INR 1.3 per km compared to 12m Non-AC diesel bus while a GCC based e-bus would be cheaper by INR 6.8 per km (8% lower).
- The TCO per-km of 9m Non-AC e-buses is likely to be INR 6.8 per km (8%) lower than the diesel 12m Non-AC buses when operated in-house and INR 8.3 per km (9%) lower when operated through GCC. The cost differential between 12m and 9m Non-AC electric buses is estimated to be 8-10%.
- Some of the cost items like the cost of conductor and administrative (admin) overheads are assumed to be the same for all technology and business model choices.

In summary, the TCO analysis shows that e-buses are already financially viable choice for BMTC even without any capital subsidy. Therefore, it is recommended that all new buses procured from 2024 shall be electric. The 840 diesel buses already approved to be procured in 2023 are recommended to be the last diesel buses procured.

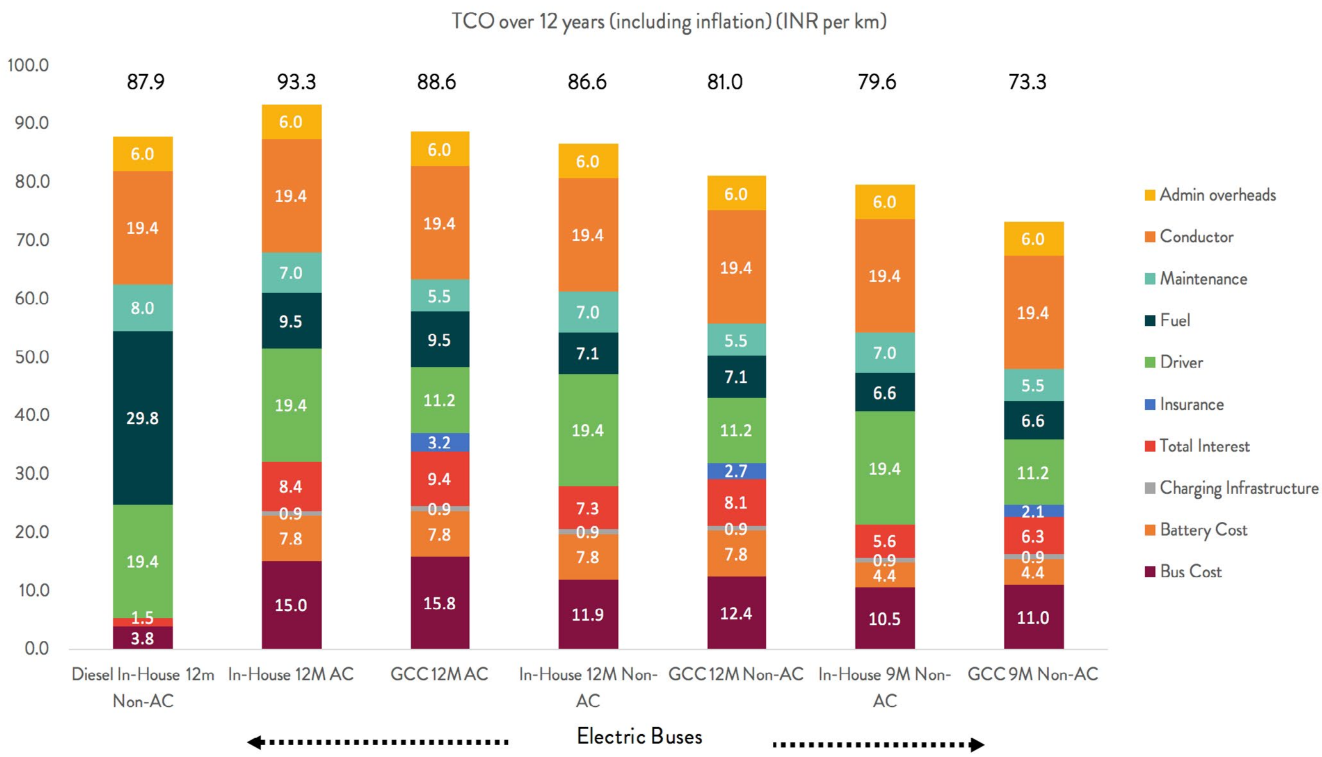


Figure 2: Comparative TCO of diesel and electric buses (12m & 9m, AC & Non-AC, In-house & GCC)

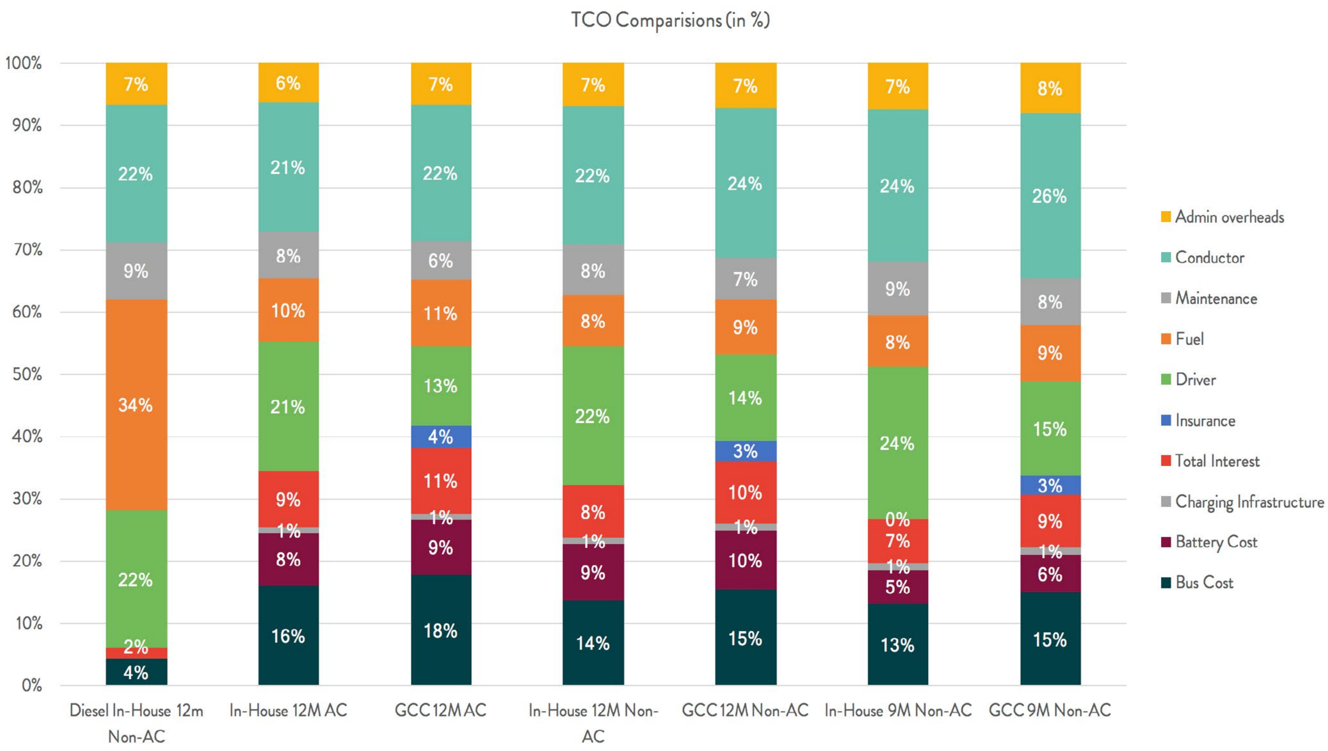


Figure 3: Comparative TCO of diesel and electric buses (12m & 9m, AC & Non-AC, In-house & GCC)

5.3 BUS-LEVEL TCO: SENSITIVITY ANALYSIS

The base-case bus-level TCO results presented in section 5.2 are based on certain fixed values for different variables. Each of these variables are likely to change over a period due to emerging operational, technological and market practice contexts. Therefore, a sensitivity analysis is carried out for some of the key variables to understand their relative impact as well as to provide an indicative impact on the overall TCO for e-buses. Figure 4 presents an overview of the sensitivity analysis carried out for TCO impact of the key variables for three e-bus types: 12m AC bus, 12m Non-AC bus and a 9m Non-AC bus. GCC is analysed as the preferred business model in all scenarios given that it is the most prevalent model for e-buses in India and across the globe. The following are the key variables tested for the sensitivity analysis and their impact on the TCO per km:

i. **Battery price:** It is well-known that the battery pack prices of Lithium-ion batteries have been reducing over the years-thereby reducing the overall price of electric vehicles[4]. Therefore, the base-case battery price of INR 12,000 per kWh (~USD 150 per kWh) is assumed to drop down to INR 10,000 per kWh (~USD 125 per kWh) and INR 7,000 (~USD 87.5 per kWh) in the two scenarios analyzed in the sensitivity analysis. While battery price constitutes about 20% of an e-bus purchase cost, it is less than 10% of the TCO-when operating costs are included. As a result, even a 40% drop in battery prices will result in only a 7% reduction in TCO. Conversely, it also indicates that even an increase in battery prices in the future due to any unexpected reasons will only increase the e-bus TCO marginally.

ii. **Bus purchase price:** The cost of bus, at the prevailing market rates makes its share of the TCO as 18-25%. Together with the cost of financing, this is the single most important variable to reduce the TCO of e-buses. The scenarios of reducing baseline bus cost in two steps of INR 30 lakhs each is tested for the three vehicle types-while the cost of battery is kept constant. Therefore, 12m AC bus cost of INR 1.8 Cr (~USD 225,000), INR 1.5 Cr (~USD 190,000) and INR 1.2 Cr (~USD 150,000) were analysed while for 12m Non-AC buses the costs assumed were INR 1.5 Cr (~USD 190,000), INR 1.2 Cr (~USD 150,000) and INR 0.9 Cr (~USD 112,500). The 9m Non-AC bus costs were considered as 1.2 Cr (~USD 150,000), INR 0.9 Cr (~USD 112,500) and INR 0.6 Cr (~USD 75,000). The overall TCO reduced by 12-14% with the overall bus cost reduction of 33-50%. The slope of the line as shown in Figure 4 indicates that reducing the cost of bus has the maximum TCO reduction potential among all variables.

*1 Cr = 1,000,000

[4] https://www.iea.org/data-and-statistics/charts/average-pack-price-of-lithium-ion-batteries-and-share-of-cathode-material-cost-2011-2021

iii. **Driver's salary** is another variable with significant implication on the business model selection given the lower driver costs inherent to the private sector led operating models like the GCC. Therefore, we analysed scenarios wherein the driver costs even for a private operator increase due to various market factors such as shortage of drivers etc. The baseline GCC driver salary of INR 20,000 per month is increased in two steps to match the BMTC in-house drivers' average salary of INR 33,000 per month. It is observed that the 65% increase in salary will only increase the TCO by 8-10% across bus types. Therefore, even a steep increase in drivers' salaries will not impact the financials of the e-bus GCC model critically.

iv. **Electricity tariff:** The current subsidized electricity tariff of INR 5.5 per kWh is estimated to increase in two steps of INR 7 per kWh and INR 8 per kWh, which is the prevailing commercial electricity tariff in Bengaluru. The 45% increase in tariff is only likely to increase the TCO by 4-5% across bus types. Therefore, even if the current subsidies on tariff are removed e-buses will continue to deliver the TCO benefits compared to diesel buses.

v. **Cost of financing:** The capital investments in the buses, batteries and charging infrastructure will require GCC operators (or Government bus companies) to raise finance from the market. The TCO at the prevailing interest rate (financing cost) of 10% per annum is compared with TCO at 9% and 8% interest rates for financing the bus, mid-life battery replacement and the charging infrastructure. The 25% reduction in interest rate reduces the TCO by only 2% across bus types. Therefore, the interest rates are not the most critical financing variables. Instead, availability of finance is identified as a critical constraint by the market (UITP 2022)[2] as many financial institutions perceive loss-making public transport agencies in India as too risky. Therefore, Governments need to focus on de-risking measures such as buffer payments for a few months in a separate escrow account, Letters of Credit and assured Viability Gap Funding (VGF) to attract finance.

vi. **Vehicle utilization (km/bus/day):** The key benefit of any electric vehicle is primarily the energy cost savings achieved due to the efficiency and lower price of energy associated with them. Therefore, the more the vehicle is utilized, the higher the savings are likely to be. Hence, vehicle utilization, i.e., the km operated per bus per day is analysed for increased and reduced operating performance. Increased km per day may be achieved through bus priority measures like exclusive bus lanes, increasing service hours, operating suburban services etc. while reduced vehicle utilization is a phenomenon already observed due to increasing congestion in many cities. Hence the base-case of 200 km/bus/day (70,000 km/bus/year) is compared with 225 km/bus/day (78,750 km/bus/ year) and 170 km/bus/day (~60,000 km/bus/year) across the three bus types. The 13-14% variation analysed in each scenario is observed to deliver a 6-7% variation in TCO, which is next only to the variation observed corresponding to the bus cost. This indicates the need to focus on service planning and operations management in addition to technology and fiscal measures analysed above.

In summary, the sensitivity analysis identified that cost of the bus and vehicle utilization are the two variables with the maximum impact on the TCO. Therefore, policy makers and cities need to identify avenues to improve on these variables to reduce their cost of transition to e-buses.

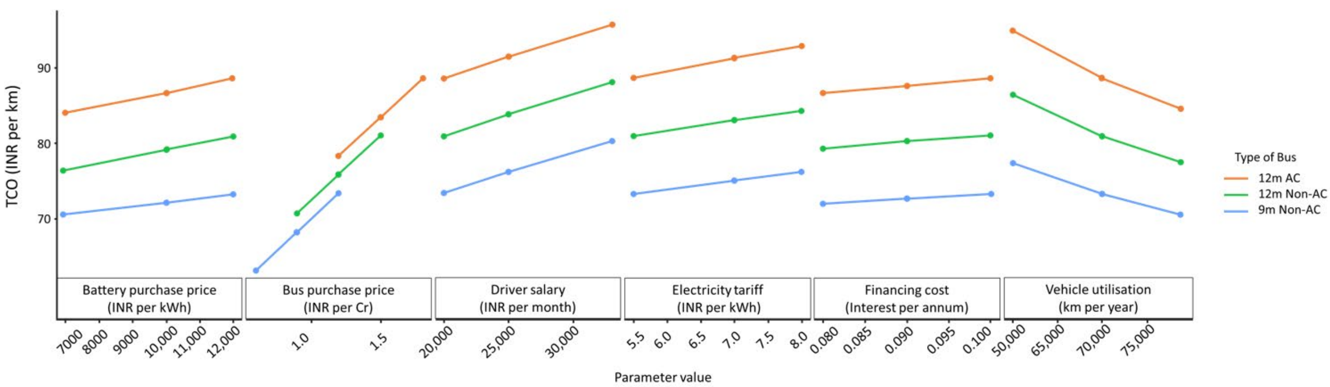


Figure 4: Results of sensitivity analysis for key variables impacting TCO

5.4 RESULTS OF FLEET-LEVEL TCO ANALYSIS

The fleet-level TCO analysis combines the fleet-induction timeline (Table 2) with the bus-level TCO analysis (5.2 and 5.3) to derive the overall cost of operations of BMTC. In addition to the costs, analysing the revenue forecasts for the horizon year will generate valuable insights to the decision makers on the approach to be adopted to attain the goals identified by the fleet-wide strategy. Hence, the financial model developed by UITP[2] is designed to calculate the item-wise annual costs and revenues across business model alternatives until 2030-the horizon year to allow alternative scenarios to be modelled towards achieving the vision. The model incorporates the current and future fleet induction timeline to provide a holistic financial analysis for the bus corporation.

The cost inputs include capital expenditure on fleet (in case of in-house operations) and infrastructure (depots and terminals) as well as their financing; operational expenditure on staff, GCC payments, fuel/ energy and as well as other miscellaneous costs for system management such as the Information technology (IT) systems, office expenditure, compensations for accident victims etc. Revenues include the farebox revenues earned through tickets and non-farebox revenues earned through commercial establishments, parcel services and advertisements. Separate current and future predictions are estimated for each of these items to derive the system-wide impact. While the model involves complex analysis, the outputs are simple enough for decision makers to identify strategic priorities.

The fleet induction timeline, segregated by the types of buses, provided in Table 2 is combined with the bus-level TCO values presented in Figure 2 to derive the fleet-level TCO values.

Figure 5 presents the likely annual costs, revenues and Viability Gap Funding (VGF) requirements for the fleet induction timeline proposed in Table 2. It is estimated that the current cost and revenue patterns of BMTC will require a VGF of INR 1,811 Cr (~USD 225m) in 2023 which will gradually increase up to INR 3,508 Cr (~USD 440m) by 2030. The need for VGF arises primarily because we use the historic trend of increase in costs not matched by increase in revenues. This is a phenomenon observed across several well-functioning public transport entities globally where the Governments compensate the public transport services through budgetary allocations. Singapore provides more than USD 600m annually to provide bus services at affordable fares to passengers while London and Sau Paulo invest more than USD 900m annually to support their bus services[5]. By that measure, the VGF needs of BMTC as lower than global peers, even though BMTC has not previously received a similar level of financial assistance from the Government of Karnataka (GoK).

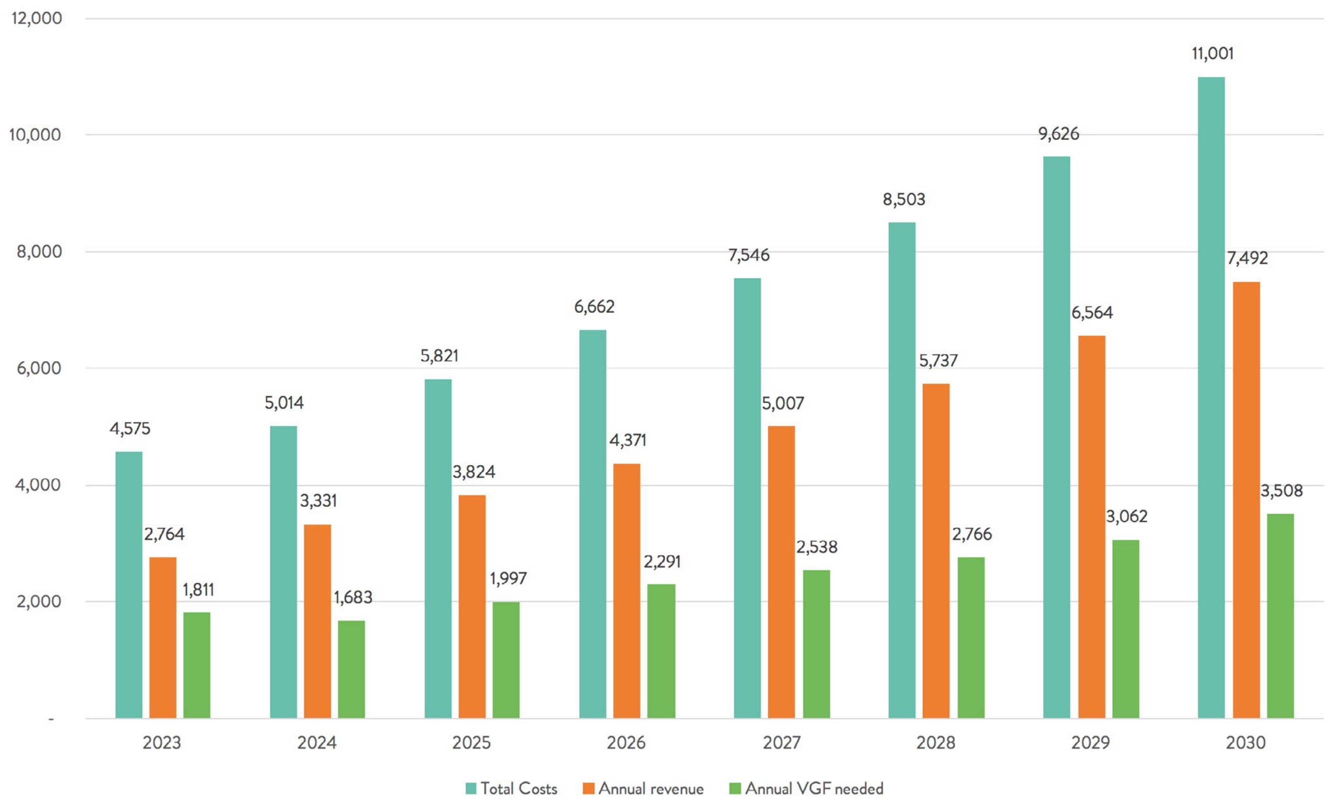


Figure 5: Fleet-level financial summary for BMTC (in INR Cr) for the fleet induction plan

[5] Page 15 of http://urbanmobilityindia.in/Upload/Conference/8ed1146d-e99c-4ea0-87ae-a241f1243d3f.pdf

Figure 6 presents the annual cost-split for BMTC for the proposed fleet induction timeline and the transition to e-buses using the GCC model in the future. It presents how the move from in-house diesel bus-oriented service provision to a GCC dominated service provision will impact the cost structure. BMTC needs to change its business rules and staff capability from being a 'operator' to a 'service provider' by strengthening aspects like customer orientation, contract management and financial management to ensure timely payments.

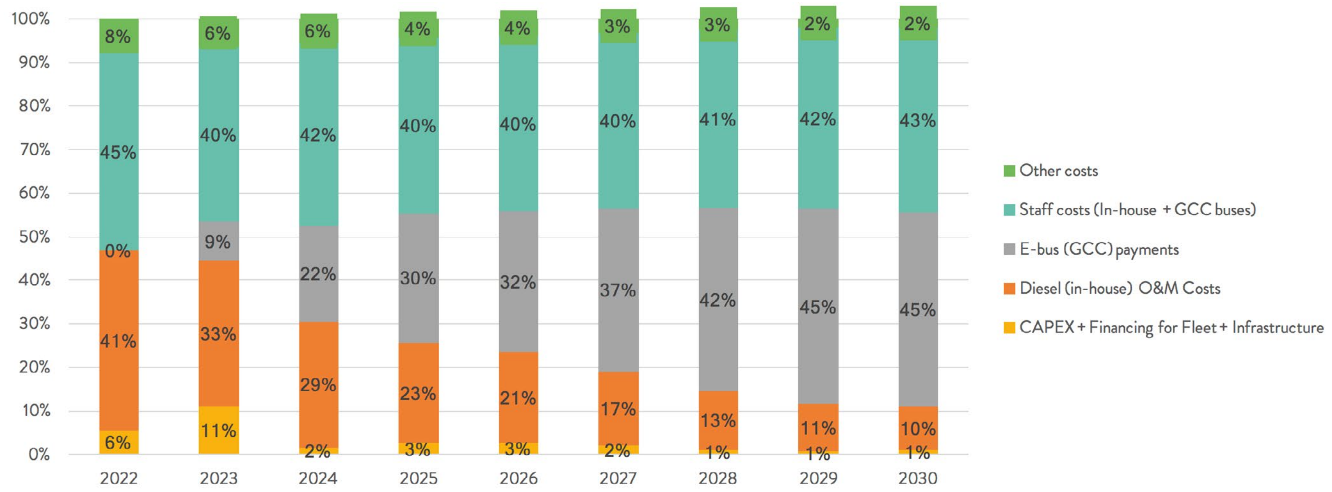


Figure 6: Item-wise split of fleet-level TCO (in %) for BMTC until 2030

The fleet-level financial model also allows decision makers to test the financial impact of various policy measures. To demonstrate the principle, we incorporate the following two policy measures-one reducing costs and another increasing revenues are analysed using the fleet-level financial model:

i. Moving towards 100% digital ticketing removing the need for an on-board conductor to issue tickets. Given that the conductor costs about INR 13 per km, i.e., about 20% of the overall cost of operation and 25% of the total revenue realized, eliminating the need for a conductor can potentially achieve significant financial benefits

ii. Improving service attractiveness to increasing the ridership and the corresponding revenue by INR 5 per km across AC and Non-AC services and achieving an annual growth rate of 5% compared to the 3% growth achieved currently. Over the years, BMTC has witnessed a reduction in ridership-which is partly compensated by an increase in fares. Reversing the current trend through measures such as customer centric service planning can potentially increase the revenues and reduce the VGF needs

Figure 7 presents the annual finances post the implementation of these two measures. It can be observed that these measures reduce the VGF needs substantially and can even help BMTC break-even financially over the next six years and help them sustain without VGF. However, these measures are analysed only to demonstrate the principle of fleet-wide financial analysis and a detailed feasibility analysis need to be conducted to implement these measures. Cities can moderate these assumptions based on feasibility or analyse other measures like reduced cost of financing, timeline for infrastructure development etc. to develop similar fleet-wide impacts and thereby take informed decisions.

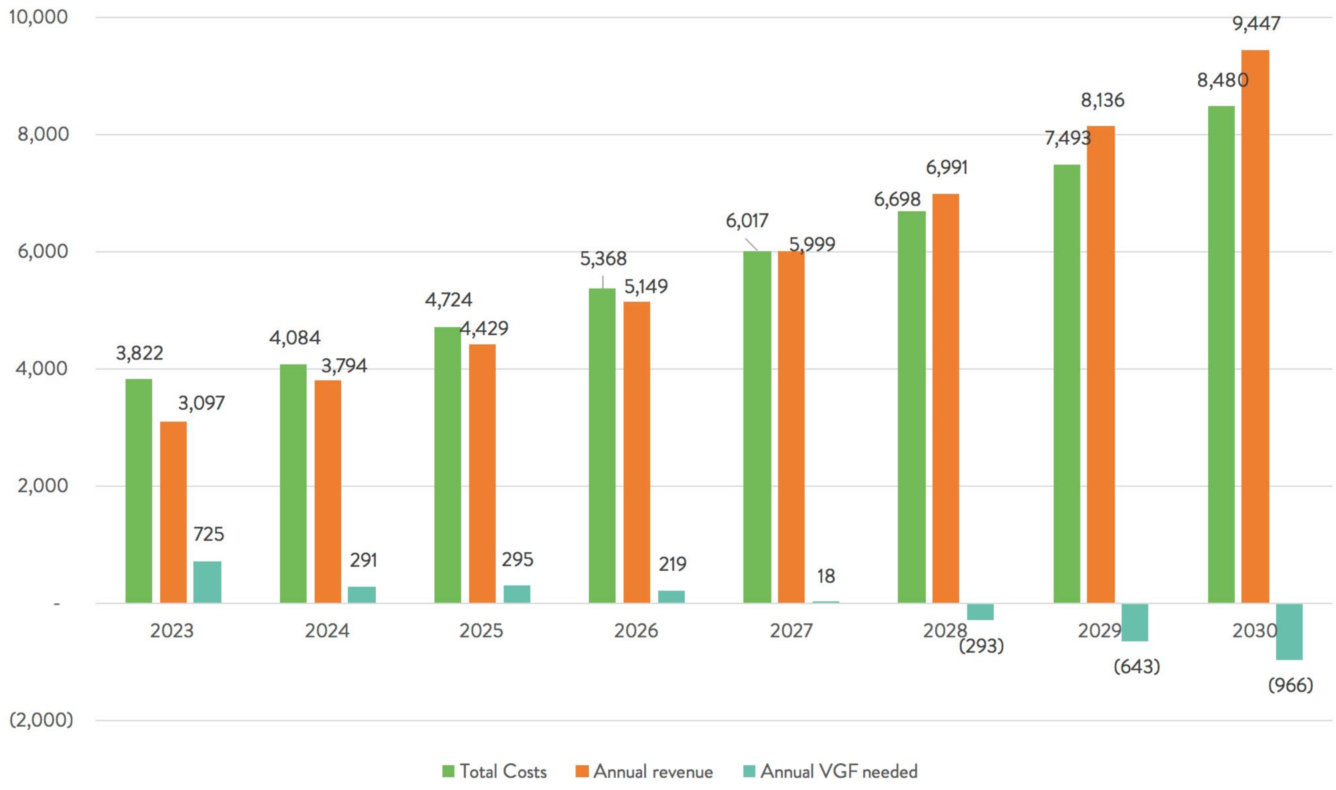


Figure 7: Fleet-level financials in case of removing conductor cost and increasing revenues

6. EMISSION REDUCTION POTENTIAL OF THE FLEET-WIDE STRATEGY

In addition to the financial benefits associated with transition to e-buses explained in section 5, they also present significant environmental benefits by reducing air-pollution and Green-House Gas (GHG) emissions. The Toolkit for Urban Bus Operations (TURBO) model developed by the ICCT is used to derive the environmental benefits of the fleet wide strategy presented in this paper wherein BMTC transitions to 40% electric fleet by 2030. The emission reduction benefits of transition from diesel to electric technology were assessed using TURBO. However, it doesn't cover for additional savings that may be achieved from shifting users from private vehicles to public transport.

The TURBO model takes environmental inputs like the GHG emission factors for fuels and electricity grid, transmission losses and Particulate Matter (PM) profile of vehicles as well as fleet specific inputs such as the vehicle stock, activity (operated km/vehicle/year), life of vehicle, share of vehicles by technology and fuel. These inputs are used to derive outputs such as emissions by vehicle type, technology, emissions control technology, fuel type, and year.

The emission benefits associated with the fleet wide strategy are summarised in this section.

CHECK OUT THE RESOURCE!

UITP Bus Tender Structure Report 2020

This report contains a comprehensive Annex IV with the Environmental Calculation Tool for the calculation of Fuel Consumption, CO_2 and regulated pollutants for 15 different bus propulsion energies.

Two scenarios of fleet electrification have been assessed for well-to-wheel (WTW) annual emission reductions. Grid decarbonisation will not affect tank-to-wheel (TTW) estimations. In both scenarios, a 40% fleet electrification is achieved, and the balance new bus procurements have been assumed to be BS-VI. In the first scenario, a business-as-usual (BAU) grid is assumed, while in the second scenario a decarbonized grid is assumed where the share of coal for electricity generation drops and the share of renewable energy increases between 2027 and 2040 (table 3). Both scenarios have been compared to emissions under BS-VI only bus procurement scenario, and the emissions avoided have been presented in Figure 8. The fleet mix in the electrification scenario has been presented in Figure 9. Total number of buses have been presented in table 3.

REGION	ELECTRICITY SOURCE	BAU			DECARBONIZATION		
		2020	2027	2040	2020	2027	2040
Bengaluru	Coal	49%	49%	49%	49%	39%	24%
Bengaluru	Natural gas	0	0	0	0	1%	1%
Bengaluru	Nuclear	12%	12%	12%	12%	10%	10%
Bengaluru	Other	39%	39%	39%	39%	50%	65%

Table 3: Grid business as usual and decarbonization scenarios

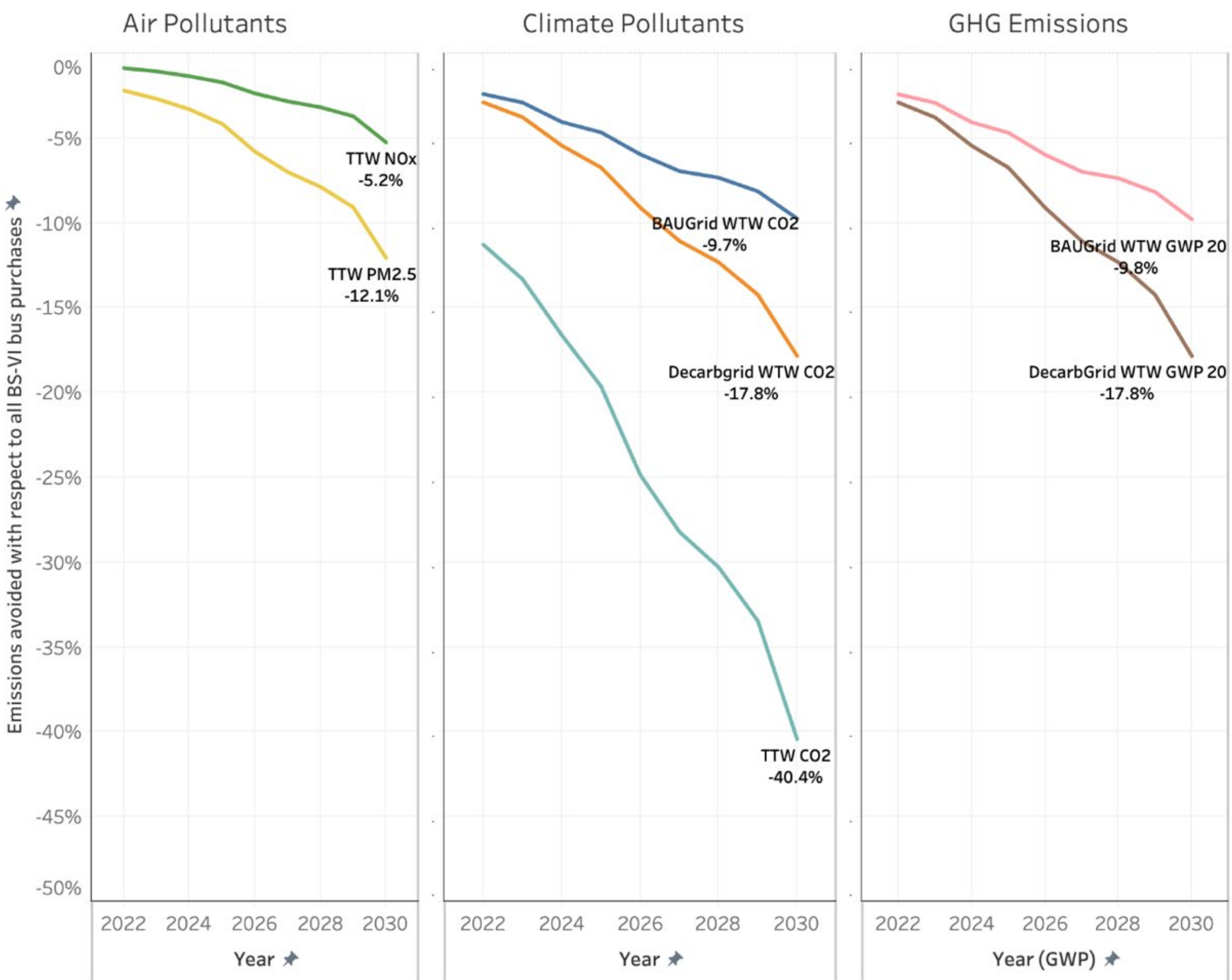


Figure 8: Emissions avoided between 2022 and 2030 by achieving 40% fleet electrification until 2030 compared to all diesel BS-VI bus purchases

Note: TTW – Tank to wheel, WTW – Well to wheel, BAU Grid – Business-as-usual grid, Decarbgrid – Decarbonized grid, GWP – Global warming potential

Within air pollutants, 5.2% NOx emissions and 12.1% PM2.5 emissions are expected to be avoided in the year 2030. The total NOx and PM2.5 emissions avoided are expected to be 2,332 tons and 78 tons respectively between 2022 and 2030. A decarbonized grid can double the WTW CO2 emissions avoided as compared to a BAU grid in the year 2030. TTW CO2 emissions avoided are about 40% in the year 2030. Between 2022 and 2030 WTW CO2 emissions avoided are 370,144 tons and 599,960 tons, respectively in BAU grid and decarbonized grid scenarios; and TTW CO2 emissions avoided are 1,318,135 tons. Finally, 9.8% and 17.8% greenhouse gases with 20-year GWP can be avoided in BAU and decarbonized grid scenario respectively which amount to 804,420 tons and 1,302,200 tons in these two scenarios.

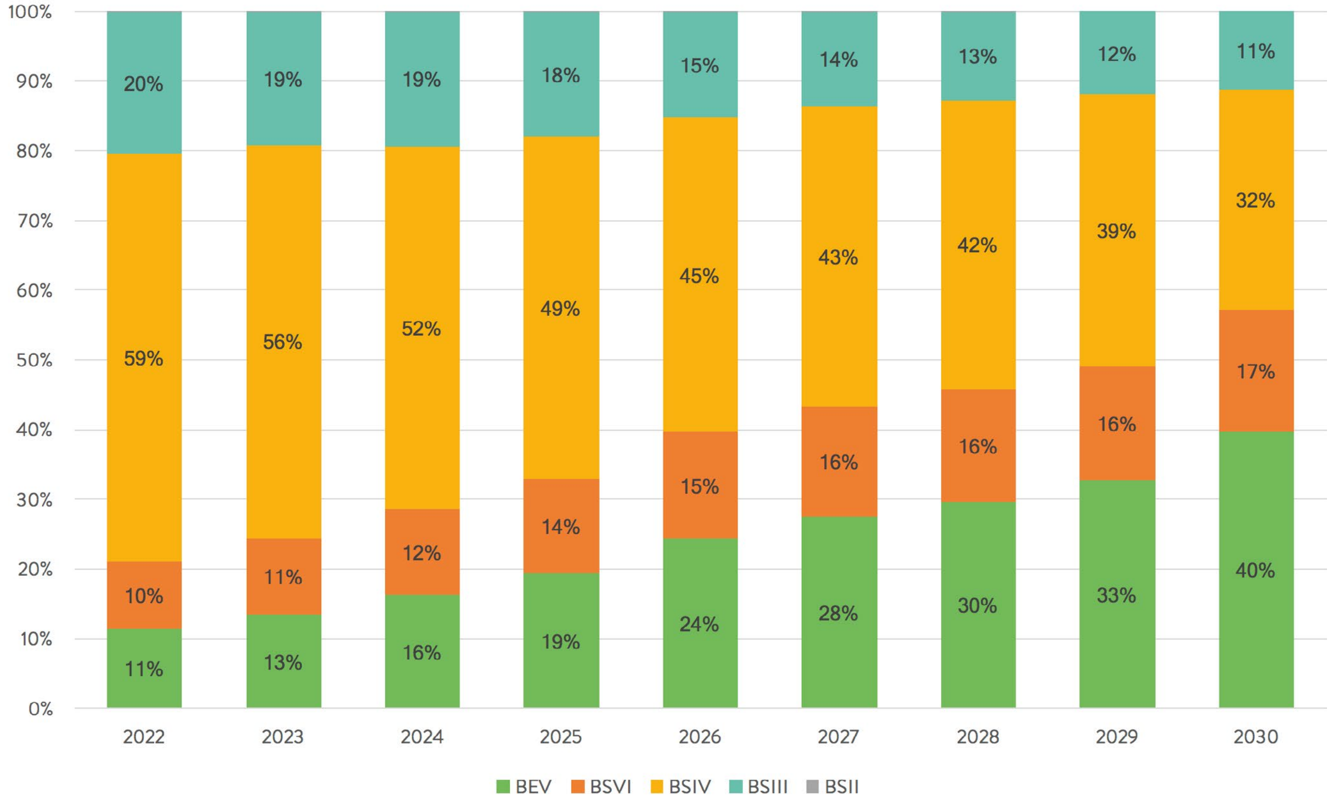


Figure 8: Assumed vehicle technology composition of the bus fleet until 2030 in the fleet electrification scenario.

7. CAPACITY BUILDING NEEDS

It is clear based on the procurement plan for BMTC, and the decarbonization strategy, that BMTC will stepwise be transitioning to operation of only electric bus fleet. However, there is a need of institutional and organisational capacity building, transition pathways and skill development for BMTC to transition from Internal Combustion Engine (ICE) to zero emission buses operation and maintenance.

Thus, an organisational training need assessment for BMTC identified a comprehensive list training across and cross departments. The trainings identified are listed below. The trainings are expected to enable BMTC to broaden their knowledge and understanding of global e-mobility issues and benefit from a comprehensive overview of electric mobility. The programme can help BMTC upskill personnel and simultaneously prepare them to tackle challenges to transition from ICE bases buses to e-Buses.

Fundamentals of Electric Bus	Introduction: An electric solution for urban bus networks	Monitoring and Control	Performance Monitoring and Evaluation at Depot level
	Technology Market and System Overview and Usage at STUs		Contract Management and Monitoring Best Practices for STU
	Infinite Range Electric Bus by In motion Charging		ITMS/MIS Systems for overall e-Bus Fleet, Charging and STU integration
	Procurement Basics Purchase Specifica-tions Design: Models and Performance Contract Design	Repair and Maintenance	Cooling Systems
	Evaluation, Testing and Inspection Best Practices for STU		Traction and other Motors, Drive, Controller and Regenerative Braking
	Safety Basics - Fire Hazards, SOPs, Pre-vention and Emergency Handling		Electronics and High voltage Electrical Sys-tems Chargers and back-end High voltage Electrical Systems
	Manpower Planning and Capacity Building		On-Board Diagnostics and Communications
	Battery Technologies		asset/inventory (inc parts)management
	Key policy drivers for introduction of E-buses in urban environment	End of life Scrapping and recycling	Warranty and End-of-Life Management
Operations Planning and Implementation	Route Selection, Operations Planning & Scheduling of e-Bus Fleet and Chargers		e-Bus and Lithium-ion Batteries Scrapping and Recycling
	Intelligent Charging and Optimization	Safety, Technology Planning, Specification Design and Selection	Battery Technologies, Sizing and Selection
	Driving Behaviours impact on e-Bus Energy Performance		Charging Technologies Sizing and Selection
	Overall System Planning and Optimisation (grid planning)		Charging and Energy Infrastructure Planning
Financial Planning and Strategy	Life Cycle Cost Benefit Analysis and STU Business Case		Depot Infrastructure and Equipment Plan-ning
	Investments and Financing for different Procurement Models		Fire Safety of Electric Vehicles
	Long term Transition Planning from ICE to electric fleet for STU		Evacuation of busses - Safe exit from Vehicle

Table 4: Training beneficial for transitioning to electric buses.

8. CONCLUSIONS AND RECOMMENDATIONS

This paper presents an approach towards developing a fleet-wide strategy towards transitioning to electric buses taking the case of BMTC, Bengaluru. This included establishing the bus fleet needs until 2030, a bus-level TCO based technology and business model alternatives assessment, the fleet-level TCO and overall financial assessment towards achieving the vision and the environmental impact of the proposed fleet-wide strategy. The following are a few key conclusions and recommendations derived from the fleet-wide strategy:

1. Need to increase BMTC service levels: The CMP of Bengaluru (2020) outlines a public transport centric strategy to achieve sustainable economic development in the city. Despite the increasing metro network, we estimate that the BMTC needs to increase its fleet from the 6,577 buses available currently to 16,582 buses by 2030 just to retain the current mode share of public transport in the city. These assessments were agreed and incorporated into the recommendations in the CMP.
2. Fleet mix: The proposed increase in fleet-size needs to be accompanied by a detailed assessment of the type of fleet needed, i.e., standard buses (12m long), mi-

di-buses (9m long), minibuses, double decker buses, AC and Non-AC buses etc. We mapped the BMTC network to establish that the BMTC provides extensive services within the municipal limits of Bengaluru but has limited coverage in the rest of the metropolitan area. Given the limited road network availability beyond municipal limits and the increasing need for feeder services to the metro, it is estimated that 40% of the new fleet procured would be midi-buses (9m) while the remaining 60% fleet would be equally split into 12m AC and Non-AC buses. These are indicative fleet-mix recommendations and may be modified based on a more comprehensive demand assessment exercise.

3. Bus-level TCO: The technology and business model for the fleet growth presented above is assessed based on a spreadsheet based TCO model which provides the lifecycle cost per km of various procurement alternatives. The TCO per km for diesel and electric buses, different bus types (12m, 9m, AC and Non-AC) and different procurement models (in-house operations and GCC) are analysed. The input values for the TCO analysis were based on prevailing market conditions established through extensive stakeholder consultations conducted during the course of this project.

   The TCO analysis established that e-buses offer lower TCO at the current market prices even without any subsidy. The 12m Non-AC e-bus deployed on GCC model is estimated to deliver 8% lower TCO compared to a 12m Non-AC diesel buses currently being operated in-house, while the same e-bus deployed in-house will offer a 1% reduction in TCO. A 9m Non-AC e-bus operated on GCC basis is likely to have a 17% lower TCO compared to a 12m Non-AC diesel bus while in-house operation of the same bus will reduce TCO by 9%.

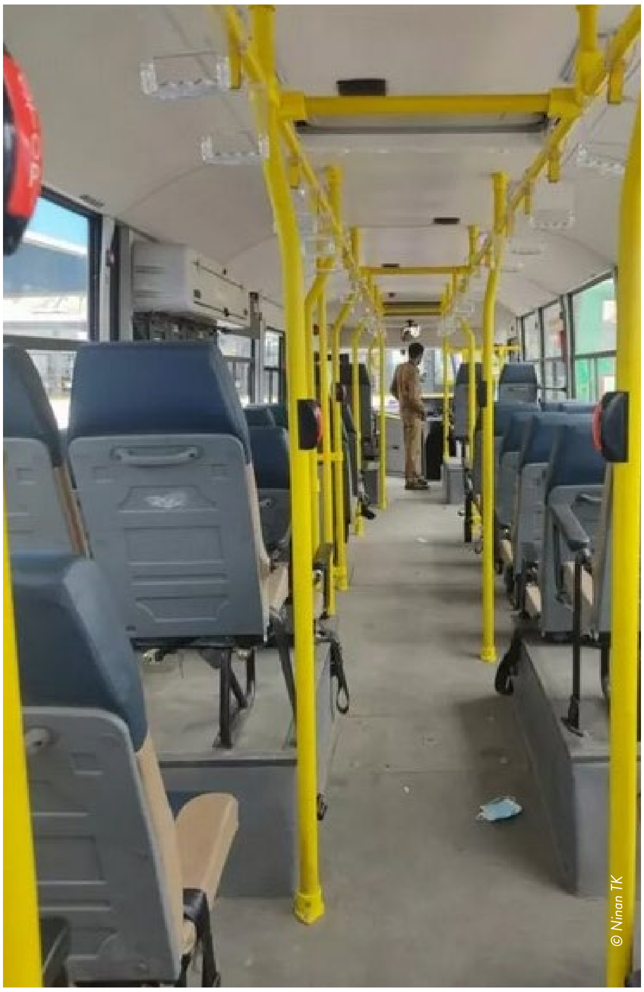
   Cost reduction is primarily driven by the lower energy costs and lower staff costs associated with GCC operators. However, even an increase in staff cost in the future will not completely eliminate the energy cost savings. Among the remaining variables, purchase cost of bus is identified as the single most important variable in determining the TCO per bus-km. Therefore, policy makers need to focus on reducing the capital cost of e-buses to ensure an accelerated uptake of e-buses in BMTC as well as the rest of India.

4. BMTC needs to take a policy decision to procure only electric buses from 2024 and prioritise GCC as the preferred business model to reduce the cost of transition to electric buses.

5. A comprehensive service analysis needs to be conducted to identify the optimal fleet mix (12m vs 9m, AC vs Non-AC) to serve the extended metropolitan area of Bengaluru.

6. Changing cost structure of BMTC: The proposed transition towards GCC based service provision for e-buses will require BMTC to change its orientation from an 'operator' to a 'manager' which will require a change in business rules as well as staff capability needs. Capacity on key topics like technology risks with e-buses, contract management, payments and financial management needs to be strengthened to ensure smooth transition to GCC based e-bus provision.

7. Fleet-level TCO model estimated the annual costs and revenues associated with alternative -technology, business model and operational choices available to BMTC. A scenario analysis with reduced need for conductors on the bus and increasing the ridership as well revenue accrued to BMTC has been modelled. Such a scenario is expanded to help BMTC achieve financial breakeven over the next 5 years which will improve their capability to undertake private investments.



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8. **VGF needs of BMTC**: The ambitious fleet expansion strategy to meet the CMP targets would also mean a consistent VGF requirement to meet the gap between increasing costs which are not matched by the revenue increase trends observed in BMTC. The VGF need are estimated to be about INR 1,811 Cr (~USD 225m) in 2023 and will increase up to INR 3,508 Cr (~USD 440m) by 2030 based on the past cost and revenue trends. While this is lower than international peers like London, Singapore and Sau Paulo which attract USD 600-900m annually to compensate for losses due to farebox collections. However, the VGF needs are significantly higher than the budgetary support received by BMTC in recent years. Therefore, measures needed to reduce the VGF and institutional mechanisms to ensure timely VGF support to BMTC need to be established to achieve the fleet growth needs.

   Attaining the fleet targets set by the CMP (2020) will require drastic change in operational practices to reduce VGF and at the same time for the remaining VGF – a mechanism that the State can follow to compensate BMTC for the remaining losses. Given the need to meet the CMP goals towards achieving the sustainable mobility targets, we recommend that Governments squeezes costs where possible and provides mechanisms for sustained VGF beyond that.

9. **Timely payments to GCC operations**: The GCC operators would need additional financial commitments from GoK in addition to the 2 months of buffer payments maintained by BMTC currently. This can include additional months of payment, Letter of Credit etc. which will reduce the bankability risk of the project and thereby help the private operators achieve financial closure as well as reduce the quoted cost due to the improved financing terms which the private operator can attract with these measures.

10. **Environmental benefits**: The proposed fleet-wide transition is estimated to benefit users through reduced air pollution and improvement in the GHG performance of e-buses. By incrementally achieving 40% fleet electrification by 2030, 2332 tons and 78 tons of NOx and PM2.5 emissions can be avoided which are public health hazards. The well-to-wheel CO_2 and GWP20 emissions benefits can be doubled if the government also decarbonizes the grid by reducing the dependence on coal. These emission reductions achieved by BMTC can provide access carbon credits in the future.

In summary, the fleet-wide strategy presented in this paper and the tools used for this analysis are developed by ICCT and UITP and can form a useful reference for other such city systems.

ANNEX 1: BMTC FLEET NEEDS ESTIMATES FOR 2030

Bengaluru has a public transport mode share of 41% of all vehicular trips within which 80% are carried by BMTC (CMP Bengaluru, 2020)[1], with a daily ridership of approx. 3.5 million (November 2022), while the metro caters to the rest. This has reduced drastically during the various waves of the Coronavirus pandemic, due to an overall decline in travel activity in the city and a shift in travel behaviour due to increased preference to work and study from home. However, majority of the pre-pandemic demand has been recovered by BMTC by November 2022. Even before the pandemic, the public transport mode share has witnessed a steady decline over the past decade or so, due to increasing personal vehicle ownership combined with systematic underinvestment in improve the quantity and quality of bus services to meet increasing travel demands and users' aspirations for their mobility services.

The CMP envisions a reversal of the personal vehicle-oriented mobility for Bengaluru to have a sustainable mobility system that supports its economic progress. Accordingly, it recommends a marked increase in the combined public transport mode-share, i.e., bus and metro-rail services to cater to 59% of all vehicular trips by 2030. Achieving the mode share targets set by the CMP require significant improvement in the service quality of public transport in Bengaluru. Despite the increasing metro network in the city and the proposed suburban rail system, buses continue to remain a key component of Bengaluru's public transport over the coming decade. Hence, we analyse the fleet growth needs of BMTC to meet the CMP targets of increased public transport mode share. We also analyse an alternative scenario to understand the implications of retaining the current bus share, which in itself is an improvement to the current situation of increasing population and decreasing bus ridership.

This section explains the methodology adopted to derive BMTC's bus fleet needs in the two scenarios selected for analysis. i.e.,

Scenario 1: retaining the current public transport mode share of 41% in 2030

Scenario 2: Increasing the public transport mode share to 59% by 2030

Figure 1 provides an overview of various steps involved in fleet estimation for each of the scenarios. It can broadly be summarized into the following three steps:

i. **Demand estimation**, i.e., the estimated daily bus ridership based on the public transport mode share assumed for the scenario. This is derived as the difference between total daily public transport trips, estimated based on the population[6], Per-Capita daily Trip Rate (PCTR)[1] and the mode-share for the horizon year[1], and the likely metro ridership, estimated based on the project network length of the metro and the ridership per-km. The metro network is likely to expand from the current length of 48.9

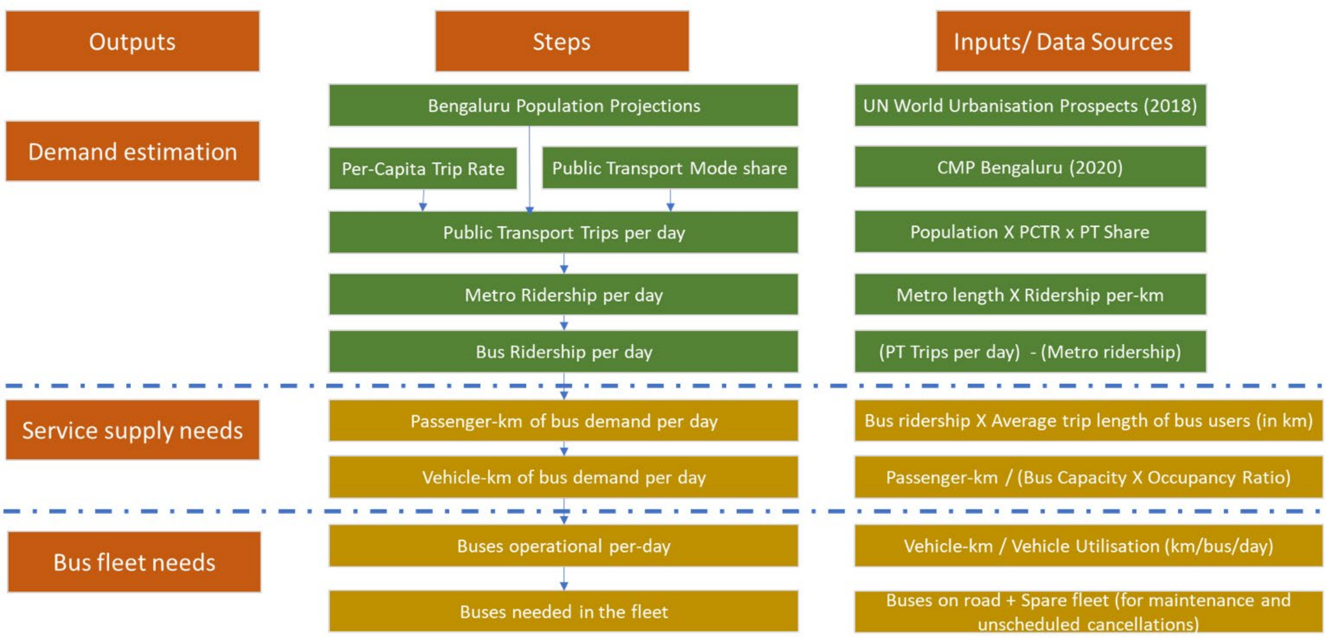

Figure 1: Process flow for estimating bus fleet needs based on mode-share targets

[6] https://population.un.org/wup/Download/

km to 200 km[1] by 2030 and its ridership will continue to be 9,520 passengers per-km as observed pre-Covid. The metro ridership estimates are comparable to the ridership achieved by a more matured system like the Delhi metro at similar network length. The mode share, metro network and ridership for the years between the base year and 2030 are interpolated assuming a linear growth pattern.

ii. **Service supply needs,** i.e., the total km of bus services to be provided to achieve the projected ridership. The likely passenger-km of bus travel demand for the estimated daily ridership was derived initially using the average trip length of bus users which is assumed to remain constant over the years. The vehicle-km of bus services needed to serve these passenger-km were derived using the average bus seating capacity of 45 passengers per bus and an Occupancy Ratio (OR) of 66.8% that BMTC is assumed to be able to achieve from the base year to the horizon year.

iii. **Bus fleet needs**, i.e., the total buses needed to be held by BMTC to achieve the required service supply volumes (bus-km per day). The daily vehicle utilisation (km/bus/day) of BMTC was used to derive the operational buses (buses on road) needed to perform the required daily bus-km. The daily vehicle utilisation was assumed to decrease from 200 km/bus/day to 180 km/bus/day between 2022 and 2030 due to the increasing congestion levels in Bengaluru. The fleet to be held by BMTC was estimated using the fleet-utilisation (percentage operational fleet out of total fleet held) value of 89% which is estimated to be maintained between 2020 and 2030

The bus fleet needs for the two scenarios analysed, i.e., mode share targets of 41% and 59% for public transport in Bengaluru were derived using the approach mentioned above. The following table provides the summary of the assumptions and results for each of the scenarios. Given that the mode share increase to 59% entails a fleet increase of more than 300% in less than a decade, retaining the 41% current mode share was identified as a more practical approach in consultation with BMTC. Therefore, the 2030 fleet target of 16,582 buses is recommended by the CMP (2020) and is also used as the input for the current fleet wide strategy paper.

VARIABLE	2022	2030	2030
SCENARIO	BASELINE	RETAIN 41% PUBLIC TRANSPORT MODE SHARE	ACHIEVE 59% PUBLIC TRANSPORT MODE SHARE
Population of Bengaluru (in million)[6]	13.2	16.2	16.2
Per-Capita Trip Rate (Motorised trips)	0.9	1.10	1.10
Public Transport Mode Share	41%	41%	59%
Metro network length	48.9	200	200
Metro Ridership (Daily) (in million)	0.4	1.9	1.9
BMTC share of public transport trips	80%	74%	82%
Bus Ridership (Daily) (in million)	3.5	5.4	8.6
Vehicle utilisation (km/bus/day)	200	180	180
BMTC Fleet: Current and Projected	6,577	16,582	26,424

Table 1: Key assumptions and outputs from BMTC fleet needs assessment for 2030

ANNEX 2: ROUTE-LEVEL TCO MODEL FRAMEWORK

The TCO model combines key cost inputs including ownership, operation, maintenance and financing which add up the overall TCO of e-buses. Figure 2 presents the broad structure of the model with its key inputs and outputs. The model broadly has two modules: i) Technology and operations, ii) Business models.

The technology and operations module of the TCO model is where the bus types, routes and charging strategy are selected for evaluation. The analytical framework developed allows the evaluation of different types of battery electric buses (BEB) against conventional technology. In this example the model is predefined with 12 m and 9 m diesel and electric buses; the electric buses can be selected with two different types of battery capacity in kWh. Additional technology aspects include the consideration

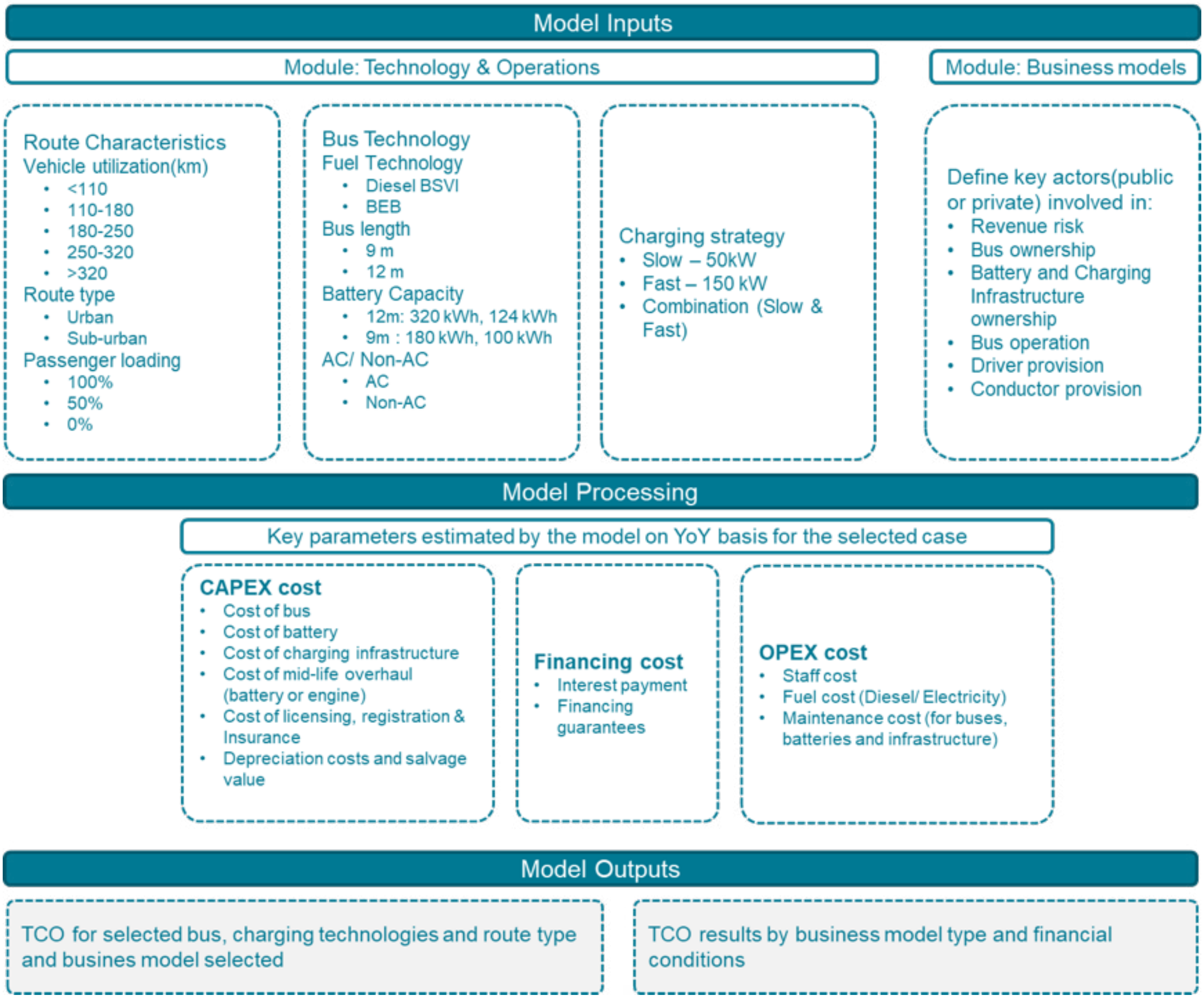

Figure 2: Key inputs and outputs of the TCO model

of air conditioning (AC) as part of the energy consumption of the bus.

In addition to the bus technology, the analysis incorporates the energy consumption (EC) from each of the bus technologies studied under a predefined set of routes. The routes were selected based on a clustering of the daily utilization requirements from 29 bus routes operated by BMTC. These were evaluated by the ICCT in 2020 as part of a feasibility analysis for electric bus adoption in those routes[7]. Energy consumption values were averaged for each of the bus technology options (bus size, battery capacity, AC use) for each of the four route clusters evaluated.

The business module provides the option for TCO evaluation to include the effects of the financial costs associated with different electric bus business models. We have modelled the traditional publicly owned and operated systems as well as the Gross Cost Contract (GCC) model being preferred for the electric buses. The business model parameters that affect the TCO and financial evaluation are the rate of interest, length of repayment term, loan-to-value ratio, cost of equity and the staffing costs. Based on the inputs selected by the user, the model assesses capital and operational costs, distributed over different years of the life of the bus.

REPLACEMENT RATIO CONSIDERATIONS ON TCO EVALUATION

Replacement ratio is defined as the number of electric buses needed to fulfil the operational requirements of an ICE bus in a particular route. It is calculated as the current daily utilization (in kilometres travelled per day) for a bus operating on a given route, divided by the estimated daily range of an electric bus on full charge[8].

[7] https://theicct.org/publication/strategies-for-deploying-zero-emission-bus-fleets-route-level-energy-consumption-and-driving-range-analysis/

[8] An electric bus's range on full charge is a function of the state of charge (SoC) of battery to be preserved at all times during the bus operation and the battery degradation over time. Factors that affect an electric bus battery range are: loading conditions, air conditioning use, and road grade.

- RR<=1 means that the e-bus maximum daily operating range in that particular route is larger than or equal to the daily utilization of an ICE bus.
- RR> 1 means that daily utilization exceeds the driving range of the e-bus technology profile selected for that route. Alternative technology options and charging strategies that can deliver a 1:1 replacement should be considered alongside other considerations that minimize the cost of electrification.

The RR metric becomes a design parameter to perform an unbiased comparison of the TCO between ICE and electric bus options. For example, an electric bus with a driving range of 250 km operating on a 300 km daily utilization route would require 1.2 more buses to fulfil the daily operational needs, unless alternative charging or larger battery capacity is adopted.

RR ratio can be improved with the adoption of fast charging equipment. In this analysis two options are presented, slow and fast charging. Fast charging is more expensive but provides the flexibility required to charge the bus during the normal service hours. This provides additional battery charge and effectively reduces the need to increase the number of e-buses to fulfil the route needs.

The analytical framework presented here includes the impact of RR on TCO. The RR affects mainly the number of buses, charging stations, and interest. It does not affect the operational costs on fuels, maintenance and costs as the extra buses would be in stand-by, waiting for depleted units to enter in service. Equation 1 provides the treatment of RR as it affects cost components in the TCO. Even though the TCO tool allows for RR variations, India already has several bus models which offer a daily range of 200km in a single charge. Therefore, an RR of 1.0 has been assumed for the TCO calculations for BMTC.

$$TCO = RR^{*}(TCO_{\text{bus cost}} + TCO_{\text{battery costs}} + TCO_{\text{charging infrastructure}} + TCO_{\text{financial}} + TCO_{\text{crew}} + TCO_{\text{energy/fuel}} + TCO_{\text{Maintenance}}$$

INPUT VARIABLES AND ASSUMPTIONS

The model estimates the capital costs based on the price of the bus, battery and the charging infrastructure as well as the salvage value of these assets. The operational costs include staffing costs, fuel/energy costs and maintenance costs. Financing costs are also added in terms of interest payment and the cost of equity. The details about the input parameters and key assumptions are provided in the Table 2 below. In terms of key outputs, the model can generate TCO for selected bus, charging technologies and route type, year on year costs over service life of buses and year on year cash flow for different actors as defined by the business model. The methodology is applied to study the adoption of e-buses in selected routes operated by the Bangalore Metropolitan Transport Corporation (BMTC). Similar steps can be applied to other bus systems.

VARIABLE FOR TCO ESTIMATION	DIESEL BSVI, 12M, NON-AC	E-BUS (12M, NON-AC)	E-BUS (12M, AC)	E-BUS (9M, NON-AC)
Bus life (in years)	12	12	12	12
Annual operating days	350	350	350	350
Annual vehicle-km per bus	70,000	70,000	70,000	70,000
Total cost of bus (w-battery) (in INR)	4,000,000	15,000,000	18,000,000	12,000,000
Cost of bus (ex-battery) (in INR)	NA	11,160,000	14,160,000	9,840,000
Cost of battery (in INR)	NA	3,840,000	3,840,000	2,160,000
Capex cost of battery/kWh (in INR)	NA	12,000	12,000	12,000
Annual decrease in battery cost	NA	5%	5%	5%
Capex cost of charger (in INR)	NA	1,800,000	1,800,000	1,800,000
GST payable on purchase of bus and battery	18%	5%	5%	5%
GST payable on purchase of charging infrastructure	NA	18%	18%	18%
Energy cost (diesel price (INR/L) or electricity price (INR/kWh))	90	5.5	5.5	5.5
Electricity price annual growth rate (%/yr)	5%	5%	5%	5%

VARIABLE FOR TCO ESTIMATION	DIESEL BSVI, 12M, NON-AC	E-BUS (12M, NON-AC)	E-BUS (12M, AC)	E-BUS (9M, NON-AC)
Energy efficiency ((km/L) or (kWh/km))	4	0.97	1.3	0.66
Applicable subsidy on capex	0	0	0	0
End of life salvage value of e-bus as % of original cost	0%	0%	0%	0%
Vehicle maintenance cost/km	6	4.5	4.5	4.5
Charging infrastructure maintenance cost (INR/DLE)	0	1.0	1.0	1.0
Other administration costs per km	4.0	4.0	4.0	4.0
Annual change in other operations costs/year	7%	7%	7%	7%
Conductor costs (INR/km)	13.0	13.0	13.0	13.0
Conductor cost annual growth rate (%/yr)	7%	7%	7%	7%
Battery capacity (kWh)	NA	320 kWh	320 kWh	180 kWh
Years for battery replacement	NA	6	6	6
Type of charger	NA	Fast (260 kW)	Fast (260 kW)	Fast (260 kW)
Charging infra life (years)	NA	20	20	20
Effective e-bus/ICE bus to be replaced ratio	NA	1.0	1.0	1.0
Cost of depot infrastructure per bus for STU (civil and upstream electrical infrastructure)	NA	INR 0.5 million per bus	INR 0.5 million per bus	INR 0.5 million per bus
Earnings per km (in INR per km)	45	70	45	35
Growth rate of earnings per km	3%	3%	3%	3%

Table 2: Key assumptions for bus-level TCO analysis

VARIABLE FOR TCO ESTIMATION	DIESEL/ ELECTRIC IN-HOUSE OPERATIONS	DIESEL/ ELECTRIC GCC
Driver costs (INR/km)	13	8
Driver cost annual growth rate (%/yr)	7%	6%
Debt share for capex on e-bus ex-battery	95%	90%
Debt share for capex on battery	95%	100%
Debt share for capex on charging infra	100%	100%
Debt share for capex on ICE bus	95%	90%
Interest rate on loan against bus, battery, charging infra	9%	10%
Tenure for all loans (yrs)	6	6

Table 2: Business model- specific TCO assumptions

ANNEX 3: EMISSIONS REDUCTION POTENTIAL

VARIABLE	VEHICLE	TECHNOLOGY	CONTROL	2020	UNIT
Energy intensity	12m AC	BEB	BEV	0.1306532663316580	DLE/km
Energy intensity	12m Non-AC	BEB	BEV	0.1105527638190960	DLE/km
Energy intensity	12m AC	Diesel	BSII	0.43	DLE/km
Energy intensity	12m Non-AC	Diesel	BSII	0.24692067361905500	DLE/km
Energy intensity	12m AC	Diesel	BSIII	0.4952774048477470	DLE/km
Energy intensity	12m Non-AC	Diesel	BSIII	0.24751018830971200	DLE/km
Energy intensity	12m AC	Diesel	BSIV	0.3735493300911740	DLE/km
Energy intensity	12m Non-AC	Diesel	BSIV	0.23729054769786300	DLE/km
Energy intensity	12m AC	Diesel	BSVI	0.4515	DLE/km
Energy intensity	12m Non-AC	Diesel	BSVI	0.252	DLE/km

Table 3. Energy intensity

VARIABLE	UNIT	2020	2025	2030
Activity	km/yr/vehicle	68,000	64,600	61,200

Table 4. Activity

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