Analysing the implications of electrification of public transport buses in Pune city, India

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The urban road transport sector in India currently faces the challenge of increased travel demand, increased use of private vehicles, traffic congestion as well as alarming levels of air pollution. The consequent public health problems, energy insecurity resulting from oil imports and pressure to mitigate greenhouse gas emissions from the sector have also emerged as serious challenges for the country. Many cities in the world are considering electric buses for public transport as one of the potential solutions to address these issues. This article analyses the feasibility of introducing electric buses in the public transport fleet by estimating the financial burden that such a shift may entail, and the corresponding emissions it would mitigate. It also provides a methodology and illustrates the same for a city in India. The results indicate that while electric buses may not be financially viable at present and require state support and subsidies for operation, careful planning and phased implementation would make them a promising option for the future. The cost analysis indicates that for the immediate future, the replacement of air-conditioned diesel buses with similar electric buses in the fleet makes better economic sense. However, it is necessary to determine how the increased cost of using electric buses is to be distributed across the population of the city to avoid disproportionately burdening one section, i.e. bus commuters, with the cost of cleaning up the city's air.

Keywords: Air pollution, electric vehicles, greenhouse gas emissions, public transport, urban roads.

THE need to improve connectivity, and provide convenient and affordable transport to citizens increases with the increase in urbanization. As per the 2011 census, India is 31.6% urbanized which is expected to go up to 50% by 2030. The urban transport sector in India currently faces the challenges of increased travel demand and trip lengths with a decrease in modal share of public transport and increased private vehicles. This has resulted in an increase in traffic congestion, alarming levels of air pollution and consequent health ailments[1] and energy insecurity due to higher import dependence on oil (82% of India's crude oil is imported)[2]. Greenhouse gas (GHG) emissions from this sector are often an additional concern. India's National Action Plan for Climate Change recommends increased use of public transport with higher penetration of biofuels and enhanced energy efficiency to mitigate GHG emissions from the transport sector[3].

Therefore there is a need for a novel approach to deal with the issues of urban transport in India. Many cities in the world are considering the option of electric buses for public transport as one of the probable ways to address these issues. In India too, municipal authorities and public transport utilities are exploring this option.

The capital cost of electric buses is about 2–4 times more than conventional diesel buses, since they need allied infrastructure for consistent charging and the batteries need to be replaced at least once in the lifetime of a bus. Battery costs currently constitute half the cost of the bus[4]. However, some studies show that due to lower variable and maintenance costs of electric buses compared to diesel buses, along with a much higher efficiency of operation, electric buses earn 82% greater profits compared to their diesel counterparts[5].

A feasibility study of introducing electric buses in the public transport fleet in a specific region, taking into consideration capital investments as well as operating costs, can provide a view of the trade-offs involved in undertaking such a transition. The Pune Mahanagar Parivahan Mahamandal Limited (PMPML), which is the municipal bus transport operating company in the metropolitan region of Pune, Maharashtra, India, has an ambitious target of inducting 500 new technology-based, fully electric buses in its municipal transport fleet to tackle the issue of air pollution in the city[6]. Pune is the second largest city in Maharashtra, and the ninth largest city in India. According to the 2011 census, the population of the metropolitan region is estimated at 7.27 million with a density of 9400 people/sq. km (refs 7, 8). According to the city bicycle plan launched by the Pune Municipal Corporation, the modal share of public transport in the city was 18% in 2011 (ref. 9). This share has been reducing continuously since then, with the number of registered vehicles currently at 3.6 million for a population of 3.5 million in the Pune city[10]. A study conducted by Shakti Foundation in 2017 mentions that the modelled urban average ambient $P.M_{2.5}$ concentration is about $56.3 \pm 12.9\ \mu g/m^3$ for the city of Pune, which is much higher than the national standard of

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40 μg/m^3 and five times that of the World Health Organization (WHO) guidelines of 10 μg/m^3. Over 24% of these emissions are from the transport sector[11]. The shift to buses and the purchase of 500 new electric buses is being seriously considered as a potential means to address air pollution in the city. In this article therefore, we illustrate the methodology for a feasibility study of transitioning to electricity buses for Pune city. While there are other studies conducted on electric buses in India[12,13], most of these consider the indirect costs of environmental pollution to assess the viability of these buses. While it is true that there are such hidden costs, their estimation is difficult, and is usually heavily dependent on assumptions drawn based on a set of normative criteria set by the authors. The transport utility, however, does have to bear an actual cost for the shift, and while the long-term societal benefits of a cleaner local environment are undoubtedly important, for the resource-starved public utilities in Indian cities, the short-term costs of such measures are significant drivers of the decisions themselves. Arriving at feasible solutions for these utilities is often also an important determinant of the long-term sustainability of the intervention. In this study therefore, a financial analysis of electric buses for Pune city has been done, without any notional monetizing of health and other benefits, to estimate the potential financial burden, if any, on the utilities and eventually on the public transport users. This can then help us to arrive at a feasible intervention plan for cleaner public transport in the city.

The available literature is clear on the fact that electric buses cannot just be operated independently, but require an entire ecosystem of allied infrastructure in place like batteries, charging stations and power supply[12–14]. Thus, to study the feasibility of electric buses in India, we need estimates of the capital costs, operation and maintenance costs, availability of electricity for charging, generation mix of the electricity that will be used for charging the buses as well as cost estimates for developing charging infrastructure and other allied services for the operation of electric buses in the city.

This article analyses the implications (in terms of costs and emissions) of introducing electric buses in the fleet of PMPML, with specific focus on answering the following key questions: (i) What are the financial implications of a shift to electric buses for the transport utility in Pune? (ii) What are the impacts of the shift on emissions and local air pollution? (iii) What are the implications on electricity supply and infrastructure to power these buses? (iv) What are the best possible strategies for transitioning to a cleaner public transport fleet?

Methodology

This study is based on an analysis of data obtained from the following main sources: Central Institute of Road Transport (CIRT), the monthly bus performance data from PMPML, Automotive Research Association of India (ARAI), Maharashtra Electricity Distribution Company (MSEDCL) – which is the electricity distribution utility operating in the region of study, Central Electricity Authority (CEA), and the data sheets and brochures of electric bus manufacturers. The secondary data analysis has been substantiated and strengthened through interviews with subject experts in this domain, namely the chief engineer of PMPML, consultants from CIRT, and original equipment manufacturers (OEMs) for electric buses.

Bus fleet analysis for Pune city

In the first part of this study, the bus variants which can be used for intra-city transport are listed and their operational characteristics are analysed. The fleet analysis includes standard models for non-AC diesel buses, non-AC CNG buses, AC diesel buses and AC hybrid buses, all of which are currently operational in the fleet, and non-AC electric buses and AC electric buses which are planned as new additions to the fleet.

The operational characteristics of each bus variant are analysed to arrive at the total cost of ownership (TCO) over the entire life cycle of 12 years for each bus type using eq. (1)

$$\mathrm{TCO}_t = \sum_{i=1}^{12} \mathrm{CC}_{i,t} + \mathrm{OE}_{i,t} - F_{i,t} - B_{i,t}, \tag{1}$$

where TCO_t is the total cost of ownership over the entire life cycle of 12 years of bus type t, $\mathrm{CC}_{i,t}$ the capital cost incurred in the ith year for bus type t (including the purchase cost of the vehicle, taxes during purchase, infrastructure cost and replacement cost of battery or engine), $\mathrm{OE}_{i,t}$ the operating expenses incurred in the ith year for bus type t (including interest on loan, maintenance costs, energy costs, staff costs, operating taxes and other operating expenses), $F_{i,t}$ the funding or incentive received in the ith year for bus type t (relevant only where t refers to electric buses) and $B_{i,t}$ is the social and environmental benefit in the ith year for bus type t.

The present value of TCO ($\mathrm{TCO}_{\mathrm{PV}}$) is then calculated using a discount rate of 11%. The choice of discount rates to be used for such investments, especially in developing countries is still hotly debated. We have chosen the discount rate of 11% based on the available market rates for commercial loans that vary between 9.5% and 12.5%. The different bus variants are then compared based on the net cost per kilometre (CPK_t), which is calculated using eq. (2).

$$\mathrm{CPK}_t = \frac{\mathrm{TCO}_{\mathrm{PV}}}{\sum_{i=1}^{12} d_{i,t}}, \tag{2}$$

Table 1. Capital costs for different bus variants

Type of expense	Cost	Basis of assumption	Source
AC electric bus	Rs 17.5 million (inclusive of taxes and an on-board charger)	A bus covers 225 km per day on an average. So a bus having a maximum range of 300 km is selected.	Ref. 30
Non-AC electric bus	Rs 16.4 million (inclusive of taxes and an on-board charger)	Non-AC electric buses are cheaper by Rs 1 million compared to AC buses due to absence of the air-conditioning unit. Rest of the components are the same.	Interview of bus manufacturer
Cost of charging infrastructure	Rs 0.5 million per bus	Charger is provided with the bus, but the infrastructure to supply power needs to be installed.	Interview of bus manufacturer
Diesel non-AC bus	Rs 3 million + taxes	Purchase cost for Pune Mahanagar Parivahan Mahamandal Limited (PMPML).	Interview with PMPML
CNG non-AC bus	Rs 5 million + taxes		
Diesel AC bus	Rs 8 million + taxes	Purchase cost for different state transport undertakings in India.	Ref. 12
Hybrid electric bus	Rs 16.7 million + taxes		
Rate of interest and discounting rate	11%	Commercial loan is available at the rate of 9.5% to 12.5% per annum from nationalized banks in India.	Ref. 32
Depot infrastructure	0	Depot land and corresponding infrastructure required for any type of bus with these physical dimensions would be the same.	–

where d_i is the total distance covered by the bus t in the ith year.

Table 1 shows the capital costs for different bus variants. Table 2 shows various operating cost components required to calculate TCO of the bus and the basis of the assumptions used.

Pollution and emissions analysis

The net carbon dioxide (CO_2) emissions from diesel buses are calculated according to the methodology prescribed by the Intergovernmental panel on climate change[15] using eq. (3).

$$C_{d,t} = \mathrm{ED}_d * \mathrm{CE}_{d,t} * Q_d, \tag{3}$$

where $C_{d,t}$ is the annual CO_2 emission (kg) due to combustion of diesel in bus type t, ED_d the energy density of diesel (MJ/l), $\mathrm{CE}_{d,t}$ the mass of CO_2 produced per unit energy by diesel undergoing mobile combustion in bus type t (kg/MJ) and Q_d is the amount of diesel consumed (litre).

The tail-pipe emissions of pollutants from diesel buses were calculated using eq. (4), considering the emission factors for BS-VI pollution norms according to the Indian emissions regulations booklet published by the Automotive Research Association of India (ARAI)[16].

$$\mathrm{PE}x_{d,t} = \mathrm{ES}x_d * \mathrm{ED}_d * Q_{d,t}, \tag{4}$$

where x represents the pollutant, viz. carbon monoxide (CO), nitrogen oxides (NO_x), total hydrocarbons (THC) or particulate matter (PM), $\mathrm{PE}x_{d,t}$ the amount of pollutant x emitted by bus type t annually (g) due to combustion of diesel, $\mathrm{ES}x_d$ the emission standard of the pollutant x for engine (g/kWh) and $Q_{d,t}$ is the amount of diesel consumed by bus type t annually (litre).

In case of CNG buses, eq. (5) was used to calculate the emissions.

$$\mathrm{PE}x_{g,t} = \mathrm{ES}x_g * D_{g,t}, \tag{5}$$

where $\mathrm{PE}x_{g,t}$ is the amount of pollutant x emitted by bus type t annually (g) due to combustion of CNG and D_t is the distance covered by type t annually (km).

Though battery electric buses (BEBs) have zero tail-pipe emissions, the battery will continue to be charged by coal-based electricity in the near future, since the Indian power sector is coal-dominant. Thus the carbon emissions during electricity generation were also considered using the CO_2 emissions factor of the national grid, which was taken from the CO_2 baseline database for the Indian Power Sector User Guide published by CEA[17].

The CO_2 emissions were calculated using eq. (6).

$$C_e = E * \mathrm{Ef}, \tag{6}$$

where C_e is the CO_2 emitted annually (tonne) due to electricity generation, E the amount of electricity consumed annually (MWh) and Ef is the CO_2 emissions factor for electricity ($t CO_2$/MWh).

After comparing the different variants of buses based on TCO, the sensitivity of different cost components that affect the TCO of electric buses was estimated. Different

Table 2. Operating cost components for different bus variants

Type of expense	Cost	Basis of assumption	Source
Engine oil, lubricants, tyres, spares	Rs 4.04 per km for diesel, Rs 3.79 per km for CNG and Rs 2.42 per km for electric buses	Cost of the consumables was taken from the STU performance reports published by CIRT and 5% inflation was assumed every year further. Electric buses have 90% lesser moving parts compared to ICE buses. So the cost of spares and lubricants for electric buses is 60% compared to that of ICE buses and engine oil is not required	Interview (CIRT)
Annual maintenance	Rs 3 per km	Assumed to increase by 10% every year with the age of the bus	Interview (CIRT)
AMC of charging infrastructure	Rs 0.1 per kWh	Assumed to increase by 5% every year	Interview (CIRT)
Staff cost	Rs 18.12 per km	According to the monthly performance reports of PMPML for 2018–19, the staff cost was assumed to increase by 10% every year due to salary increments	Ref. 33
Operating taxes and miscellaneous costs	Rs 1.06 per km	STU performance report for 2016–17	Interview (CIRT) and ref. 29
CNG fuel	Rs 45 per kg	Approximate average price of fuel in the state as charged by the state-owned distribution companies	–
High-speed diesel fuel	Rs 70 per litre	Assumed to rise by 2% every year as observed in the past trends	–
Electricity	Rs 6 per kWh	According to the tariff order approved by the State Electricity Regulatory Commission. The wheeling charges and night-charging discount nullify each other Assumed to rise by 2% every year (since the same is considered for diesel and CNG)	Ref. 34
Engine overhauling and refurbishment	Rs 2 million	–	Ref. 13
Battery replacement	US$ 350 per kWh. These rates are decreasing by 10% every year	The range of the battery goes down to 80% when it is due for replacement. Current rate in the market is US$ 220–250 per kWh. India imports these batteries, and the net cost becomes US$ 350. Based on the international market reports, it is assumed that the battery cost goes down by 10% every year	Interview (Bus manufacturer and CIRT) and ref. 35
Funding, incentives and benefits to the environment	0	The study does not consider any special funding or incentives available The benefits to the environment due to electric buses have been calculated. However, these are not monetized and included in total cost of ownership (TCO), since PMPML does not bear these notional costs in monetary terms	–

scenarios were constructed to arrive at results for the financial viability of electric buses. Assuming the most ideal conditions that may exist based on a business as usual (BAU) scenario, the year by which purchasing and operating the BEBs would be at parity with Internal Combustion Engine (ICE) buses was also calculated and an implementation plan for PMPML to replace its existing fleet with electric buses was suggested, if such a transition is to be undertaken. This article suggests a methodology that can similarly be used for other metropolitan regions where a transition may be possible and planned.

Data analysis and discussion

Total cost of ownership

Figure 1 shows the TCO, present value (PV) of the TCO, and CPK at the present value of TCO (TCO_{PV}) for a BAU scenario. In this scenario, battery costs do not change throughout the life cycle, and all other cost components vary as described in Tables 1 and 2.

The capital expenditure for electric buses is exceedingly high compared to ICE buses, whereas the operating expenses are comparable. To know the overall impact on TCO, CPK is used as the basis for comparison. Results show that it is economical to buy pure electric AC buses instead of diesel or hybrid AC buses. Non-AC electric buses are more expensive compared to their non-electric counterparts by Rs 9 per kilometre.

Table 3 shows the break-up of all cost components of different bus variants. The benefit of having a low operating expense for electric buses is compromised by the high capital cost, which is 22% of the TCO compared to 6–10% in case of conventional non-AC buses, and the battery replacement cost which is 12% of the TCO compared to 2–3% cost for engine overhauling in conventional buses.

Table 3. Total cost of ownership of various bus variants for the business-as-usual scenario

	Type of expense	Diesel non-AC	CNG non-AC	Diesel AC	Hybrid AC	Electric AC	Electric non-AC
Bus parameters	Length of the bus (m)	12	12	12	12	12	12
	Bus runs (km per day)	220	220	220	220	220	220
	Number of the days the bus is on the road (days)	340	340	340	340	340	340
	Annual distance covered (km)	74,800	74,800	74,800	74,800	74,800	74,800
	Lifetime distance covered (km)	897,600	897,600	897,600	897,600	897,600	897,600
	Life of the bus (years)	12	12	12	12	12	12
	Battery replacement/engine overhauling (years)	6	6	6	6	6	6
Capital expense	Net cost of bus (inclusive of taxes; Rs million)	3.84	6.40	10.24	21.38	17.50	16.40
	Depot land required (acre)	0.00	0.00	0.00	0.00	0.00	0.00
	Depot civil infrastructure cost (Rs million)	0.00	0.00	0.00	0.00	0.00	0.00
	Net cost of battery replacement (Rs million)	0.00	0.00	0.00	1.39	92.51	92.51
	Slow charging infrastructure (Rs million)	0.00	0.00	0.00	0.00	0.50	0.50
Operating expenses	O&M costs per km (Rs)	7.04	6.79	7.04	6.79	5.42	5.42
	Personnel cost per km (Rs)	18.12	18.12	18.12	18.12	18.12	18.12
	Interest on debt (%)	11	11	11	11	11	11
	Fuel charges per km (Rs)	21.88	15.20	35.00	14.00	6.69	6.10
	Operating taxes and miscellaneous expenses per km (Rs)	1.06	1.06	1.06	1.06	1.06	1.06
	Insurance premium (percentage of capital cost)	2	2	2	2	2	2
TCO	Total capital expenditure (Rs million)	5.84	8.40	12.24	23.51	27.25	24.74
	Total operating expenditure (Rs million)	62.30	56.31	77.97	62.14	52.92	50.25
	TCO (Rs million)	68.14	64.71	90.21	85.66	80.17	75.09
	Present value of the total cost of ownership over 12 years (TCO_{PV}; Rs million)	35.31	34.33	49.03	50.32	45.13	42.26
	Net cost of operation per bus per km at the present value (CPK; Rs)	39.34	38.25	54.63	56.07	50.28	47.07

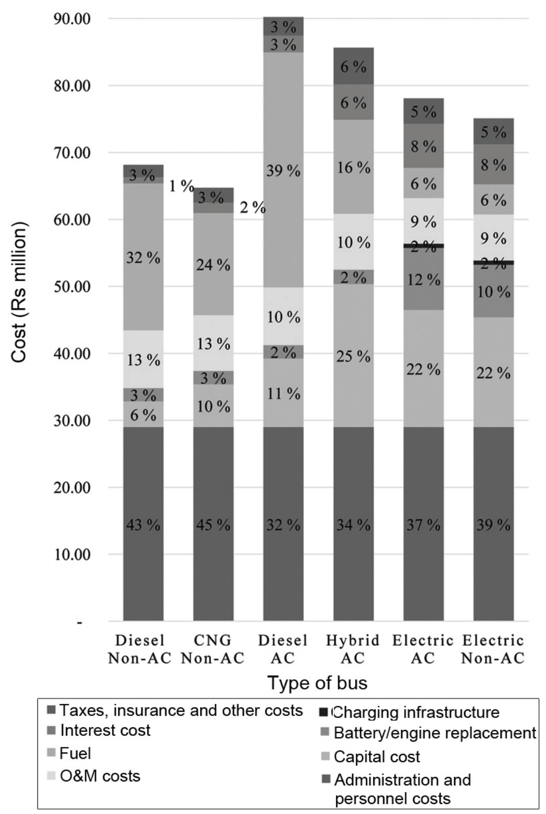
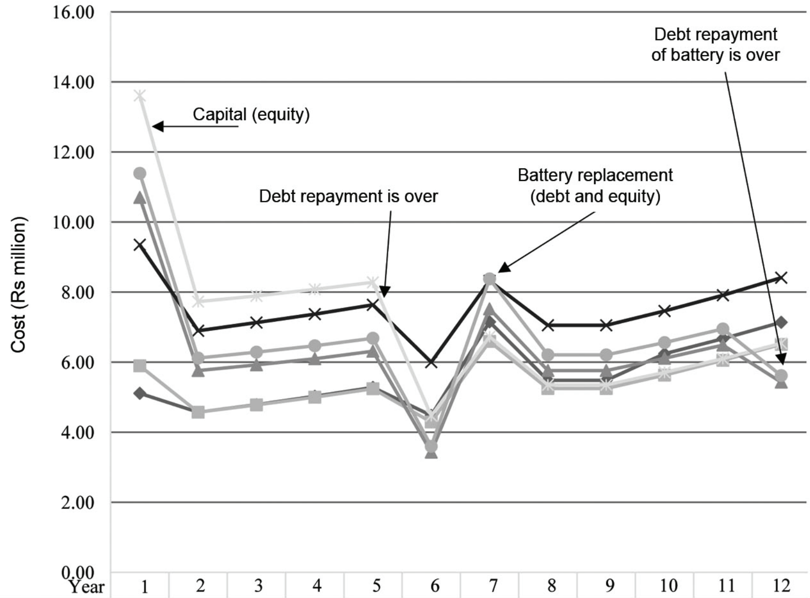


Figure 1. Break-up of cost components of total cost of ownership for different bus variants (Rs million).

Life-cycle cost analysis of different bus variants shows that cost of electric buses is significantly high in the first year and seventh year due to the equity component of the capital cost and battery cost respectively. The cost falls steeply thereafter and reduces to below that of conventional buses in the 6th and 12th years, once the debt is repaid. Based on this, it is observed that operating cost of BEBs is low compared to ICE buses. Figure 2 shows a graph of the life-cycle cost of different bus variants calculated over 12 years.

A similar study conducted for electric buses in Delhi pointed out that the TCO of CNG was Rs 626 million and that of electric bus was Rs 783 million over the period of 12 years. The analysis showed that procurement cost of electric buses was four times that of CNG buses, with the operational costs of electric buses being 3% more at Rs 46.02/km compared to CNG buses with an operating cost of Rs 44.47/km. However, electric buses showed huge savings of 45% on maintenance cost at Rs 8.47/km against Rs 14.91/km of CNG buses[18].

A study carried out by Centre for Science Technology and Policy (CSTEP)[12] for electric buses in Bengaluru, Karnataka calculated TCO to be Rs 33.3 million for diesel non-AC buses, Rs 62.6 million for diesel AC buses, Rs 65.5 million for hybrid AC buses and Rs 80.1 million for electric AC buses over a period of 10 years. The study further stated that capital cost of electric AC buses was



Year	1	2	3	4	5	6	7	8	9	10	11	12
Diesel non-AC (Rs)	5.11	4.57	4.79	5.03	5.28	4.48	7.15	5.48	5.48	6.24	6.67	7.14
CNG non-AC (Rs)	5.90	4.57	4.78	5.00	5.24	4.29	6.59	5.25	5.25	5.63	6.05	6.51
Electric non-AC (Rs)	10.70	5.76	5.92	6.10	6.31	3.43	7.52	5.76	5.76	6.11	6.49	5.43
Diesel AC (Rs)	9.35	6.90	7.13	7.37	7.64	6.00	8.32	7.05	7.05	7.46	7.91	8.41
Hybrid AC (Rs)	13.61	7.73	7.89	8.08	8.28	4.47	6.73	5.35	5.35	5.71	6.10	6.54
Electric AC (Rs)	11.39	6.12	6.29	6.47	6.68	3.60	8.38	6.21	6.21	6.56	6.95	5.62

Figure 2. Distribution of life-cycle cost of different bus variants (Rs million).

37% of the TCO, whereas for diesel buses it was just 9%. The study assumed that the battery price would be 50% of the present market price at the time of battery replacement. Further, the sensitivity of several factors such as variations in capital cost, interest rate, daily run, fuel price and battery replacement cost on TCO was analysed. The TCO of electric buses was Rs 95/km against Rs 74/km for diesel buses, when the best-case scenario was considered, i.e. diesel costs are high, battery rates are low, interest rates are low and subsidy is availed for electric buses from the Government. However, in the pragmatic scenario, the TCO of electric buses is as high as Rs 103/km compared to Rs 66/km for diesel buses. The societal costs were included in the TCO, i.e. the cost of carbon emissions and noise pollution-related health costs were added in the TCO[12]. Studies on electric buses in Finland, and California, USA also showed that the life-cycle costs of electric buses were heavily impacted by capital costs, including purchase costs of the buses and charging devices, and over the 12 years of service life, electric buses could have slightly lower life-cycle costs than diesel buses, but on an average they had 7% higher life-cycle costs[19].

There is a minor difference between the CPK of electric AC and non-AC buses (Table 3). So electric AC buses are considered next in the analysis. It is assumed that urban transport utilities would eventually want to transition to AC buses as these would provide better passenger comfort, thus encouraging more commuters to shift to public transport.

Emissions from different bus models

The net CO_2 emissions from diesel buses were calculated using eq. (3). For this, the product of energy density of diesel (ED_d) and mass of CO_2 per unit energy by diesel undergoing mobile combustion ($CE_{d,t}$) was considered to be 10.131 kg/gallon, i.e. 0.276 kg/litre (ref. 20). Other pollutants emitted from diesel buses were estimated according to the Bharat Stage-VI emission standards for the steady state, as stated by ARAI (ref. 16). In case of transient state, the emission factors are much higher.

For CNG buses, the emission standards were taken from the working paper on exhaust emissions of transit buses by EMBARQ (ref. 21).

Table 4 shows the tail-pipe emissions from different bus variants. In case of Indian cities, the actual emissions would be higher due to congestion on the roads.

A well-to-wheel analysis of the emissions of running a bus includes analysing the emissions from well-to-tank which includes emissions during feedstock production, transportation, fuel production and fuel distribution, and tank-to-wheel which includes emissions during fuel utilization to move the vehicle[22]. Analysing well-to-tank emissions for different fuel components is outside the

Table 4. Emissions from different bus variants

Type of bus	CO_2 emissions (tonnes/year)	CO emissions (kg/year)	THC emissions (kg/year)	NO_x emissions (kg/year)	PM emissions (kg/year)
Diesel non-AC	62.55	351.51	30.46	93.74	2.34
CNG non-AC	20.82	237.86	29.70	172.41	1.80
Electric non-AC	0.00	0.00	0.00	0.00	0.00
Diesel AC	100.08	562.42	48.74	149.98	3.75
Hybrid AC	40.03	224.97	19.50	59.99	1.50
Electric AC	0.00	0.00	0.00	0.00	0.00

Table 5. CPK for different financing scenarios

Scenario	Business as usual scenario	Scenario 1	Scenario 2	Scenario 3	CNG
Capital structure	30% equity; 70% debt	30% equity; 70% debt	30% equity; 70% interest-free loans	Capital grants	30% equity; 70% debt
Rate of interest/discounting per annum (%)	11	11	11	11	11
Tenure of loan (years)	5	5	5	NA	5
Financing for battery replacement	Same as bus	Same as bus	Same as bus	Capital grants	100% equity
Total capital expenses (Rs million)	27.25	22.21	22.21	0.00	8.40
Total operating expenses (Rs million)	52.92	51.68	46.32	46.82	56.31
TCO (Rs million)	80.18	73.90	68.56	46.82	64.70
Present value of TCO (Rs million)	45.13	43.52	38.69	25.38	34.33
CPK (Rs)	50.28	47.37	43.10	28.28	38.25

scope of the paper. Here we focus mainly on tail-pipe emissions (tank-to-wheel), as these are the main source of pollution in the cities. Well-to-tank emissions are not relevant to the problem of city transport. It is a problem at a much larger level, since the emissions at the places where the manufacturing takes place have to be considered. As in this case, an electric bus consumes around 82,198 units (kWh) of electricity per year. According to eq. (6), carbon emissions due to electricity required to charge the batteries of AC electric buses are 59.26 tCO_2/year, whereas those from non-AC electric buses are 53.93 tCO_2/year. Thus, given the current mix of electricity supplied through the grid, electric buses would not contribute significantly to climate-change mitigation considering well-to-wheel emissions at this point of time. In some countries, like China, the net emissions were reduced by 19–35% (ref. 23), whereas in countries like Australia the net emissions had increased by 1.2–1.4 times[24]. To achieve the goal of reducing the net carbon emissions by a shift to electric buses, a shift in grid-based supply is also required. However, as shown in Table 4, electric buses have a significant potential to mitigate the consequences arising from tail-pipe emissions, contributing to a cleaner local environment.

A similar study conducted by Shakti Foundation with CSTEP for electrification of public transport buses in Bengaluru[12] and with India Smart Grid Forum for Kolkata[13] reported that replacing a diesel AC bus with an electric AC bus mitigated tail-pipe carbon emissions by 79.19 and 87.1 tCO_2 annually in Bengaluru and Kolkata respectively. Another study done for Delhi found that replacing a single CNG bus by an electric bus in passenger transport could mitigate 48.9 tCO_2, 120 kg of CO, 364 kg of NO_x, 99 kg of CH_4, 34 kg of PM and around 60 kg of hydrocarbons annually[18].

Scenarios for financing

TCO is affected by the interest on debt for bus purchase and battery replacement to a large extent (around 8% of TCO for electric buses compared to 2% in case of CNG). Hence, different financing scenarios were explored as shown in Table 5, assuming that the battery costs will reduce in the future as projected.

CPK can reduce by almost Rs 3 compared to the BAU scenario, if the battery rates are reduced as projected (scenario 1). Further, if PMPML gets interest-free loans for procuring electric buses as an incentive for moving towards cleaner energy use, CPK can reduce to Rs 43.10, which means that PMPML would pay Rs 4/km towards interest on the debt at current financing conditions with projected battery prices. Thus, having an alternative funding mechanism like interest-free loans for PMPML can help in decreasing the overall CPK substantially, with enhanced passenger comfort and safety. If PMPML receives capital grants from the Government as mentioned in scenario 3, the AC electric buses can run at much lower costs (only operating expenses) compared to non-AC CNG buses.

The present FAME II scheme of the Central Government aims at providing a capital subsidy of Rs 5 million per bus for 7090 buses in the country, which would cost the Government Rs 3.5 billion (ref. 25). Capital cost of an electric bus is around three times that of a conventional bus; so the expenditure involved is significant. Capital grants will provide tail-pipe emission-free buses, but by indirectly burdening citizens. Therefore, it may be opportune to explore alternative methods such as taxation of private cars and polluting vehicles, to finance these capital grants.

The first phase of the FAME scheme of the Indian Government had offered 60% of the purchase cost up to Rs 10 million as an incentive, which was given to a selected few cities[26]. The second phase of the scheme offered an incentive of Rs 5 million for Pune city as an incentive to procure 150 buses[27]. While the Maharashtra State Government has offered a subsidy of Rs 2 million per bus for the first 1000 electric buses in the state, different state Governments are coming up with such schemes at the state level[28]. This may seem a good start for electrification of public transport buses, but for a country whose total fleet strength was 149,095 ICE buses in 2016–17 (ref. 29), providing incentives for 5595 buses does not seem to be a sustainable solution. It is possible to explore options of financing through multilateral funds such as the green climate fund for such schemes.

Pessimistic scenario (battery is replaced after every three years)

If the battery is replaced after every three years instead of seven, it cannot be procured through a five-year debt cycle, and thus it is assumed that the battery replacement is done by 100% equity. Figure 3 shows the life-cycle costs of electric buses when the battery is changed after every three years compared to the life-cycle cost of CNG buses. If the battery is replaced after every three years, CPK at the present value of TCO is estimated at Rs 52.64, which is still less than the conventional diesel AC buses but not comparable to CNG buses. Thus in this scenario, it would not be economically feasible to have electric buses soon.

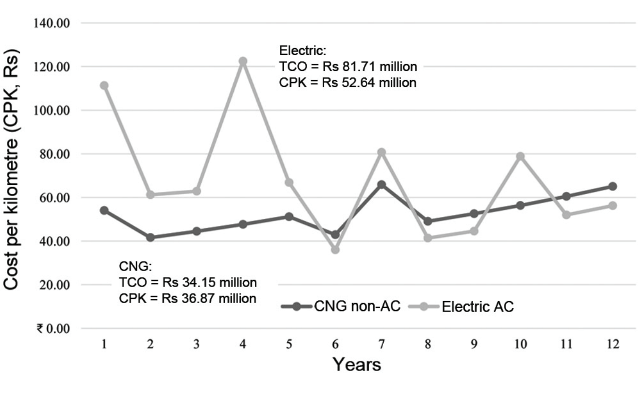


Figure 3. Life-cycle cost of electric buses for battery replacement after every three years.

Parity check with CNG buses

With battery prices assumed to decrease and the overall cost of electric buses also expected to reduce, we have assumed 10% reduction in the electric bus prices and 2% rise in the price of conventional CNG buses every year. We have estimated the parity of costs between these two bus types using the assumptions mentioned in the methodology.

Figure 4 provides a comparison of CPK of electric buses and CNG buses purchased over various years. The net CPK is calculated based on the present value of the TCO of the bus with the year of procurement as the base year.

With these assumptions, which are highly favourable to electric buses, the cost of electric AC buses becomes comparable to that of conventional CNG, non-AC buses by 2022–23. Till 2023, therefore, any decision taken for a transition based on other benefits of the buses, such as reduction on local environmental pollution, would still add to the cost and decisions would have to be made as to who will bear this additional cost.

Phase-wise electrification of the existing fleet

Analysis in the previous section showed that cost of AC electric buses may become comparable with non-AC, CNG buses by 2023, and thus fleet replacement may be considered by 2023 or later. Even so, at projected rates, a 12 m long electric AC bus would cost Rs 1.15 billion in 2023 and the cost of replacing the entire fleet of 1465 buses with electric buses at one go would be Rs 16.74 billion. This would put a huge burden on PMPML in a single year and thus a phase-wise replacement of the existing fleet is recommended, as is the normal practice.

The depot-wise route list of PMPML shows that there are total 2098 buses in its fleet, of which 1445 are owned by PMPML and 653 buses are hired on gross cost

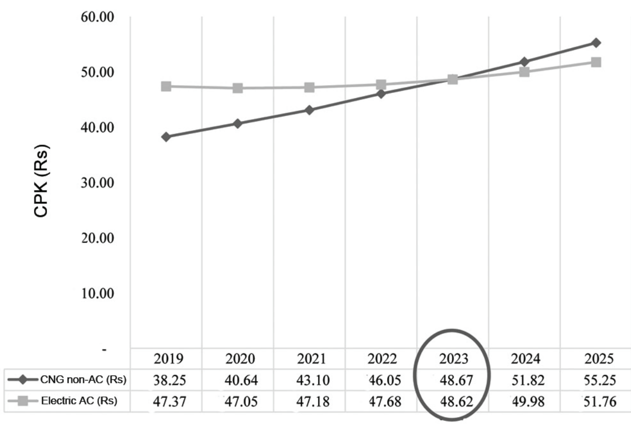


Figure 4. Comparison of CPK for electric buses and CNG buses purchased during various years.

Table 6. Daily distance covered and bus age profile

Daily distance covered by the buses		Bus age profile		
Distance range	Fleet strength	Age group (years)	Fleet strength	Emission standard
		0–5	212	BS-IV
Up to 150 km	109	6–10	713	BS-III
151–300 km	1024	11–12	313	BS-III
Above 300 km	244	13–15	180	BS-II
Monthly contract	35	Above 15	28	BS-II
Off-road	687	Hired	653	BS-III
Total	2099	Total	2099	

Table 7. List of electric buses selected for PMPML

Bus specification	Battery capacity (kWh)	Range (km)	Price as of April 2018 (Rs million)
12 m long, 900 mm height	125	150	8.8
9 m long, 650 mm height	162	200	12.3
12 m long, 400 mm height	320	300	17.5

Table 8. Potential plan for replacement of existing buses with electric buses

Phase	Year	No. of buses	Bus type	Description
1	2019	62	12 m long, 150 km range	Buses procured between 2000 and 2004. Replace oldest buses which are mostly deployed on shorter routes. This will also reduce the initial high investment
		45	12 m long, 300 km range	
2	2020	101	12 m long, 300 km range	Buses procured in 2005–06 (That would have completed 14 years 2020)
3	2021	267	12 m long, 300 km range	Buses procured in 2007–08 (That would have completed 13 years by 2021)
		45	9 m long, 200 km range	
4	2022	227	12 m long, 300 km range	Buses procured in 2009–10
5	2023	217	12 m long, 300 km range	Buses procured in 2011
6	2024	269	12 m long, 300 km range	Buses procured in 2012
7	2027	11	12 m long, 300 km range	Buses procured in 2015
8	2030	201	9 m long, 200 km range	Buses procured in 2018

contract (GCC) basis. Table 6 shows the profile of buses based on the age and distance covered.

The DHI website has a list of electric bus models in India[30]. Based on the distance covered, battery capacity needed, and size of the bus corresponding to the existing fleet, three models were selected. Table 7 shows their specifications.

Considering the age, distance covered, available models and cost, Table 8 shows a potential plan for replacement. We do not argue that this is the only or the most optimal plan for transition. However, it provides an illustration of the possible consideration of parameters when the transition is undertaken.

Based on the assumptions made in this study, the TCO for these buses is calculated and represented in 2019 value terms. Table 9 shows the total cost of replacement of the entire fleet of 1445 buses owned by PMPML with air-conditioned electric buses of similar capacity and features. The total cost of replacement of the entire existing fleet of PMPML would be Rs 12.04 billion, as calculated in 2019 value terms.

Table 10 shows the tail-pipe emissions (tonne/annum) that can be mitigated if the utility shifts to electric buses. The calculations were done according to the emission factor for the current fleet of buses under the norms of the Indian emissions regulations[16] and exhaust emissions of transit buses[21].

Replacement of conventional buses by electric buses in the PMPML fleet can help mitigate about 1 million tonnes (mt) of CO_2 emissions, 680 tonnes of carbon monoxide, 190 tonnes of hydrocarbons, 1250 tonnes of nitrous oxides and 26 tonnes of PM emissions within the city of Pune every year. This does not account for the increase in CO_2 emissions at the site of electricity generation, as discussed in the previous section.

Considering that electricity to charge these buses will be generated mainly using coal, gradual mitigation of carbon emissions reaching 1 mt of CO_2 per year once all buses are replaced after 11 years may not seem substantial. However, as stated earlier, in India the attraction to electric vehicles is not driven so much by the prospect of lower carbon emissions, but by the promise of a cleaner local environment due to zero tail-pipe emissions.

Effect on electricity consumption

Adding the electricity consumed by each bus for charging the battery per day, Table 11 gives the cumulative additional demand that the city will have to cater to.

Table 9. Cost of replacement of the entire fleet of PMPML by electric buses in a phased manner

		Net expense (Rs million)			Present value of net expense (Rs million)		
Phase (year)	No. of buses	Capital expense	Operating expense	Total	Capital expense	Operating expense	Total
1 (2019)	107	17.5	48.5	65.9	12.9	24.9	37.8
2 (2020)	101	24.3	66.8	91.1	16.5	30.8	47.3
3 (2021)	312	56.8	209.6	266.4	33.9	86.3	120.2
4 (2022)	227	39.5	170.3	209.8	21.3	62.9	84.1
5 (2023)	217	34.4	173.2	207.6	16.7	57.2	73.9
6 (2024)	269	38.8	229.9	268.6	17.0	68.1	85.1
7 (2027)	11	1.2	11.7	12.8	0.4	2.5	2.9
8 (2030)	201	7.7	143.6	151.4	1.8	22.3	24.1
Total	1445	22.02	105.35	1273.7	120.4	354.9	475.3

Table 10. Net tail-pipe emissions mitigated per annum

Phase	CO_2	CO	THC	NO_x	PM
1	6746.13	101.35	27.58	177.63	4.20
2	6556.99	93.92	25.98	166.85	3.56
3	21,090.41	142.81	42.72	321.12	6.34
4	15,208.98	188.30	50.53	320.99	6.81
5	19,243.37	51.62	6.44	37.41	0.39
6	23,854.69	63.99	7.99	46.38	0.48
7	693.53	10.31	2.84	18.04	0.39
8	12,672.64	188.41	51.81	329.72	7.07
Total per annum	106,066.75	840.71	215.90	1,418.15	29.25

Table 11. Additional electricity demand due to electrification of the existing fleet

Year	Cumulative electricity demand (MWh per day)
2019	24.09
2020	58.16
2021	156.61
2022	233.19
2023	306.39
2024	397.13
2027	400.84
2030	429.74

An increase in demand by 430 MWh per day indicates an increase in the annual demand by 146.2 million kWh, which is just 0.7% of the projected demand of 2022 (21,111 million kWh) according to the data published in the 18th Electric Power Survey of India by CEA[31]. This is a negligible rise in demand and that too in stages over a period of 11 years.

The BEBs presently have a high capital cost, but low operating cost. However, the benefit of low operating costs can be reaped only if the buses are able to complete their scheduled trips per day. This is a challenge as currently, scheduled trips cancelled due to various reasons like congestion on roads, increased time for completing a trip, shortage of operating staff, breakdown of buses, etc. About 28% of the scheduled trips in November 2018 had to be cancelled due to various reasons. To run electric buses in a cost-effective manner, bus operation must be efficient.

The cost of electricity required for charging electric buses is around 6% of the TCO. The mitigation of carbon emissions is also limited since electricity is taken from the coal-dominated national grid. The chances of PMPML entering long-term contracts with renewable energy producers or setting up its own renewable energy generating stations in the outskirts of Pune city must be explored. If PMPML can get renewable energy from standalone plants at a rate lower than the present tariff of the electricity distribution company, it can bring down the electricity cost with lower operational emissions.

In this study, the fuel prices are assumed to be rising at 2% per annum and all other consumables at 5% per annum. We have approached real-time data according to market surveys, but if the actual rise is not in line with the assumptions, the real outcome of electrification of the buses would be different from the results of this study. As mentioned previously, ready-to-use battery packs are imported in India and the battery prices considered for this study are based on the interviews conducted and the projected battery prices are according to the available research. Getting the real-time battery prices in India from manufacturers would give a more realistic value of the costs involved.

Conclusion

A cost–benefit analysis for transition to electric buses for Pune city was carried out in this study. The actual financial burden on the public transport undertaking and the commuters was estimated and compared with the emissions and pollution reduction benefits that such a transition offers.

The analysis shows that even in the BAU scenario, it is viable to use battery-operated, electric AC buses which have CPK of Rs 50.28 compared to AC diesel and hybrid buses which have CPK of Rs 54.63 and Rs 56.07 respectively. However, AC buses are overall more expensive compared to non-AC buses and in the public bus transport segment, non-AC CNG buses are still the cheapest at a CPK of Rs 38.25. The analysis of emissions in the BAU scenario shows that while electric buses reduce local environmental pollution, the decrease in net carbon emissions is limited as the grid-based electricity that will be used would still primarily come from coal-fired thermal power plants. The mitigation of tail-pipe emissions for a cleaner local environment would come at a certain cost. Even if the cost of batteries reduces at a rate of around 10% per annum and interest-free loans are availed by the transport utility, CPK of an electric bus would be Rs 43.10, which is around Rs 4 more than that of a non-AC CNG buses. Based on the assumptions made in this study, it is possible that the AC electric buses would be at parity with non-AC CNG buses around the year 2023. However, to avoid financial burden on public transport utilities all at once, even when parity is achieved, a phase-wise replacement of the existing fleet is suggested based on the age of the buses.

Transitioning to electric buses in the public transport also requires an overhaul of repair services, infrastructure and skilled manpower. For example, the structure of automobile maintenance courses in industrial and vocational training institutions will need to be modified for this shift from ICE-based technology to electric motors-based technology. Such changes and knowledge upgradation are necessary not only in the automobile industry, but all the allied industries that support it.

Further, even as the cost of battery replacement is borne by the State Transport Understandings (STUs), little attention has been given to the disposal of used batteries. This will add significantly to environmental pollution if proper means of disposing the batteries or recycling them are not available. The normal convention is that an electric vehicle battery needs to be replaced once it reaches 80% of its full capacity. This means that the battery disposed by the vehicle can still be used for static purposes, where space constraints do not exist. So they can be used in PMPML buildings as inverter batteries or for rooftop solar units. These batteries can also be used in solar or wind energy farms for off-grid storage. Therefore, there are many indirect costs, even as there are some benefits, involved in this transition.

In 2017, the southeastern city of Shenzhen in China declared that all of its 16,359 buses were electric[4]. The city started the electrification of buses in 2012 and gradually replaced the entire fleet over the span of five years. Shenzhen was able to achieve its target by availing local and national subsidies from the Government, leasing some buses directly from bus manufacturers, developing optimum charging infrastructure and making it available for private vehicles to generate revenue, and availing lifetime warranties from battery manufacturers. According to a study conducted by the World Bank and Global Environment facility, the TCO of e-buses in Shenzhen as of 2016 (including procurement, energy and maintenance costs over an eight-year period) was US$ 375,457, almost the same as that of a diesel bus (US$ 342,855)[4]. Shenzhen's experience proves that it is possible for cities to cost-effectively electrify their bus fleets. According to the report released by UITP India[36] on the status of electric bus procurement in the country, different cities have managed to procure at different rates. Table 12 shows the rates that various cities have received for operation of electric buses. It can be observed that rates quoted for various cities vary largely.

The present study evaluates the real cost of introducing electric buses in a fleet. The findings clearly show the high economic burden of such a shift. However, the benefits for local environmental protection may make the transition necessary. Innovative financing mechanisms need to be explored to reduce the financial burden of high capital cost on transport utilities and citizens till the electric buses become financially viable.

Table 12. Rates for operations of electric buses in various cities

City	Bus size (m)	Rate (Rs) quoted (per km)
Bengaluru	9	29.28 + electricity charges
	12	37.35 + electricity charges
Hyderabad	9	36 + electricity charges
	12	40.3 + electricity charges
Ahmedabad	9	48 (including electricity charges)
Mumbai	9	57 (including electricity charges)
Jaipur	9	70 (including electricity charges)

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