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The Case for All New City Buses in India to be Electric

Authors
Khandekar, Aditya
Rajagopal, Deepak
Abhyankar, Nikit
et al.

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Summary: We illustrate that when the benefits of recent dramatic declines in Lithium battery prices are fully realized, the total cost of ownership of urban (intra-city) electric buses is lower than that for diesel buses in India even without subsidies. Factoring in the air quality benefits, projected reductions in the cost of batteries and solar electricity, it becomes evident that transitioning to an all-electric bus fleet presents an enormous opportunity for India to reduce urban air pollution while improving the finances of urban bus transit agencies. Applying relevant lessons from the policy ecosystem that delivered substantial price reductions and large-scale rapid deployment of solar PV and LEDs could achieve similar outcomes for battery electric buses. Well-designed high volume auctions and clear long term ambitious targets could achieve rapid electrification with little net public subsidy in the long-run.

Authors:
Aditya Khandekar[1], Deepak Rajagopal[2,3], Nikit Abhyankar[2], Shruti Deorah[2], and Amol Phadke[2]*

[1] Building Technology & Urban Systems Division, Electronics, Lighting & Networks Group
[2] Energy Analysis and Environmental Impacts Division, International Energy Studies Group
[3] Institute of the Environment and Sustainability, UCLA
*Corresponding author

Energy Technologies Area
Lawrence Berkeley National Laboratory

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Executive Summary

Summary: We illustrate that when the benefits of recent dramatic declines in Lithium battery prices are fully realized, the total cost of ownership of urban (intra-city) electric buses is lower than that for diesel buses in India even without subsidies. Factoring in the air quality benefits, projected reductions in the cost of batteries and solar electricity, it becomes evident that transitioning to an all-electric bus fleet presents an enormous opportunity for India to reduce urban air pollution while improving the finances of urban bus transit agencies. Applying relevant lessons from the policy ecosystem that delivered substantial price reductions and large-scale rapid deployment of solar PV and LEDs could achieve similar outcomes for battery electric buses. Well-designed high volume auctions and clear long term ambitious targets could achieve rapid electrification with little net public subsidy in the long-run.

Indian cities are struggling to keep the air breathable for inhabitants, due in part to emissions from diesel buses. While the case for electric buses, and more generally, zero emission buses, has always been clear from an urban air pollution perspective, the economic case depended strongly on their environmental benefits. However, the situation seems different today.

By the end of 2017, lithium-ion battery costs had fallen more than 80%—to less than $175 per kilowatt-hour (kWh)—relative to their cost in 2010. Consequently, the cost of producing electric buses have fallen steeply, and electric buses are gaining market share worldwide. For example, electric bus sales in China have increased tenfold over the last five years, to 100,000 units per year.

Given these recent developments, we develop a model to estimate the total (or lifecycle) cost of ownership (TCO) of both electric and diesel buses from the bottom-up (i.e., using cost of individual major components and sub-systems in a bus) while taking into account the cost of charging infrastructure, and battery replacement. We use this model to analyze the sensitivity of the difference in the TCO of electric and diesel bus to different future scenarios of battery cost, bus utilization rates, and lastly, to different policy interventions (subsidies, tariffs, and electricity rates). We do this analysis for four different bus configurations - 9 meter (m) non-air-conditioned (AC), 9m AC, 12m Non-AC, 12m AC.

Across a broad range of average daily utilization rates from 150 to 250 kilometers, and at the current unsubsidized cost of electricity supply, we find that electric buses have a lower TCO relative to diesel buses not only in the absence of EV subsidies but even after factoring in the 30% tariff on import of EV batteries into India (see Figure A). A few other recent studies have compared the TCO of both electric and diesel buses. However, because those studies assume battery cost that are 2X to 4X the cost in 2017, they result in greater TCO for EVs.

We also compare our bottom-up estimates with actual bids received by various Indian cities under the Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) policy which provides generous subsidies for procuring EV buses. This data suggests that while TCO of the electric bus to the buyer (i.e., city bus agency) is comparable to that for diesel buses in most cases[1],

[1] To be clear, there is variability in how the bids compare to our bottom-up estimates for each of the four different bus specifications – 9 metre AC and non-AC, 12 metre AC and non-AC and for each specification depending on whether

the total price received by the manufacturers, which is the price paid by the buyer plus the subsidy, translates into a higher TCO relative to diesel bus, which appears to contradict the bottom-up estimate.

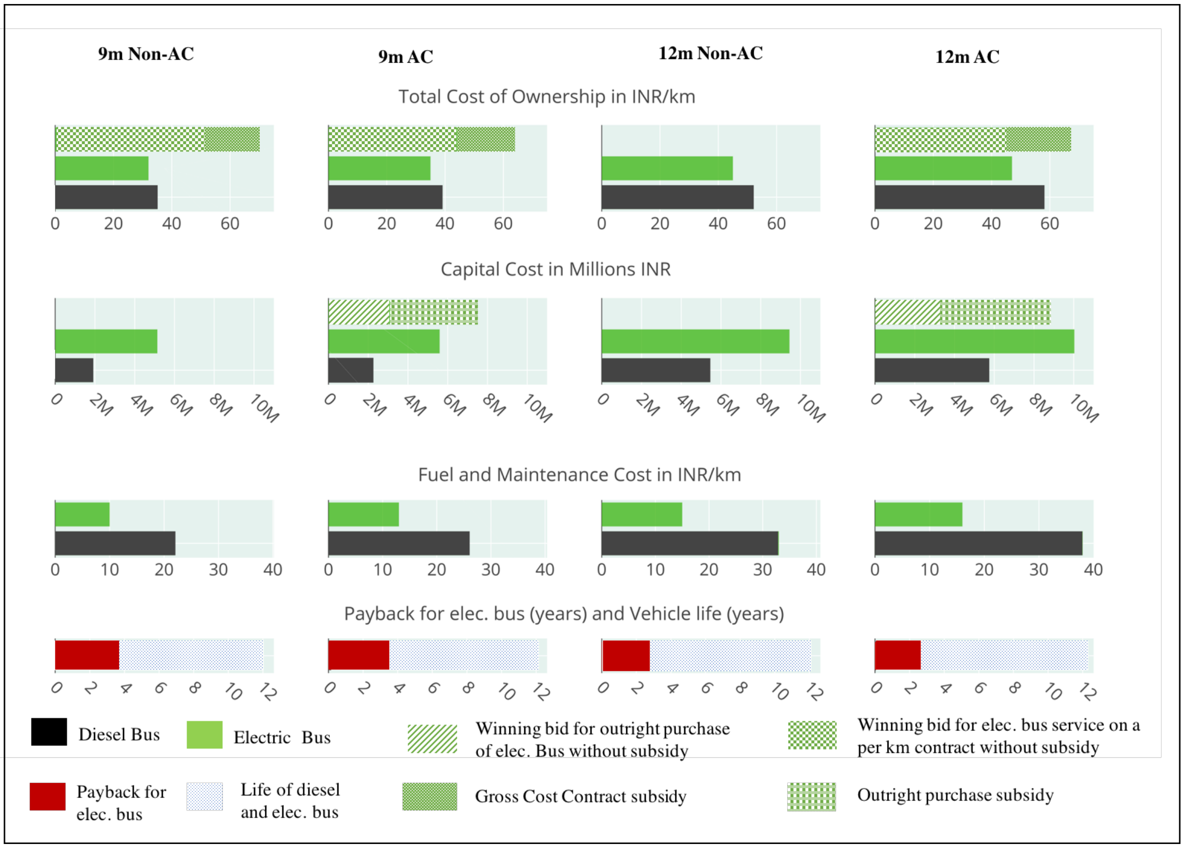


Figure A: Comparison of TCO, capital cost, fuel and maintenance cost for four different classes. Comparison – 9 metre (m) non-air-conditioned (AC), 9m AC, 12m Non-AC, 12m AC -- of buses for average operation of 200 km/day. Figure also shows how the TCO derived from bottom up cost estimates of vehicle production cost (solid green bars) compares to the winning bids for electric bus service on a per km contract basis (green checkered bars). All diesel bus metrics are based on bottom-up estimation of vehicle production cost. It also shows how the bottom up estimate of electric vehicle production cost (solid green bars) compares to winning bids for outright procurement of electric buses (hashed green bars). It also depicts the payback to electric buses relative to an assumed common useful life of 12-year life for both diesel and electric buses. Note that for 9m Non-AC bus, the bids for electric bus service exceeds our bottom up estimate.

Plausible reasons as to why the bid data suggest a higher TCO relative to the bottom-up estimates include imperfect competition (most cities had one or two bidders)[2], information asymmetry, and battery prices that are out-of-date with recent trends. At the same time, it is plausible that our bottom-up estimates are biased downward due to hidden costs including transaction costs and higher actual cost of capital.

bid was for outright purchase of the bus or a bid for bus operations on a cost-per-km basis. More details are in the full report.

[2] When there is imperfect competition, bidders might set their price to the buyer at or close to the TCO of diesel bus, which is easy to estimate, so as to capture the full benefit of the subsidy.

Notwithstanding the higher total cost (i.e., with the subsidy) revealed by the bids as well as the estimates in the literature, our bottom-up analysis is aimed at illustrating how in the long-run the difference in costs fundamentally ought to reflect the incremental cost of the battery, the savings in engine cost, and savings in fuel and maintenance costs. Viewed from this perspective, given the projected future decline in battery prices (from $200 to $100 per kilowatthour (kWh)), the reduction in the cost of solar electricity (from INR 6/kWh to INR 4/kWh), and the air quality benefits, the case for embarking on a transition to an all-electric future for city bus transportation today is evident.

Furthermore, unlike diesel prices which are volatile, EV buses are poised to take advantage of low and 20-year nominally fixed solar electricity prices which are substantially lower than today's average cost of electricity supply (see Figure B).

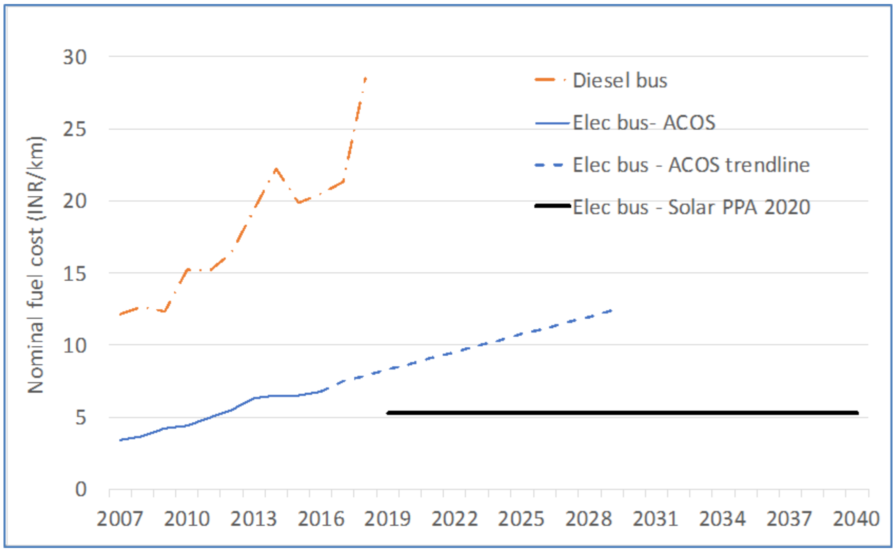


Figure B: Nominal fuel cost per kilometer for diesel buses (orange and dashed dot) and for electric buses under for two different scenarios for electricity prices – average cost of supply for state-owned utilities in India (ACOS) (solid blue and dashed trend line) and under 25-year nominally fixed solar power-purchase agreements (PPAs) effective from 2020 (solid black line). Diesel bus fuel cost is based on average annual diesel price and a fuel economy of 2.5 km/liter of diesel. Electric bus fuel cost is based on a fuel economy of 0.8 km/kWh for electricity and solar PPAs at INR 5.3/kWh (which is inclusive of a transmission and distribution cost of INR 1.5/kWh).

Most publicly owned bus systems in large Indian cities generally recover only about 70 to 90 percent of operating costs. Complete electrification of publicly owned fleets would more than offset the current net loss incurred by these agencies, which could enable these agencies to improve their finances without raising fares and then spur increased ridership in a virtuous cycle of performance and growth. Electrifying all 160,000 buses owned by state and city road-transport corporations across India would increase national electricity consumption by only about 1%.

India has significant experience in bringing down the prices of key clean energy technologies such as solar PV and LEDs with a robust policy ecosystem and well-designed large scale auctions. Relevant lessons from this experience can potentially be applied to bring down the electric bus prices in India including the use of large volume reverse auctions enabled by aggregation of demand, clearly defined uniform technical specification, clear long term policy target, and provision of supporting infrastructure.

India's Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) policy facilitates electric bus deployment, but our analysis suggests the need to improve the allocation of funds and address other shortcomings in the current scheme. For instance, despite FAME's generous per-vehicle subsidies, allocating the entire budget of INR 3,500 Crores set aside for electrification of buses and cabs would electrify less than 1% of the national stock of public and private buses combined. Low- or zero-interest loans to finance bus procurement, lowering the cap on maximum subsidy per bus, differentiating subsidies for AC and non-AC buses, adopting ambitious overarching goals such as ensuring all new public buses are electric, selecting a few major cities for demonstrating the feasibility of this idea, facilitating bus procurement on a large scale to exploit scale economies, and removing informational asymmetries and barriers would represent steps in this direction.

Introduction

Indian cities are struggling to keep the air breathable for inhabitants (Nature 2018). Worldwide, emissions from transportation play an outsized role in urban air quality (Molina and Molina 2004). Vehicular traffic is frequently the single largest contributor of particulate matter emissions in major cities, and it accounts for 37% in Indian cities (Karagulian et al. 2015). According to the World Health Organization, suspended particulate matter is responsible for the premature death of more than half a million people per year globally. Surveys also suggest that pollution drains cities of skilled human capital.[3]

Despite constituting only a small fraction of total vehicles on city roads—heavy-duty vehicles, a large proportion of which are diesel buses—account for a disproportionate share of particulate matter emissions. For instance, in Sao Paulo, Brazil, heavy-duty vehicles represent only 5% of all vehicles but are responsible for 40% of the benzene and 47% of the black carbon in the atmosphere, and city transit buses and urban cargo vehicles combined account for 30% of particulate emissions (Brito et al. 2018).[4] There is now consensus that exposure to diesel engine exhaust is carcinogenic (IARC 2012).

While the urban air-quality benefits of electric buses are unquestionable, electric buses historically presented two challenges to cities. First and foremost, their upfront cost was prohibitively high for subsidized and cash-strapped public agencies (Pucher 2004).[5] Second, although electric vehicles emit no pollution at point of use, their lifecycle environmental benefits depend largely on the source of electricity used for charging.[6] The situation on both these fronts is dramatically different today. The last two years have witnessed a rapid decline in the cost of battery technology, which is the main cost component of an electric bus (Figure 1), which is substantially lowering the total lifecycle cost of electric vehicles. Given the rapidly growing share of renewables in grid electricity,[7] electric buses also appear to be cleaner than diesel buses on a lifecycle basis with respect to climate change and air pollution.

[3] https://www.scmp.com/article/732181/air-pollution-may-cause-brain-drain-study-finds
[4] http://www.wrirosscities.org/sites/default/files/Exhaust-Emissions-Transit-Buses-EMBARQ.pdf
[5] http://wricitieshub.org/online-publications/71-costs-and-revenues-understanding-bus-operations
[6] Fuel cell vehicles offer the same local air-quality benefits and suffer similar limitations as EVs relative to internal combustion engines. However, fuel cell technology has not witnessed the types of breakthroughs that battery-electric vehicles have in the last few years, which justifies our focus on electric buses. We focus here on reductions in the cost of battery and solar PV systems (Figures 1 and 2).
[7] https://cleantechnica.com/2018/06/10/india-increases-its-massive-2022-renewable-energy-target-by-28/

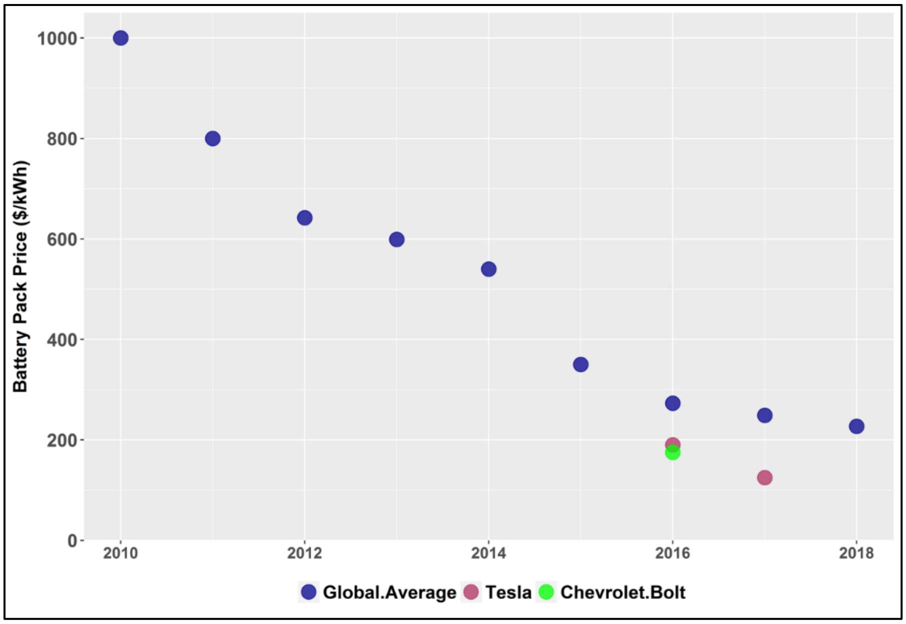


Figure 1: Recent trends in lithium-ion battery cost and projections (post-2017) by Bloomberg New Energy Finance (BNEF 2018)

Unlike diesel prices which are volatile, EV buses are poised to take advantage of low and 20-year nominally fixed solar electricity prices which are substantially lower than today's average cost of electricity supply. Figure 2 compares fuel cost per km for diesel buses and electric buses charged with solar power, demonstrating increasing diesel prices but solar PPA prices that are fixed (in nominal terms) over the duration of the PPA (typically 25 years in India). For example, in the fiscal year 2018-19 (up to October 2018), the capacity-weighted average of bid prices across 11 reverse auctions for 8.6 GW of solar capacity was INR 2.67/kWh. This average price will be realized once these projects are commissioned, about 18-24 months from signing of the PPAs. On the other hand, the diesel price reached INR 75/liter in Delhi in October 2018, an increase of 11% since July 2018. Thus, the gap between the fuel cost of diesel versus solar-based electricity will continue to increase, even if we assume a modest CAGR for diesel prices in future. Given the anticipated availability of ultra-fast charging,[8] electric buses can potentially charge during daytime to take advantage of low, constant solar electricity prices, unlike the rising and volatile diesel prices.

A few recent studies have compared the total cost of ownership of electric, diesel, and CNG buses (CSTEP 2018, ADB 2018, BNEF 2018). BNEF study finds that electric buses achieve TCO parity with diesel in 2018 for several of the cases they analyze whereas the ADB study focused on China finds TCO to be 35% higher than diesel. CSTEP is the only study on TCO of electric buses in India and finds that it is 19% higher than diesel (for their pragmatic scenario) even with more than 50% capital subsidy on electric buses.

[8] For example, Proterra, a leading electric bus manufacturer in the United States, claims to offer a 60-km range recharge in 10 minutes (https://www.proterra.com/press-release/proterra-introduces-new-high-power-interoperable-ev-charging-technology/). Similarly, VDL offers 500-kW charging (https://www.electrive.com/2018/09/18/vdl-presents-new-batteries-and-ultra-fast-charging-options/).

We argue that all else equal, the incremental cost of an electric bus is at most the additional cost of the battery, since the cost of the additional components required in an electric bus is typically lower than the cost of the engine and transmission that are not required. Hence battery price is one of the most important variables determining the TCO of electric buses. BNEF, ADB, and CSTEP assume incremental cost of 10-12m AC electric buses to be $98K, $156K, and $280K respectively implying a battery price of $400/kWh[9], $480/kWh[10], and 860/kWh[11] respectively compared to the prevailing prices for batteries for cars of about $200 kWh in 2017 (BNEF 2018) although there are no fundamental technical differences between the two. BNEF study states that higher prices for bus batteries are due to low volumes and should converge with those sold for cars with higher volumes, an assessment confirmed by our conversations with industry experts.

Given India has one of the largest bus markets in the world and can potentially have a large electric bus market, we focus on assessing the TCO of electric buses at high volumes where prices for batteries procured for buses are similar to those for cars. Hence our TCO estimates for electric buses are lower than those found by other studies and closer to what can be achieved with higher volumes.

We assess the new economics of electric buses using two different approaches: bottom-up cost estimation and analysis of bids received by different cities in India, both of which appear consistent and show that city bus fleets are ripe for transformation to an all-electric future even without valuing the environmental benefits. If electric vehicles can fully exploit the reduction in solar electricity cost (e.g., through direct PPAs with solar generators), then the benefits of electrification would be even greater.

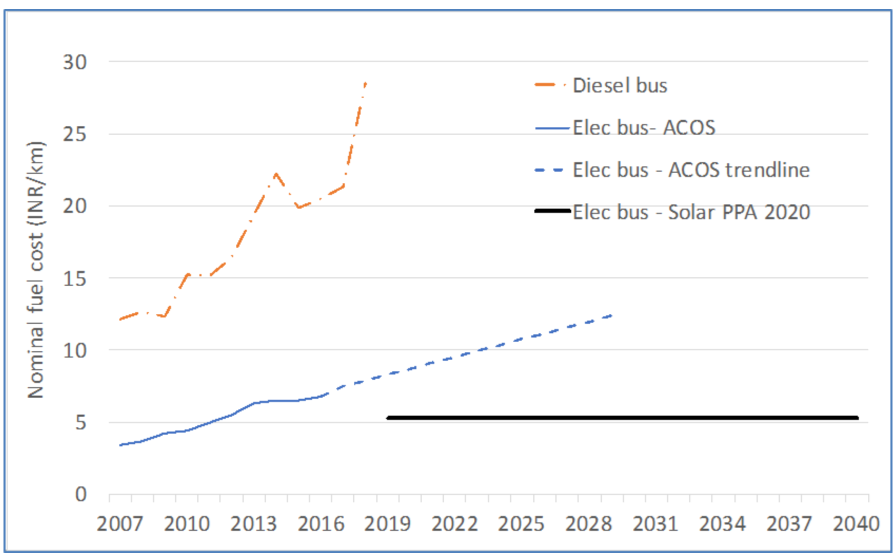


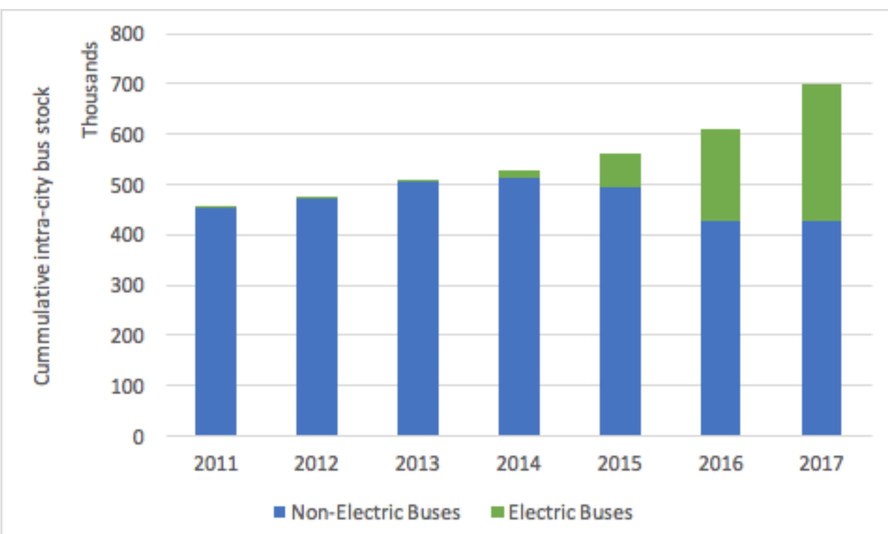
Figure 2: Nominal fuel cost per kilometer for diesel buses (orange and dashed dot) and for electric buses under for two different scenarios for electricity prices – average cost of supply for state-owned utilities in

[9] $98K of incremental cost for an electric bus with 250 kWh battery
[10] $ 156 K of incremental cost for an electric bus with un known battery size, assumed to be 330 kWh
[11] $280K (INR 2 Cr) of incremental cost for an electric bus with a 330 kWh battery;

India (ACOS)[12] (solid blue and dashed trend line) and under 20-year nominally fixed solar power-purchase agreements (PPAs) effective from 2020 (solid black line). Diesel bus fuel cost is based on average annual diesel price and a fuel economy of 2.5 km/liter of diesel. Electric bus fuel cost is based on a fuel economy of 0.8 km/kWh for electricity and solar PPAs at INR 4.2/kWh (which is inclusive of a transmission and distribution cost of INR 1.5/kWh)

Recent trends in electric bus adoption

The electric bus market is dominated by pure battery-electric buses, although plug-in hybrid and hybrid-electric buses hold market share as well. Our focus is on pure battery-electric buses only. Today, China is the largest producer and consumer of pure electric buses. Bloomberg New Energy Finance (BNEF 2018)[13] reports that 17% percent of China's entire bus fleet was electric as of 2017, and Chinese manufacturers account for 99 percent of the 385,000 electric buses operating around the world (Figure 3). For reference, the total fleet size of state road-transport corporations across India is about 160,000 buses. The Chinese city of Shenzhen became the first in the world to replace its entire fleet of diesel buses with electric buses, and several other Chinese cities are set to follow suit. In the United States, New York, Los Angeles, and San Francisco have announced plans to become all electric over the next two decades. The International Association of Public Transport (UITP) documents that, by 2025, 18 European cities expect to have a total of 6,100 electric buses in service, representing 43% of the combined fleets.[14] In 2015, Bogotá, Columbia; Quito, Ecuador; Caracas, Venezuela; Buenos Aires, Argentina; Mexico City; and Brazil's Curitiba, Rio de Janeiro, and Salvado each committed to eliminate diesel buses by 2020 (although it is not clear if these will all be electric).[15] In future, the Asia-Pacific region is predicted to dominate the market for electric buses.



[12] Data on the average cost of supply (ACOS) for state owned utilities in India (covering ~90% of total electricity sales) is obtained from annual reports on the Performance of State Power Utilities produced by the Power Finance Corporation Limited, a Government of India undertaking.
[13] https://www.bloomberg.com/news/articles/2018-04-23/electric-buses-are-hurting-the-oil-industry
[14] http://zeeus.eu/uploads/publications/documents/zeeus-ebus-report-internet.pdf
[15] https://energytransition.org/2017/12/e-mobility-latin-america/

Figure 3: Evolution of intra-city stock of electric and non-electric buses in China from 2011 to 2017. The share of intra-city stock that is electric increased from less than 1% in 2011 to nearly 50% in 2017.

India's Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) national scheme,[16] originally adopted in 2015, and currently in process of being redesigned, represents recognition by Indian policymakers of the need to foster a robust domestic electric vehicle industry. FAME intends to allocate a total of INR 3,500 Crore (USD 470 Million)[17] toward incentives for procurement of electric buses and cabs across India. It also allocates INR 1,000 crore for establishment of 15,000 slow-charging and 30,000 fast-charging stations across India. Electric bus buyers can take advantage of one of two incentive schemes depending on the level of localization, i.e., domestic production's share of overall cost (Table 1).

Table 1: Subsidy for electric buses under FAME

Level	Percentage of localization	Subsidy
Level 1	Min 15%	60% of purchase cost or INR 85 Lakhs, whichever is lower
Level 2	Min 35%	60% of purchase cost or INR 100 Lakhs, whichever is lower

With support from FAME and other state-level policies, several Indian cities are beginning to experiment with electric buses. A total of 390 electric buses are being procured by cities with FAME incentives: 40 buses each for Ahmedabad, Hyderabad, Mumbai, Kolkata, Jaipur, Lucknow, and Indore; 15 buses each for Jammu and Guwahati; and 80 buses for Bangalore. In addition, many cities have announced plans to procure electric buses, including Delhi (planning to procure 1,000 electric buses[18]) and Pune (500 electric buses[19]). The Kerala State Transport Undertaking is evaluating the performance of electric buses, with tentative plans to purchase 300 buses if trials are successful.[20]

Despite these efforts, the diesel bus sector continues to grow. The Indian medium- and heavy-duty bus market grew 7.6% during fiscal year 2016-17 (sales of 47,262 units, vs. 43,909 in FY 2015-16) and this was driven largely by growth in demand from state and city bus agencies.[21] Given this context, a central motivation of our study is to convince public agencies of the clear economic case for public bus agencies at the city and state level to embrace electrification as a central strategy, thus promoting an informed policy ecosystem at the national and state levels.

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16 https://www.moneycontrol.com/news/economy/policy/electric-vehicles-government-raises-incentives-under-fame-ii-to-rs-5500-crore-2878261.html
17 Assuming a conversion rate of 1 USD = 74 Indian Rupees (INR)
18 https://www.business-standard.com/article/current-affairs/plan-for-procurement-of-1-000-electric-buses-in-4-months-delhi-govt-to-sc-118091101066_1.html
19 https://timesofindia.indiatimes.com/city/pune/pmpml-to-add-500-ac-electric-buses-to-its-fleet/articleshow/64035253.cms
20 https://www.thenewsminute.com/article/kerala-starts-trial-run-electric-buses-thiruvananthapuram-83267
21 http://commercialvehicle.in/indian-bus-industry-is-changing/

Unit-cost comparison for electric and diesel buses

This section compares the unit costs of electric and diesel buses using two approaches: estimation of production costs, and comparison of winning bids for supplying diesel versus electric buses and operating with these buses.

Comparison based on bottom-up production cost estimation

Using manufacturer data on the cost of major components and subsystems, we derived bottom-up estimates for the cost of manufacturing of both 9-meter and 12-meter diesel and electric buses, each with and without air-conditioning system. Full details of the actual commercial model of electric and diesel[22] along with a break-down of the cost for the various sub-systems is in the appendix. The basic motivation for the bottom-up cost estimation is to be able to estimate the cost of an electric bus directly based on battery cost and operating (fuel and maintenance) costs. Since in the long-run the difference in costs of electric and diesel buses fundamentally ought to reflect the incremental cost of the battery, the savings in engine cost, and savings in fuel and maintenance costs, a bottom-up estimate can be compared with current prices for buses and ascertain how closely do current market price for electric buses differ from the potential long-run prices under competition and under different future scenarios of battery and fuel prices.

Figure 4 shows the TCO, capital cost, fuel and maintenance cost for four different bus classes of diesel and electric buses for an average operation of 200 km/day. Our calculations of TCO include bus purchase cost, fuel and maintenance cost, one battery replacement at the end of year 7 over the course of a 12-year life[23], charging infrastructure cost, and labor cost for one driver (Table 2). Across all four classes of buses, the bottom-up cost based comparison suggests that while electric buses are costlier (by 80% to 300%) to procure, their lifecycle cost of ownership is 17%–34% lower (at a 10% discount rate), and their payback period is about 4 years, which is well below the 12-year life.

For the 9m and 12m AC bus categories, Figure 4 shows that TCO derived from bottom up cost estimates of vehicle production cost (solid green bars) is below the winning bids for electric bus service on a per km contract basis (green checkered bars) and that the latter is still lower than the bottom-up estimate for TCO of diesel bus. However, for the 9m non-AC bus, our TCO estimates are substantially below the bids for per-km contract and furthermore, these bids even exceed the bottom up estimate for the 9m non-AC diesel bus. However, it is interesting to note that the per-km bid for 9m non-AC electric bus service is actually about 30% higher than the bid for 9m AC electric bus service.

Additionally, Figure 4 also shows how the bottom-up estimate of electric vehicle production cost (solid green bars) compares to winning bids for outright procurement of electric buses (hashed green bars). Here, whereas the bottom-up estimate closely matches the bids for 12m, the bid price is much higher than our estimate for the 9m AC bus. Using this higher value for capital cost almost

[22] Volvo 8400 diesel and a BYD K9 electric—commercially available low-floor, air-conditioned (AC) models.
[23] Even assuming a 5-year battery life only adds 1 INR/km to the total cost of ownership.

doubles the payback from 2.4 to 4.8 years for the 9m AC bus (not depicted in Figure 4). No outright purchase bid data was available for either the 9m or 12m non-AC buses.

A more detailed analysis of the bids is discussed in a separate section below. Ignoring the anomaly in the per-km contract bid for 9m non-AC electric bus, it appears that electric buses are the economic choice even without placing a monetary value on their environmental benefits. More importantly, it suggests that electric buses could be the rational choice without subsidy. Given the higher markup of AC diesel buses relative to non-AC diesel, the difference in upfront cost between electric and diesel buses is smaller when they are both AC buses than when they are non-AC, which is reflected in the longer payback for non-AC electric buses at any given level of utilization (Table 3).

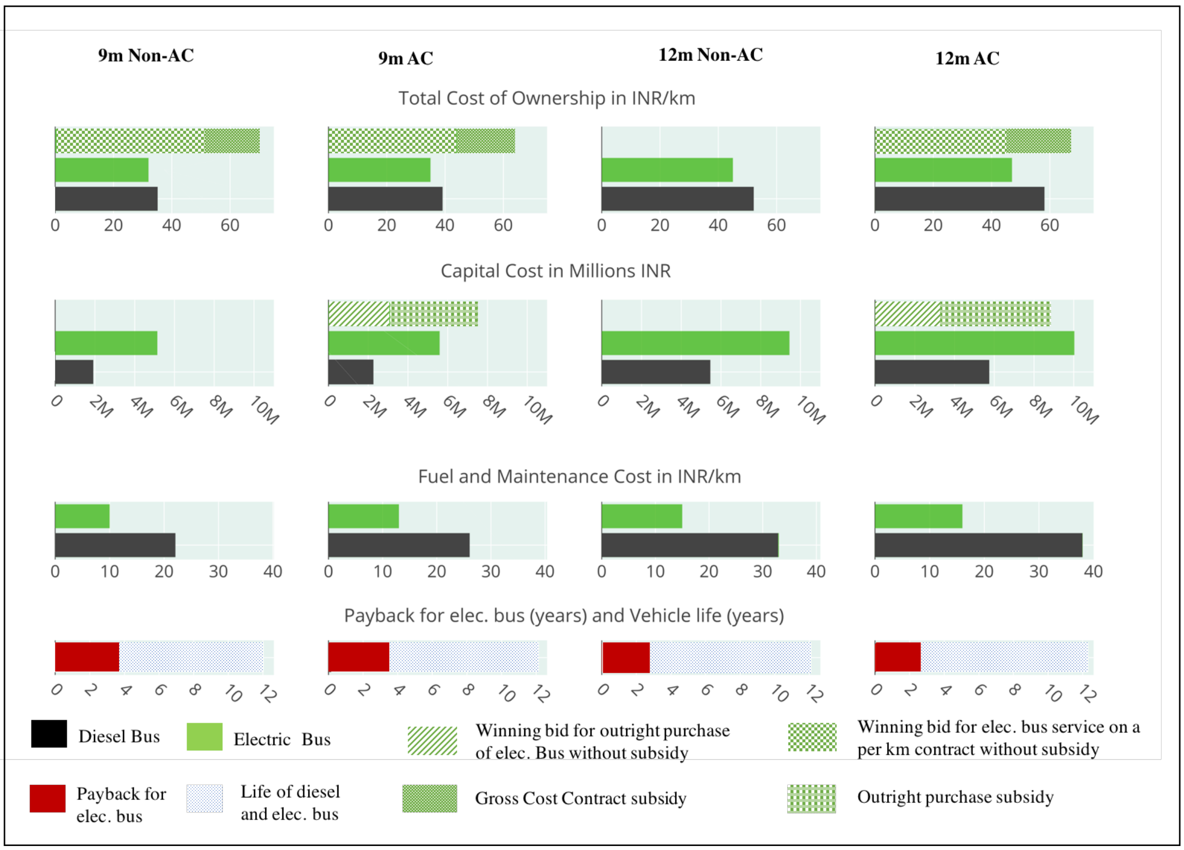

Figure 4: Comparison of TCO, capital cost, fuel and maintenance cost for four different classes – 9 metre (m) Non-air-conditioned (AC), 9m AC, 12m Non-AC, 12m AC -- of buses for an average operation of 200 km/day.

Table 2: Assumptions for 12-m AC electric and diesel buses

	Diesel	EV
Vehicle production cost (INR)	60,00,000[24]	100,031,094[25]
Diesel Engine ($)/Battery cost ($/kWh)	$30,000	$200/kWh[26]
Import tariff of battery system components		30%[27]
Fuel cost	75 Rs/L[28]	6 Rs/kWh[29]
Fuel economy	2.5 km/L[30]	0.8 km/kWh[31]
Maintenance cost	8 Rs/km[32]	4 Rs/km[33]
Charging infrastructure cost	NA	2.5 Rs/km[34]
Battery capacity[35]	NA	320 kWh
Battery range	NA	250 km
Ground clearance	350 mm	360 mm
Discount rate	10%	
Vehicle life	12 years	

[24] Diesel bus production cost is a bottom-up estimate developed by LBNL using part costs from Volvo and the specification of the Volvo 8400 bus model.
[25] Electric bus production cost is a bottom-up estimate by LBNL using BYD K9 bus specifications and market cost data for parts
[26] Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2. Bloomberg new Energy Finance Report March 2018. Accessible at https://data.bloomberglp.com/bnef/sites/14/2018/05/Electric-Buses-in-Cities-Report-BNEF-C40-Citi.pdf
[27] With a 30% tariff on battery imports, effective price of battery is 1.3*$200/ = $260/kWh
[28] For diesel price, we assume a current price of Rs. 75/Liter and a nominal 3% annual rate of increase in price.
[29] For electricity price, we assume a current price of Rs. 6/kWh and a nominal 3% annual rate of increase in price.
[30] Fuel economy for diesel buses is taken from reports of Indian State Transport Undertakings.
[31] Fuel economy for electric buses is taken from manufacturer specifications.
[32] Maintenance cost for diesel buses is taken from reports of Indian State Transport Undertakings. However, according to BMTC data, Volvo maintenance cost is 23 Rs/km. This is significantly more than our conservative estimate of 8 Rs/km.
[33] Maintenance cost for electric buses is assumed to be 50% of diesel bus maintenance cost.
[34] We assume that the bus-charger cost (including grid connection, transformer, converter and other power electronics, and control system) to be similar to the balance of system cost of a solar power plant or a grid-scale storage plant since they include mostly the similar components. This cost is approximately $316/kW. For a 70kW bus charger assumed here, the total capital cost of one charger would be approximately Rs 1.55 million, which approximately matches Tata Motor's quote of Rs 1.6 million for a 70kW charger in Kolkata. Fleet level electrification may require transmission and distribution system upgrades. However, their incremental cost is small and not included here. Refer to the subsequent section and appendix for more discussion on charging infrastructure.
[35] Battery capacity is taken from specifications published for electric bus procurement by Bangalore.

Table 3: Comparison of TCO and payback for electric vs. diesel buses, including AC vs non-AC for two different sizes (9 and 12 m) and three different average daily utilization rates

		Non-AC			AC		
	Bus length (meters)	TCO diesel Rs/km	TCO elec. Rs/km	*Payback elec. (years)*	TCO diesel Rs/km	TCO elec. Rs/km	*Payback elec. (years)*
150 km/day	9	36	35	*5.1*	41	39	*4.8*
	12	56	51	*4.3*	62	54	*3.7*
200 km/day	9	35	32	*3.9*	39	35	*3.6*
	12	52	45	*3.2*	58	47	*2.8*
250 km/day	9	34	30	*3.2*	38	33	*2.9*
	12	50	41	*2.6*	56	43	*2.2*

Figures 6 and 7 show the sensitivity to various factors of TCO and simple payback for the 12-meter AC bus. The sensitivity analysis is carried out by changing one input at a time while holding other inputs fixed at their base values (which are listed in Table 2). The low and high values for each input are arbitrary, but they are meant to represent plausible extremes.

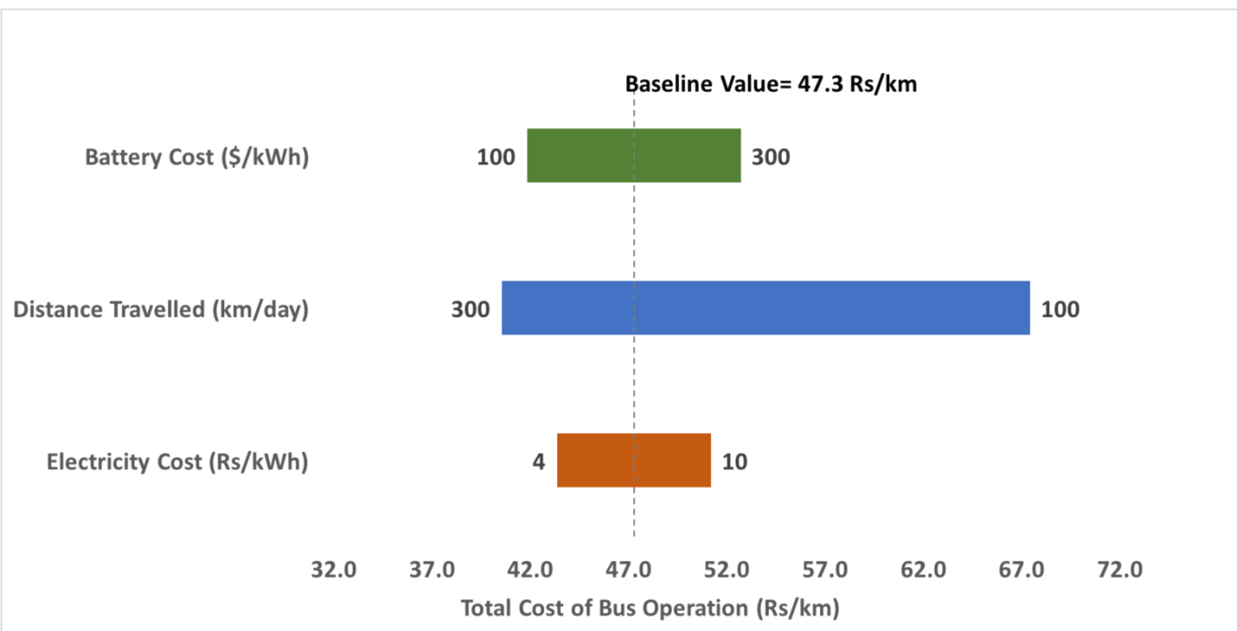

Figure 6: Sensitivity analysis of TCO for a 12-m electric AC bus

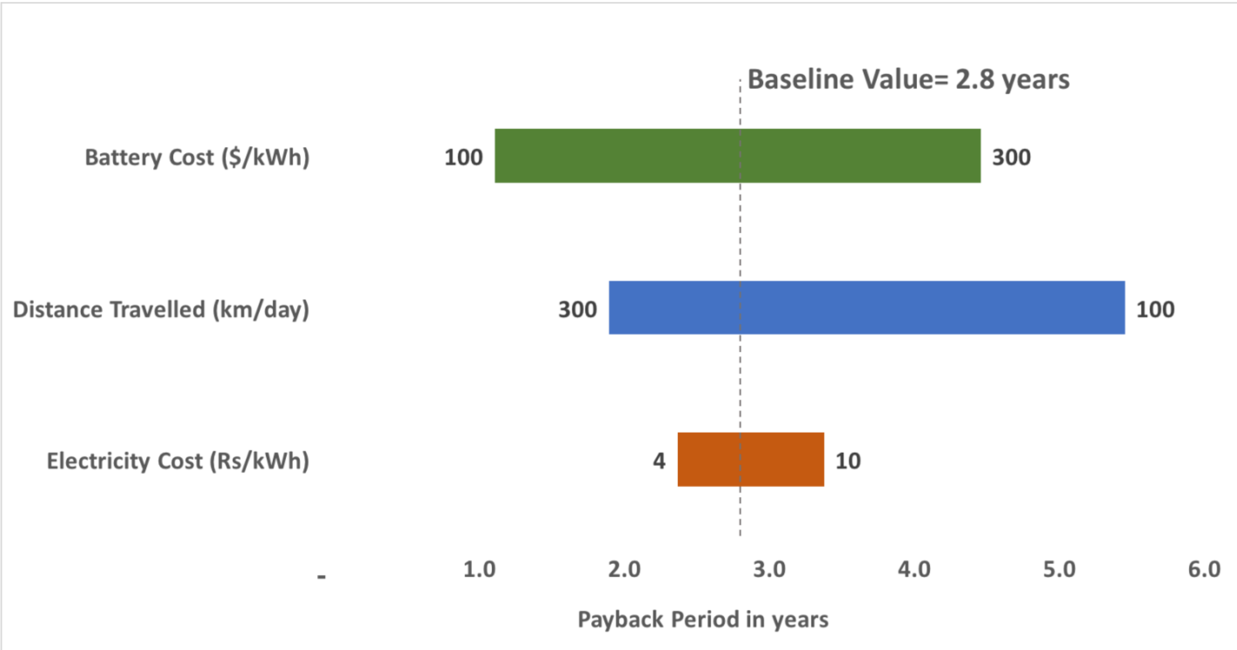

Figure 7: Sensitivity analysis of simple payback for 12-m electric AC bus

Figure 8 shows the potential reduction in TCO under a combination of technology and policy improvements in the future. Specifically, it shows the effect of elimination of the 30% tariff of imports of battery system, a reduction in unit battery cost from $200 to $100 per kWh, and a reducing in electricity cost from INR 6 to INR 4/kWh[36]. These three scenarios combine to yield a reduction of 17% in the TCO. The figure for comparison also shows the effective TCO incurred by the buyer (which is net of the subsidy) and the price paid to producers which is the sum of the TCO to the buyer and the effective subsidy received from the government.

[36] In 2018, solar PV PPA prices in India have dropped to Rs 2.4/kWh. For competitively bid solar projects, the interstate transmission charges and losses have been waived. Many states have also waived or lowered intrastate transmission charges for renewable energy projects. Therefore, it is possible that transport utilities can procure solar power through open access at a delivered price of Rs 3.5/kWh, and we use that as a lower bound for the electricity price. Prior to creating a special tariff for electric vehicle charging, the charging stations were being charged at commercial tariffs in Delhi (Rs 8-9/kWh). Therefore, we use a nominal commercial rate of Rs 10/kWh as a higher bound on electricity price.

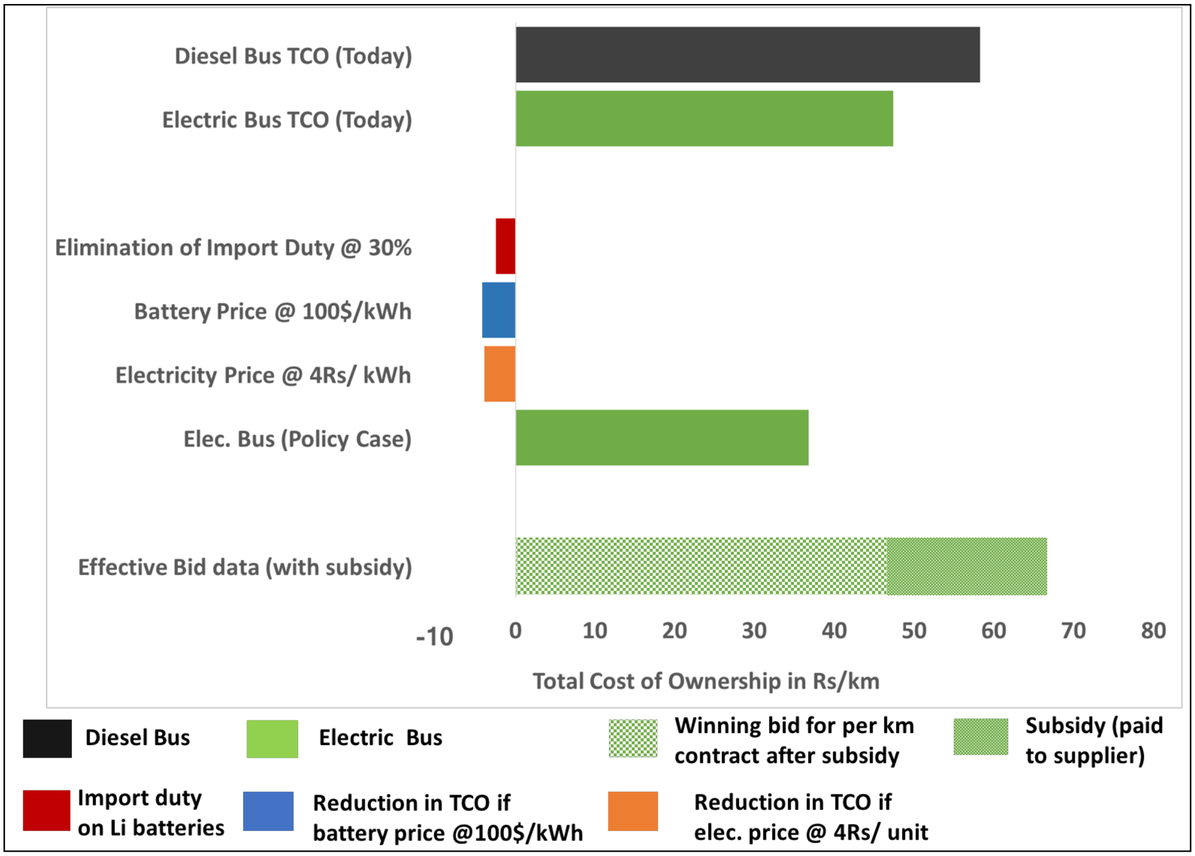

Figure 8: Projection of cumulative reduction in TCO achievable given certain developments

Analysis of bids received by 10 Indian cities

Comparing our bottom-up estimates with actual bids received by several Indian cities[37] highlights the following. First, electric bus services are being adopted under two different models. One involves outright purchase of buses by city transport agencies (Kolkata, Lucknow, Indore, Guwahati, and Jammu), and the other involves contracting on a cost-per-km-operated basis[38] (Jaipur, Mumbai, Bangalore, and Hyderabad). Second, there is variability across cities for each type of contract, for which there are two plausible reasons. One is that the bus specifications vary across cities. For instance, having AC or not, bus length (9 or 12 meter), seating capacity (27 to 31), bus range on full charge (150 to 300 km), battery capacity (125 to 320 kwh), and bus floor height above ground (400 to 900 millimeter) can influence the cost. Table 4 shows specifications associated with the buses procured by different cities. Another reason for variability in bids across cities is the immaturity of the electric bus industry, which creates relatively steep cost reductions over time owing to learning and economies of scale: different cities might receive different prices for identical products depending on the timing of and size of the contracts. However, the bids were all obtained within a relatively narrow time window, which makes this a weaker basis for variation.

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37 https://dhi.nic.in/writereaddata/UploadFile/Benchmark%20price%20for%20Electric%20Buses636662995963975616.pdf

38 The price-per-km contracts include the cost of charging infrastructure, driver, and vehicle maintenance.

In some instances, contracts with identical bus specifications have received widely varying prices from the same vendor, which is difficult to explain.

Table 4: Specifications for electric buses procured (outright purchase) and electric bus services (fixed per-km price contract)

	Units	Lucknow	Kolkata	Mumbai	Mumbai	Mumbai	Bangalore
		Outright Purchase	Outright Purchase	Per km contract	Per km contract	Per km contract	Per km contract
AC/Non-AC		AC	AC	AC	Non-AC	AC	AC
Length of Bus	m	9	12	9	9	9	12
Range	km	150	150	200	200	80	300
Floor Height	mm	900	900	650	650	890	400
Seating Capacity		31	40	31	31	27	40
Battery Capacity	kWh	125	125	162	162	124	320
Price	Lakh Rs	75	88	170	162	167	240
Order Size		40	20	20	20	40	40

Let us focus on the comparison of 12-meter AC buses. Figure 9 compares our bottom-up TCO to with the bids received for cost-per-km contracts (Hyderabad and Bangalore) for a 200-km/day utilization rate. It is quite striking that the effective cost of per-km contracts to bus agencies is similar to the TCO for diesel bus while the effective price to supplier, which is the cost to buyer plus the subsidy is much higher. This lends some support to the idea that suppliers are pricing the contracts to just make it attractive enough to buyer and might be capturing most of the benefits of the subsidy. If such is the case, it could be due to imperfect competition for bus supply.

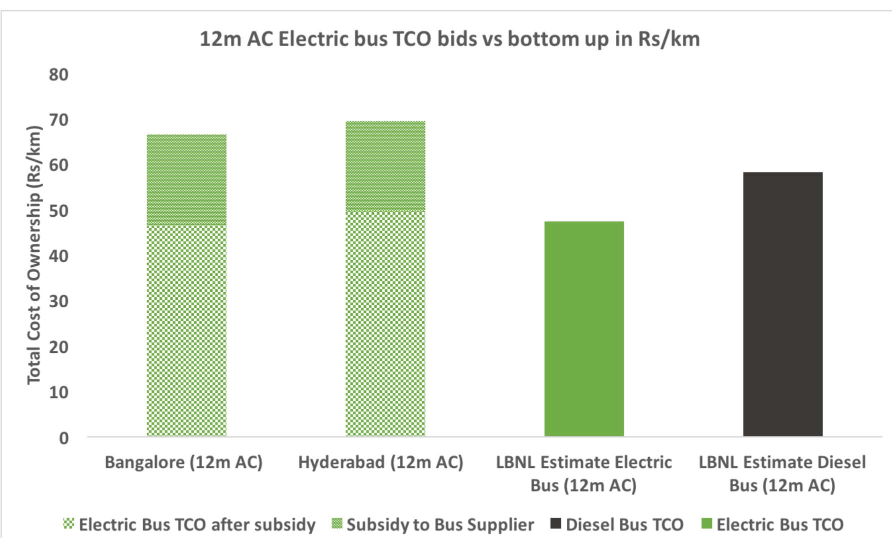

Figure 9: TCO for 12-m AC electric buses in India: 2018 bids harmonized with bottom-up estimate. The estimate for Kolkata is based on the winning bid for outright purchase, while those for Bangalore and Hyderabad are the winning bids for cost-per-km contracts. The LBNL electric bus estimate and the red line showing the diesel bus TCO are based on our bottom-up analysis.

Potential implications on a national scale[39]

If electric buses were deployed on a national scale in India, they would provide substantial economic and environmental benefits, while requiring a well-planned charging infrastructure. Here we simply linearly extrapolate the savings estimated from unit bus cost based comparison to a national scale.

Economic impacts

Electric buses pay back the extra upfront investment in about 3 years (which is quick relative to a 12-year service life), and TCO savings per electric bus range between INR 67 Lakhs and INR 132 Lakhs (Table 5). According to the Central Institute of Road Transport, Pune, state road-transport corporations across India reported an annual combined net loss of Rs 12,500 Crores (INR 125 billion) during 2015-16.[40] Complete electrification of this bus fleet offers potential savings representing 126% to 248% of the annual loss (Table 5), thus more than offsetting the current net loss incurred by bus agencies. Studies suggest that most publicly owned bus systems in large Indian cities generally cover about 70 to 90 percent of operating costs, much higher than in many other countries.[41] Switching to electric vehicles would allow bus agencies to redress this situation without raising fares, which could spur an increase in ridership and further improve the finances.

Table 5: Potential implications of transforming the entire national public stock of 160,000 state road transport corporation and municipal buses across India to an electric fleet

Daily average use (km/day)	**150**	**200**	**250**
Savings in national diesel consumption	3.1%	4.2%	5.2%
Increase in national electricity consumption	0.7%	0.9%	1.2%
Levelized cost in INR per km diesel	63	59	56
Levelized cost in INR per km electric	45	39	35
Simple payback for electric bus (years)	2.1	1.6	1.3
Lifecycle cost savings per bus (INR Lakhs)	67	100	132
National lifecycle cost savings (INR Crores)	1,078	1,600	2,121
Annual savings as a fraction of annual operating loss of state bus corporations	126%	187%	248%

[39] Based on data from Central Institute of Road Transport http://www.cirtindia.com/pdf/Fleet%20Strength%20As%20On%2031st%20March%202016.pdf

[40] http://www.cirtindia.com/pdf/Key%20Statistics2015-16%20.pdf

[41] https://www.nctr.usf.edu/jpt/pdf/JPT%207-4%20Pucher.pdf

Environmental impacts

On a per-passenger, per-kilometer (pass-km) basis, electric buses eliminate about 2 to 20 mg/pass-km of $PM_{2.5}$ emissions and 0.3 to 0.5 g/pass-km of NOx emissions. The lifecycle environmental impacts of replacing diesel buses with electric buses depends on the lifecycle environmental footprint of the electricity generation, which in turn depends on the share of coal in the electricity supply. Public agencies could ensure that electric buses minimize lifecycle emissions through PPAs with renewable energy producers, which can deliver a double dividend in the form of lower emissions and electricity prices that are lower than average grid electricity prices.

Infrastructure requirements

Our calculations suggest that converting the entire fleet of 160,000 buses owned by state road-transport corporations across India would increase national electricity consumption by 0.7% (150 km/day) to 1.2% (250 km/day). Creating appropriate fast-charging infrastructure is the key to rapid electrification of the bus fleet. However, the following two concerns are typically cited as key bottlenecks – cost of the fast-charging infrastructure and upgradation of transmission / distribution system for integrating the charging load.

Using the bottom-up cost estimates for solar PV and grid-scale battery storage plants, we estimate the total capital investment for the charging infrastructure in India would be about $300-350/kW. Refer to the appendix for a detailed break-up. Therefore, for installing a fast charger delivering 320kW (enough power to fully charge the 12m low floor AC electric bus in 1 hour), would entail a capital investment of approximately INR 7 million per charger including the grid connection, transformer, and power electronic components. For a city like Delhi, full fleet electrification of its 6,000 buses would require installation of about 1,000-1500 fast-chargers assuming 4 - 6 buses share one charger. This implies a total capital investment of about Rs. 700 - 1,000 Crore, which is significant. However, the amortized cost of the charging infrastructure would be only about Rs. 2 to 5 per km because the infrastructure has a life of 15-20 years. If the charging facilities are shared between additional buses or with other private users, the infrastructure cost per km would drop even further.[42] If cities opt for a slower charging infrastructure (comprising of 70kW chargers that can charge the 12m low-floor AC bus in 4-5 hours), the investment requirement would be smaller – about INR 1.6 million per charger. However, given the long charging times, multiple buses may not be able to share this charger implying installation of over 4000 slow-chargers (capital investment of about INR 600 Cr) for full fleet electrification in Delhi. Please refer to the appendix for details.

Second important concern is of the transmission and distribution system upgrades. Note that converting the entire fleet of 160,000 buses owned by state road-transport corporations across India would increase national electricity consumption by 0.7% to 1.2%. Therefore, at the national or state power system level, no major upgrades may be necessary. However, this issue needs a more nuanced assessment considering local network constraints – at city or division level. A charging station for a bus-depot with 100 fast-chargers (capable of charging a total of 300-800

[42] Shenzhen (the first city in the world to have an all-electric bus fleet, with more than 16,000 buses) has installed an average of one charger per three buses, with five-hour charging supporting 250 km of driving—a full day of operation for most city buses.[42] The chargers are placed at bus depots, but these charging facilities are also made available to private users to improve financial performance.

buses each day) would have a total peak load of approximately 30MW, which would necessitate building a separate high voltage substation. The typical cost of a transmission / distribution substation is anywhere between Rs. 0.5 to 1 Cr/MW – implying a system upgradation investment of approximately Rs. 15-30 Cr per depot, which translates to an additional cost of Rs. 0.8 to 1.5/km. Please refer to the appendix for details. While economic impact of system upgradation appears small, real-estate availability in the depots and right of way issues for extending the high voltage lines within the city need to be assessed in more detail.

Policy discussion

Our study shows that a 15% lower TCO for electric buses compared to diesel can be achieved even today without any subsidy. Given projected reduction in battery prices, elimination of import duty on batteries, and lower electricity prices, the TCO could be 40% lower even before one factors in the environmental and energy security benefits. Indeed, these conclusions depend on electric bus manufacturers procuring batteries at scale realizing prevailing battery prices similar to those for cars and passing on these benefits to consumers due to competition in the procurement process. India has significant experience in bringing down the prices of key clean energy technologies such as solar PV and LEDs with a robust policy ecosystem and well-designed large scale auctions. For these technologies, not only India has achieved price reductions of more than 80% since 2010 in line with the global trends, but has realized one of the lowest prices for these technologies in the world.[43] Relevant lessons from this experience can potentially be applied to bring down the electric bus prices in India including the use of large volume reverse auctions enabled by aggregation of demand, clearly defined uniform technical specification, clear long term policy target, and provision of supporting infrastructure.

India has one of the largest bus markets in the world with sales of 80,000 buses in 2017 and increasing every year. Note that share of buses used in the public sector is only 10% of these. There are several examples where procurement by public sector agencies has helped reduce costs and establish technologies which has accelerated their wider adoption. Experience from the UJALA program (EESL's bulk procurement LED program started in 2014) is compelling. Since the launch of UJALA, about 1,200 million LED lamps have been installed in India. Out of these, only 300 million have been installed by EESL[44] – but plausibly because of the large volume of their orders, LED prices in the retail market have also fallen significantly leading to the large increase in the overall LED uptake – even outside the UJALA program (Chunekar, Mulay, and Kelkar 2017). Opportunities to realize similar market transformation benefits through public procurement also exist in the bus market.

The FAME policy, originally adopted in 2015 and currently in process of being redesigned, provides strong financial incentives for adoption of electric buses in India by public sector agencies, but our analysis reveals opportunities for improvement. While FAME establishes a strong policy- ecosystem containing incentives for different market segments, and incentives for creating a supporting charging infrastructure, it lacks an overarching long-term goal against which

[43] Solar electricity price in India is about half that of Indonesia and China and similar to the US despite much lower financing costs in the US.
[44] Source: https://economictimes.indiatimes.com/industry/energy/power/eesl-distributes-30-cr-led-bulbs-helped-save-rs-15k-cr-annually/articleshow/64234103.cms

the policy's performance could be measured and improved with time. In the specific context of public bus fleets, an aspirational goal such as ensuring all new public buses (or a large fraction) are electric is warranted. But as the national government lacks jurisdiction over municipal and state bus agencies, national policy could target a select set of cities to demonstrate the feasibility of such a goal. Such a strategy could have greater impact in the long run as opposed to a strategy that allocates subsidies in a diffused manner across every city. A nationally coordinated strategy would also better exploit economies of scale in both bus procurement and installation of charging infrastructure.

Educating decision makers in bus agencies about the new economics of electric buses may address inefficiencies arising from lack of information. To this end, a concerted effort to disseminate information on developments in the electric bus industry would increase the efficacy of the overall FAME scheme. Still, financially constrained bus agencies may be averse to adopting new technologies with high upfront costs. The common approach worldwide, and the one employed by FAME as well, is to subsidize the cost of electric vehicles. A third suggestion is that the high upfront cost barrier could be addressed by simply offering low-cost or interest-free loans to finance the incremental cost of investing in electric buses and charging infrastructure. With this approach, a greater number of buses could be electrified for a given total subsidy budget. For instance, a 12m AC electric bus priced at about Rs. 75 lakhs receives a subsidy of Rs. 45 Lakhs under the Level 2 incentive, even though it costs only Rs. 15 lakhs more than an equivalent AC diesel bus—the per-vehicle subsidy is three times the difference in upfront cost. When allocated in this fashion, the total subsidy budget of Rs. 3,500 crores, would help electrify less than 4% of the entire national stock of public road transportation buses, and only about 1% of the national stock of publicly and privately owned buses combined.[45]

Another important priority is ensuring access to cheap and clean electricity. The additional electric generation required for nationwide adoption of electric buses represents a small fraction of current national generation. Supplying this power through dedicated renewable energy generation would maximize the economic and environmental net benefits. Today's utility-scale solar power plants can generate electricity at less than Rs 2.5/kWh, which is cheaper than the cost of baseload coal power plants. Owners of electric bus fleets should therefore be empowered to exploit the cheapest electricity resources without undue burden from transmission and distribution companies. On a related note, there is also a need for clear policy direction on standards for charging heavy-duty vehicles.

To conclude, electric buses can improve urban air quality and unleash a virtuous cycle of better financial performance for bus agencies, followed by improved quality of service and growth in ridership. While the FAME policy is a step in this direction, refining and reinforcing the framework can accelerate the transition at lower cost. To this end, we recommend applying relevant lessons from the transformation of the solar PV and LED market to electric buses including reforming the subsidy regime, adopting ambitious overarching goals such as ensuring all new public buses are electric, selecting a few major cities for demonstrating the feasibility of this idea, and disseminating information on the economic case for electric buses.

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[45] Assuming an average subsidy of Rs 60 Lakhs per bus and a national public transport fleet of 160,000 buses. We impute the national stock of private buses based on the following. In 2016-17, about 47,000 new buses were sold. If a 10-year life is assumed, this implies a national stock of about 500,000 buses.

References

Brito, Joel, Samara Carbone, Djacinto A. Monteiro dos Santos, Pamela Dominutti, Nilmara de Oliveira Alves, Luciana V. Rizzo, and Paulo Artaxo. “Disentangling Vehicular Emission Impact on Urban Air Pollution Using Ethanol as a Tracer.” *Scientific Reports* 8 (1): 10679. https://doi.org/10.1038/s41598-018-29138-7. (2018)

Bloomberg New Energy Finance (BNEF) "Electric Buses in Cities Driving Towards Cleaner Air and Lower CO2" https://data.bloomberglp.com/bnef/sites/14/2018/05/Electric-Buses-in-Cities-Report-BNEF-C40-Citi.pdf (2018)

Center of Science Technology and Policy (CSTEP) “Implementation Plan for Electrification of Bus Public Transport in Bengaluru” (2018) http://www.cstep.in/uploads/default/files/publications/stuff/SSEF_CSTEP_EV_report_20042018.pdf

Chunekar, Aditya, Sanjana Mulay, and Mrudula Kelkar “Understanding the Impacts of India’s LED Bulb Programme, ‘UJALA.’” Pune (India): Prayas Energy Group. (2017)

Electric Buses in Cities: Driving Towards Cleaner Air and Lower CO2. B*loomberg new Energy Finance Report* March 2018. Accessible at https://data.bloomberglp.com/bnef/sites/14/2018/05/Electric-Buses-in-Cities-Report-BNEF-C40-Citi.pdf

F. Karagulian et al. Contributions to cities' ambient particulate matter (PM): A systematic review of local source contributions at global level. *Atmospheric Environment*, Volume 120, 475-483. (2015)

Filthy air is a global disgrace, *Nature* **561**, 285 (2018)

Asian Development Bank (ADB) and Global Environmental Facility (GEF), “Sustainable Transport Solutions: Low Carbon Buses in the Peoples Republic of China” https://www.adb.org/sites/default/files/publication/468921/sustainable-transport-solutions-peoples-republic-china.pdf (2018)

International Agency for research on cancer (IARC), “Diesel Engine Exhaust Carcinogenic”. World Health Organization. (2012)

IRENA. “Renewable Power Generation Costs in 2017.” International Renewable Energy Agency. (2018)

Joel Brito et al. Disentangling vehicular emission impact on urban air pollution using ethanol as a tracer, *Scientific Reports*, Volume 8, Article number: 10679 (2018)

J. Pucher, N. Korattyswaroopam, and N. Ittyerah, The Crisis of Public Transport in India: Overwhelming Needs, but Limited Resources, *Journal of Public Transportation*, Vol. 7, No. 4, 2004

Mark Bolinger and Joachim Seel: Utility Scale Solar: Empirical Trends in Project Technology, Cost, Performance, and PPA Pricing in the United States – 2018 Edition, *Lawrence Berkeley National Lab Report*

Molina, M. J. & Molina, L. T. Megacities and Atmospheric Pollution. *J. Air Waste Manage. Assoc*. 54, 644–680 (2004)

Noah Kittner, Felix Lill & Daniel M. Kammen. Energy Storage Deployment and Innovation for the Clean Energy Transition. *Nature Energy* Volume 2, Article number: 17125 (2017)

Pucher, John, Nisha Korattyswaroopam, and Neenu Ittyerah. "The Crisis of Public Transport in India: Overwhelming Needs but Limited Resources." *Journal of Public Transportation* 7 (4): 1. (2004)

Appendix

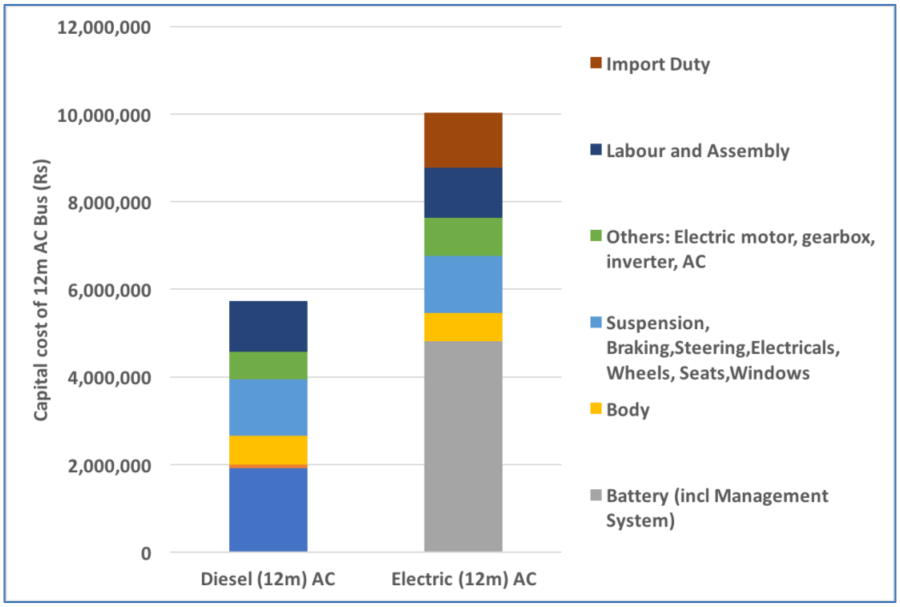

Figure A1: Production costs for diesel and electric 12-m, low-floor, AC buses based on major component and subsystem costs.[46,47]

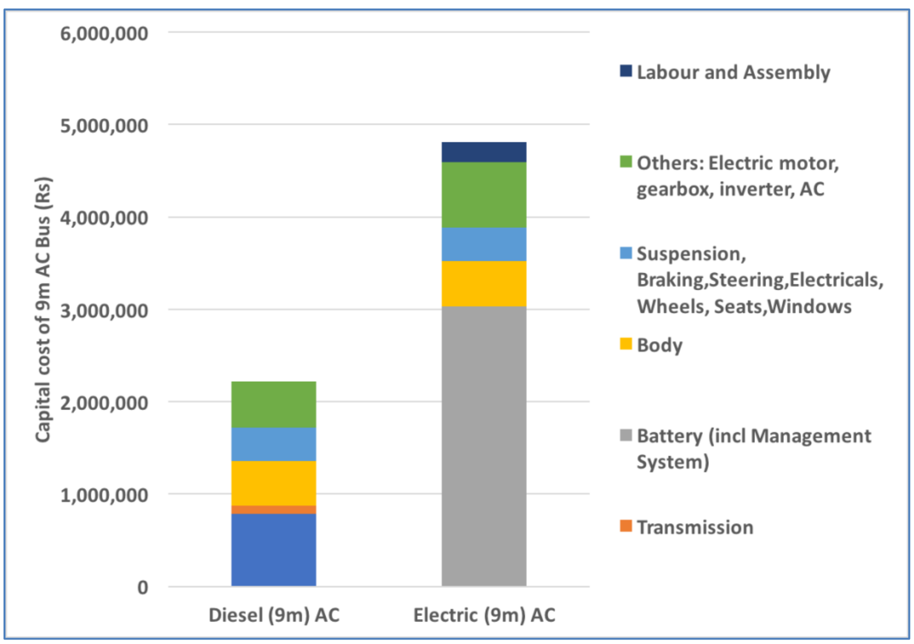

Figure A2: Bottom-up estimate of 9m electric and diesel AC bus.

[46] BYD bus component specifications from http://www.byd.com/usa/bus/k9s-electric-transit-bus/#specs.

[47] Volvo bus cost from https://www.volvobuses.co.uk/content/dam/volvo/volvo-buses/markets/uk/our-offering/services/Parts-catalogue.pdf.

Break-down of Charging Infrastructure Cost

In order to estimate the charging infrastructure cost, we have used the BOS cost estimates for solar power and energy storage projects. These projects include very similar equipment such as a transformer, converter / inverter and other power electronics and the charge control systems for the battery storage plants. The capital costs for India are given in Table A1. Note that these costs generally match with the costs quoted by Indian manufacturers. For example, in Kolkata, Tata Motors have quoted a 70kW charger cost of Rs 1.6 million (equivalent to ~$300-350/kW). The charging infrastructure costs in China are in the similar range ($250-300/kW).

Table A1: Detailed breakdown of the charging infrastructure capital cost in India

Charging System Component	**Capital Cost $/kW**
Grid Connection (including Transformer)	74
Cabling / Wiring	81
Converter	46
Electrical installation	38
Safety and security	66
Inspection	9
Monitoring and Control	3
Total capital cost ($/kW)	**316**

Data Source: IRENA (2018).

In table A2, we estimate the total and per km costs of two types of electric bus chargers - a baseline charger with 70kW capacity (typically installed in India) and a fast charger of 320kW capacity that charges the 12m AC bus battery in 1-hour (equivalent to 1C charging rate).

Table A2: Total Capital Investment and per km Cost of a Regular and a Fast Charger

	Baseline Charger (70kW)	**Fast Charger (320kW)**
Total Charger Load kW	70	320
Total Capital cost of the charger (Rs)	1,547,910	7,076,160
Bus battery size (12m low floor electric bus) kWh	320	320
Time to charge one bus (0 to 100%) hours	4.6	1.0
Number of buses sharing a charger	1	3
Charging Infrastructure life (years)	20	20
Cost of capital (Interest rate) %	10%	10%
Annualized Cost per charger (Rs/yr)	181,817	831,163
Total distance traveled km per day per bus (km/day/bus)	200	200
Charging Infrastructure Cost Rs/km	**2.5**	**3.8**
Total peak load for 100 chargers installed in a bus depot	7	32

Table A3: Transmission and Distribution System Upgradation Cost

Typical capital cost of new transmission / distribution substation Rs Cr/MW	0.5
Individual fast-charger load kW	320
Number of fast-chargers in a depot	100
Peak Charging Load for 100 chargers (serving 300-800 buses) MW	32
Total Investment per depot Rs Cr	32
Life of the substation years	30
Interest Rate	10%
Annualized payment Rs Cr/yr	1.7
Total number of buses served by 100 fast-chargers each day	300
Total system upgradation cost Rs per km	**0.8**