Air-pollution and economics: diesel bus versus electric bus

S. R. Adheesh, M. Shravanth Vasisht and Sheela K. Ramasesha*

Divecha Centre for Climate Change, Indian Institute of Science, Bengaluru 560 012, India

The Bangalore Metropolitan Transport Corporation (BMTC) took an initiative to check the overall benefits of introducing electric buses as a suitable replacement for the diesel buses to tackle the burgeoning pollution in the city of Bengaluru, India. For a trial run of three months, an electric bus was procured from a Chinese company 'Build Your Dreams' (BYD). Data were collected by BMTC on the operation and maintenance of the bus. This new initiative, if rightly guided, could have a direct impact on the lives of those in the city. An economic analysis of the running as well as maintenance of the electric buses within the city limits was performed. For comparison, the same analysis was performed for the data from the existing diesel bus operating on the same route. On the basis of the study, it can be concluded that the introduction of electric buses as a means of public transport in the city would be beneficial both economically as well as environmentally. The electric bus also makes much less noise, thereby helping reduce noise pollution and makes less vibration when compared to the diesel bus. This results in a more comfortable journey for the passengers.

Keywords: Air pollution, electric and diesel buses, economic analysis, public transport, vehicular emissions.

THE Intergovernmental Panel on Climate Change (IPCC) was the first to dispel many uncertainties about climate change. Change in the existing climate system for the worse in the future years is now unequivocal. It is now clear that the present global climate warming is mainly due to man-made emissions of greenhouse gases (GHGs). Over the last century, atmospheric concentrations of carbon dioxide have increased from a pre-industrial value of 278 parts per million to 396 parts per million as of July 2014 (ref. 1). It has been predicted that the GHG emissions could rise by 25–90% by 2030 in comparison to 2000, and the Earth could get warmer by 3°C this century. Even with a small rise in temperature of 1–2.5°C, the IPCC has predicted that it could induce serious effects, including reduced crop yields in tropical areas leading to increased risk of hunger and spread of various climate-sensitive diseases[2].

Vehicular emissions are one of the largest contributors of anthropogenic emissions of GHGs. Rapid urbanization and growth of motor vehicles are causing health issues in people and affecting the environment to a great extent. Most cities in India and across the globe suffer from extremely high levels of urban air pollution. Figure 1 shows the exposure to particulate matter in 1600 cities around the world as given by the World Health Organization[3].

Road traffic is the largest emission source of many health-related air pollutants which adversely affect the health of people inhaling them. Air pollutants such as carbon monoxide (CO), nitrogen oxides (NO_x), benzene, 1,3-butadiene and primary particulate matter PM_{10}, some of which contribute to the formation of ozone and secondary particles largely cause respiratory issues in humans[4]. Road traffic becomes an increasingly important sector polluting the atmosphere with particulate matter. The decrease in particle size is related to high mortality from chronic cardiovascular and respiratory diseases at the higher ambient exposures that are common in cities in Asia and in some developing countries outside Asia[5].

An alternative fuel vehicle (AFV) runs on a fuel other than the conventional petroleum fuels; it also refers to any technology of powering an engine that does not involve only petroleum. AFVs give-off fewer emissions and usually comply with current and anticipated international air emission standards. The AFVs such as electric vehicles (EVs) give zero GHG emission in the form of tailpipe emission. Hybrid-electric vehicles produce less of emission when compared with vehicles powered by conventional non-renewable sources of energy[6].

There has also been a reduction in the recharging time of batteries of EVs thanks to the new technologies such as regenerative braking; from over 8 h to about an hour[7]. Still, they do not usually have widespread adoption as it would call not just for new ways of managing the interface between vehicles and the electric grid due to the extra load that the grid would have to bear to recharge the vehicles every day, but also for new ways of valuing the fuel savings and emission reductions[8,9].

Automakers are now developing alternatives to internal combustion engines (ICE) such as EVs, including hydrogen fuel cell-powered vehicles and ICE-electric hybrids. Adoption dynamics for alternative vehicles is complex due to a number of factors such as the size and importance of the auto industry and also vehicles that have an installed base already present in the market. The successful diffusion of AFVs into the existing markets is both enabled and constrained by a number of powerful positive feedbacks arising from scale and scope economies, research and development, driver experience, and also complementary resources such as fuelling infrastructure[10].

The increasing popularity of SUVs and light trucks, subject to lax government fuel efficiency standards, as well as the rise in vehicle miles travelled (VMT) are usually the determining factors that offset the air quality gains brought by pollution reduction technologies such as catalytic converters, fuel injection and variable valve control[11]. There is an urgent need to reduce the road

*For correspondence. (e-mail: sheela@caos.iisc.ernet.in)

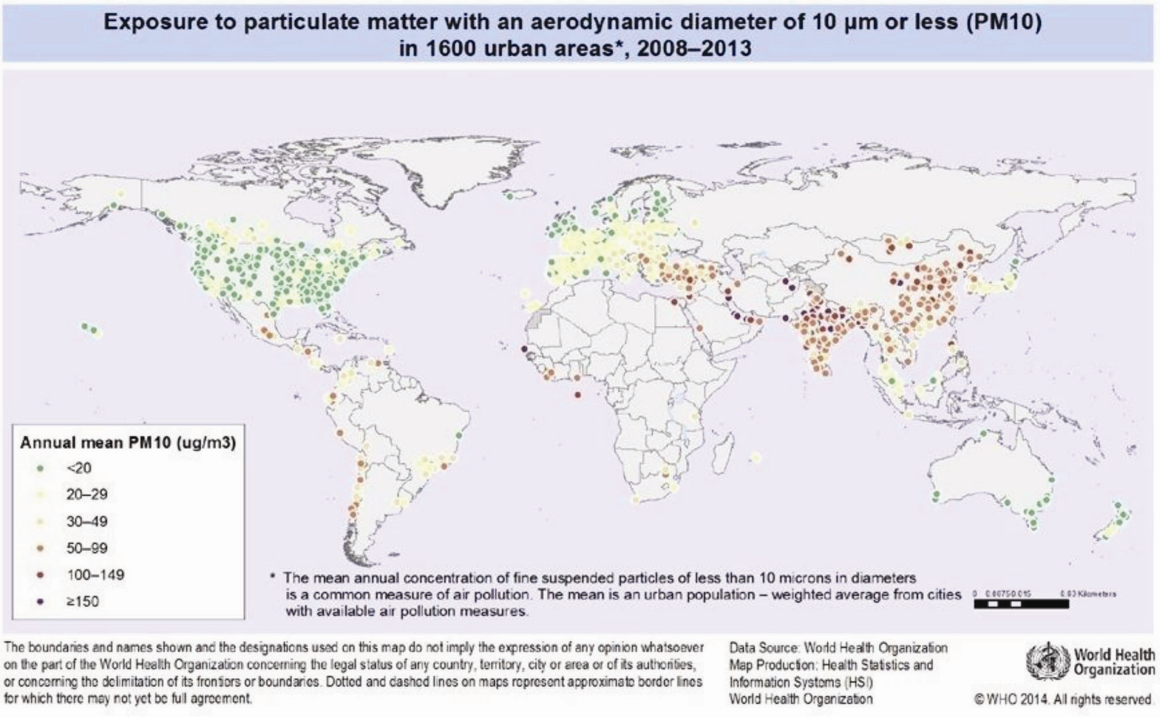

Figure 1. Statistics of the World Health Organization on particulate matter.

transport emission levels within the growing metropolitan cities. The inadequacy in emission reduction improvements has led to the stagnation in the automobile fuel economy over the last 25 years in India[12]. Hence, there is an urgent need to introduce AFVs in the country. People would not find AFVs attractive without ready access to fuel, spares parts, accessories and also repair services. Energy producers, automakers and governments will not invest in AFV technology and infrastructure without the prospect of a large market[13]. To promote the use of AFVs, tax incentives can be given by the government. Also, AFV use on a small scale as a part of the public transport would help generate awareness about the benefits of using it.

Though the problem faced by automobile manufacturers and the government cannot be tackled overnight, if steps are taken definitively in the process of modifying, reforming and bringing in change in the policies adopted, in a few years there can be significant progress in reducing road transport pollution and also moving towards a more environment-friendly future.

Public transport is a key element that would be responsible for great change in the mobility of people in cities with high density of population. According to the International Union for Public Transport (2011), in Europe, urban mobility consumed about 140 million tonnes of oil equivalent per year and emitted about 470 million tonnes equivalent of CO_2 which accounted for about 8% of the total emissions. Public transport in urban areas carried approximately 200 million people every day in Europe, which was equivalent to about 21% of total motorized mobility and was responsible for roughly 10% of transport-related GHGs emissions in cities[14]. The public transport statistics of Europe has been used above, as it has been more effective in the introduction of policies that are environment-friendly when compared to Asia[15,16].

The growing use of electric buses, trams and metropolitan 'light railways' offers an environment-friendly option to significantly reduce local emission of pollutants in the expanding cities of the future. Additionally, electric engines on buses and trams cause less vibration, making journeys more comfortable for passengers; the resulting decreased vibration reduces maintenance time and costs as well.

Buses which have well-defined short routes and travel distances of less than 200 km daily, are well suited to battery only electric technology. Li-ion (lithium-ion) technology is the most commonly used. Pure electric buses can be grouped into those using high-power density Li-ion batteries alone and those with large banks of super-capacitors on the roof to manage fast charge and discharge and increase battery life.

To study the usefulness of EVs for public transport, a specific case was considered. This study can be adapted to a bus route in any city in the world. The present study was carried out in Bengaluru metropolis, India, to test the feasibility of introduction of electric buses as public transport vehicles, to compare the efficiency of usage of a diesel bus compared to an electric bus and most importantly, to highlight the environmental issues involved in using these buses. The economics of the bus transport has been discussed in detail to show that the environment-friendly option is also economically feasible.

For the study, an electric bus (Figure 2) which was provided by a Chinese company 'Build Your Dreams' (BYD) to the Bangalore Metropolitan Transport Corporation (BMTC) for a free trial run of three months was considered. BYD is a manufacturer of automobiles and rechargeable batteries based in Shenzhen, Guangdong Province, China. All production work is performed only in BYD's Chinese locations[17] and the buses have to be imported directly from China. This can be considered as a hurdle as the price of the buses becomes very high compared to the Volvo diesel buses which are manufactured in India. Hence, when a company such as BYD offered to showcase and give a trial run of its product, it was well received by the BMTC and the bus was taken for a trial test run on the roads of one of the busy bus routes of Bengaluru city.

The distance travelled per unit electricity consumed was calculated by dividing the number of kilometres travelled by the electricity consumed. The charging cost or the travel cost for the bus was calculated by multiplying the cost per kWh, which is INR 7.65 as set by the Regional Electricity Board with the total number of units in kWh consumed for charging the bus. The earning per kilometre for the electric bus was calculated by dividing the revenue generated by the number of kilometres travelled by the bus on the particular day.

The Passenger-Kilometres was calculated by multiplying the Total Passengers Carried (TPC) measured in terms of number of passengers and Total Distance Covered (TDC) measured in kilometres.

The travel cost for the diesel bus was calculated by multiplying the cost of 1 litre of high speed diesel (HSD) with the total number of litres consumed by the bus on a particular date. The distance travelled per litre of HSD consumed was calculated by dividing the number of kilometres travelled by the number of litres of HSD consumed. The earning per kilometre for the diesel bus was calculated by dividing the revenue generated by the number of kilometres travelled by the bus on a particular day.

Figure 2. Electric bus introduced by the BMTC.

To examine the suitability of the electric bus in Bengaluru and to evaluate the feasibility of substituting a diesel bus by an electric bus, a diesel bus plying in the same route taken by the electric bus was considered. The data for March–May were considered. Table 1 provides the costs incurred each day and other relevant data of the electric and diesel buses. The days on which the electric bus did not travel were not considered for the calculations.

Table 1 shows that there is not too much variation in the number of passengers travelling in electric and diesel buses. The only small variation is due to the capacity in terms of the number of seats available for use, which is more for the diesel bus. The passenger kilometres travelled is much more for the diesel bus even though the number of passengers travelling is almost the same for the entire day, as the distance travelled by the diesel bus is more because it is operational for longer hours than the electric bus. This can be attributed to the fact that the electric bus has a fixed number of battery hours and that recharging is done only at night.

From Figure 3, it can be seen that the revenue generated by both the electric bus and the diesel bus is almost the same, though the capacity in terms of the number of seats available for use is less in the electric bus. This can be attributed to the enthusiasm of the city dwellers to help promote pollution reduction by greater preference for the electric bus, as the fare charged for the passengers was the same for both buses. Figure 3 clearly shows that the travel cost of the electric bus is much less compared to the diesel bus. This can be attributed to the rising diesel prices and higher efficiency of operation of the electric bus, though the buses were plying on the same route.

From Figure 3, which compares the profits, it can also be inferred that the profits obtained for electric bus are significantly higher than those obtained for the diesel bus. This is because the maintenance and variable costs incurred by the electric bus are much lower when compared to the diesel bus, and also because of much higher efficiency of operation in terms of consumption of energy.

Table 1 also shows the estimation of various parameters, assuming that both the electric and diesel buses cover a distance of 170 km in a day. It is clear that the operational benefits of using an electric bus are much higher compared to a diesel bus. However, the costs involved in the procurement of an electric bus are more than twice compared to that of a diesel bus. This is mainly due to the fact that the electric automobiles are still to get a decent user base in the markets and there are not many manufacturers of electric automobiles and buses.

Return on investment (ROI) is calculated to better understand the economic considerations that have to be taken into account before conclusions are made. The ROI for substituting the diesel bus by an electric bus is calculated by considering the basic economic parameters as shown in Table 1.

Table 1. Comparison of electric and diesel buses

	March		April		May	
	Electric bus	Diesel bus	Electric bus	Diesel bus	Electric bus	Diesel bus
Average number of passengers travelled	225	218	237	238	219	245
Average energy consumed per day (kWh)	269.28	–	275.23	–	264.69	–
Average high-speed diesel (HSD) consumed per day (litre)	–	102	–	107.34	–	106.83
Average cost of HSD per litre (INR)	–	59.40	–	60.00	–	61.20
Average revenue generated per day (INR)	11,502	10,648	12,502	11,865	11,905	12,838
Average passenger kilometre travelled per day (km)	37,451	47,367	39,463	53,550	36,203	55,125
Average charging cost per day (INR)	2060	–	2105	–	1754	–
Average travel cost per day (INR)	–	5887	–	6276	–	6290
Average total cost (INR)	–	5957	–	6346	–	6360
Average profits earned per day (INR)	8992	4716	10,396	5522	10,150	6400
Average earnings per kilometre (INR)	66.00	51.00	69.00	54.60	73.20	58.80
Average loss occurring per day (INR)	–	7.80	–	0	–	0

	Electric bus	Diesel bus
Average profits earned per day, considering 93 days of operation of the bus	10,393	5692
Parameters for travel of 170 km by both the buses		
Average energy consumption per day (kWh)	269.84	–
Average diesel consumption per day (litre)	–	80.19
Average revenue per day (INR)	11,781	9256
Average travel cost per day (INR)	2064	4843
Average profits earned per day (INR)	9717	4344
Estimation of return on investment for diesel and electric buses		
Annual profits earned (INR)	10,393*365 = 3,793,445	5692*365 = 2,077,580
Losses (INR)	–	7.80*365 = 2847
Net annual profit (INR)	3,793,445	2,074,733
Price of the bus (INR)	30,000,000	8,500,000
Return on investment	30,000,000/3,793,445 = 7.90 years	8,500,000/2,074,733 = 4.09 years

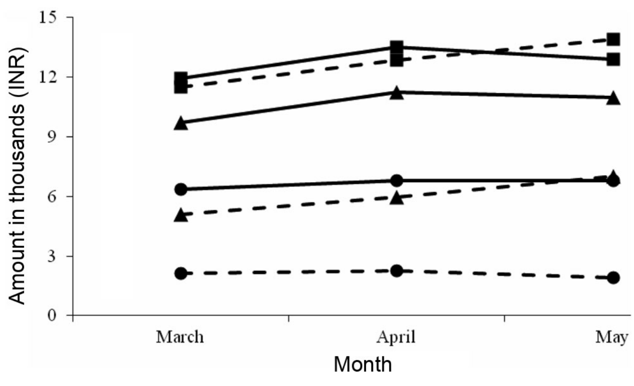

Figure 3. Comparison of revenue (squares), travel costs (circles) and profits (triangles) of electric (solid line) and diesel (broken line) buses.

The losses of the diesel bus per day are taken as INR 7.80, as this is the averaged out value for each day for which the bus was in operation. The losses occur due to breakdown of the bus and additional maintenance costs.

From Table 1, it is clear that the electric bus takes a longer time when compared to the diesel bus for ROI. Also, the carbon credit cost is not taken into account here. The ROI would reduce if the electric buses are manufactured indigenously and hence would be an effective solution for reducing the fossil-fuel consumption and mitigation of climate change.

The substitution of a diesel bus by an electric bus would provide significant impact on the environment. One litre of diesel emits 2.64 kg of CO_2 (refs 18, 19). Taking the distance travelled by both the diesel and electric buses to be 170 km in a day, the average fuels consumption by the diesel bus will be 80.45 litres with an emission of 212 kg of CO_2. Thus, in a year each diesel bus will emit as much as 77 tonnes of CO_2. Considering the total number of diesel buses plying on the roads of the city, the amount of CO_2 emitted from their exhaust turns out to be many kilo tonnes. In addition, the particulate emissions from these vehicles also need to be accounted.

When electric buses are considered, though there are no direct emissions from the tailpipes, indirectly the energy consumed for charging the bus contributes to emissions. The amount of CO_2 generated per kWh of energy utilized is in the range 0.8–1.05 kg (ref. 20). Thermal energy contributes to approximately 60% of the energy being utilized by Karnataka[21]. Hence 60% of CO_2 generated per kWh of energy is considered for the calculation. This implies that for consumption of 274 kWh, for recharging the battery of the electric bus to travel a distance of 170 km, there is an emission of 132–173 kg of

CO_2, which is less by around 50 kg of CO_2 than that is emitted by the diesel bus. So, annually over 25 tonnes of CO_2 emissions can be saved if we replace even a single diesel bus by an electric bus. If solar panels are set up at the battery charging stations of the electric buses, then this emission can also be prevented.

From the analysis, it is found that the operation of an electric bus would prove to be a much better option in the long run when compared to a diesel bus. The electric bus has many advantages like absence of tailpipe exhaust fumes and less noise when compared to other buses. It would also not have idling motor energy losses at bus stops or traffic signals. Less vibration of the bus would result in a more comfortable and smoother journey for the passengers, in addition to longer vehicle life. The electric bus has lower and more predictable operating costs compared to the fluctuating price and availability of imported fossil and other liquid fuels. Fewer moving parts and the 'slide out/slot in' modularity of the electric traction packages make the maintenance of the vehicle simpler and cheaper. The electric bus has regenerative braking that helps it use its motors as generators and recycle energy into the batteries. However, the bus battery would be recharged during off-peak hours (typically overnight).

Since the battery technology has improved to a large extent, in the electric bus the battery can be recharged 6000 times. This implies that the bus can be in operation for 16 years before the battery needs to be changed. Though the initial investment of the bus is very high, the ROI of the bus would be 8 years. The reason for the high rate of ROI for the electric bus when compared to the diesel bus is that the operation and maintenance costs are low and also since people would more actively choose to travel in an electric bus due to their awareness of the environmental benefits of using EVs[22].

There are some factors that act as detractors in introducing electric buses. If steps are taken to improve the manufacturability of such AFVs, they would help act as game changers in the fight against rapid climate change. Another drawback of the electric bus is that the number of kilometres it can travel depends exclusively on the capacity of its batteries. Unlike a diesel bus, an electric bus cannot be refuelled immediately and be back on the roads.

1. Earth System Research Laboratory, Trends in Atmospheric Carbon Dioxide. NOAA – Global monitoring division, Trends in Atmospheric Carbon dioxide, Recent Global CO_2, 2014; http://www.esrl.noaa.gov/gmd/ccgg/trends/global.html
2. Field, C. B. *et al.*, IPCC, 2014: Summary for Policymakers. In *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, United Kingdom, 2014, pp. 1–32.
3. WHO, Public health and environment, ambient air pollution, exposure city level. Global Healthy Observatory Data Repository, World Health Organization, 2014; http://www.who.int/gho/phe/outdoor_air_pollution/phe_012.jpg
4. Chen, H., Namdeo, A. and Bell, M., Classification of road traffic and roadside pollution concentrations for assessment of personal exposure. *Environ. Modell. Software*, 2008, **23**(3), 282–287.
5. Burnett, R. T. *et al.*, An integrated risk function for estimating the global burden of disease attributable to ambient fine particulate matter exposure. *Environ. Health Perspect.*, 2014, **122**(4), 397–403.
6. Managi, S., Analysis of alternative fuel vehicles by disaggregated cost benefit. REITI Discussion Paper Series, 2012, 12-E-035.
7. Muneer, T. *et al.*, Energetic, environmental and economic performance of electric vehicles: experimental evaluation. *Transp. Res. Part D*, 2015, **35**, 40–61.
8. Lemoine, D. M., Valuing plug-in hybrid electric vehicles' battery capacity using a real options framework. *Energy J.*, 2009, **31**, 09–022.
9. Salah, F. *et al.*, Impact of electric vehicles on high-voltage grids: a Swiss case study. Social Science Research Network, 2013.
10. Ziegler, A., Individual characteristics and stated preferences for alternative energy sources and propulsion technologies in vehicles: a discrete choice analysis for Germany. *Transp. Res. Part A*, 2012, **46**(8), 1372–1385.
11. Burgelman, R. A. and Grove, A. S., The drive towards the electric mile: a proposal for a minimum winning game. Graduate School of Business, Stanford University, USA, 2009.
12. United Nations Environment Programme, 2010; http://www.unep.org/transport/gfei/autotool/case_studies/apacific/india/INDIA%20-CASE%20STUDY.pdf
13. Struben, J. and Sterman, J. D., Transition challenges for alternative fuel vehicle and transportation systems. *Environment Plann. B*, 2008, **35**(6), 1070.
14. International Association of Public Transport Union Internationale des Transports Publics position paper, Towards low/zero-carbon urban mobility in Europe. *Focus*, 2011, 1–6; http://www.uitp.org/sites/default/files/cck-focus-papers-files/FPNov2011.pdf
15. Banister, D., The sustainable mobility paradigm. *Transp. Policy*, 2008, **15**(2), 73–80.
16. United Nations Economic and Social Commission for Asia and the Pacific, Regional Expert Group Meeting on Sustainable and Inclusive Transport Development, Ahmedabad, 2014; http://www.unescap.org/sites/default/files/3b.3_AsianEnvironSustainTransport-Initiative_CRC%20Mohanty.pdf
17. Aldeguer, C. C., BYD Company Limited: a case review. Social Science Research Network, 2010; http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2422240
18. Europa – European Commission, Annex 5 – Subsidy level indicators for the case studies, 2012; http://ec.europa.eu/environment/enveco/taxation/pdf/Annex%205%2020Calculations%20from%20-the%20case%20studies.pdf
19. Environment Canada – Fuel Combustion, GHG emissions quantification guidance. Useful conversion factors and units, 2013; http://www.ec.gc.ca/ges-ghg/default.asp?lang=En&n=AC2B7641-1.17.
20. Central Electrical Authority, User Guide. Baseline Carbon Dioxide Emissions from Power Sector, Government of India, 2014; http://planningcommission.gov.in/reports/genrep/rep_arpower1305.pdf
21. Karnataka Power Corporation Limited, 2014; http://karnataka-power.com/generation/
22. Ewing, G. and Sarigollu, E., Assessing consumer preferences for clean-fuel vehicles: a discrete choice experiment. *J. Public Policy Market.*, 2015, **19**, 106–118.

ACKNOWLEDGEMENT. We thank Sri Kumar Pushkar (Director, Information Technology, BMTC) for sharing the bus operation data.

Received 10 August 2015; revised accepted 24 October 2015

doi: 10.18520/cs/v110/i5/858-862