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ORIGINAL PAPER

Study on possible economic and environmental impacts of electric vehicle infrastructure in public road transport in Kolkata

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Abstract Transport sector in India accounts for 20 % of total commercial energy demand of the country, of which a considerable amount is consumed in the form of liquid and gaseous fuel. A major part of these fuels are imported by the Government. Apart from the import expenditure, Government of India has subsidized these fuels to make it available at affordable prices. To check the financial burden and achieve environmental benefits, technical advancement in present system or alternative infrastructure is required. The present study examines the possible impacts on economy and environment by the implementation of battery electric vehicles (BEVs) along with the conventional road transport system in metropolitans with a case study of Kolkata. The major impact has been observed in controlling the vehicular emission with a decrease in CO_2 level by 26.27 t per day, on replacement of only 2 % of the present public transport by suitable BEVs. Maintaining similar service for the passengers the electrical energy required by the alternative vehicles has been estimated to be 41,766 kWh per day. This energy has been proposed to be supplied by remodeled fuel stations equipped with solar photovoltaic systems, if charging strategy is based on renewable sources. In case of fuel economy, the infrastructure has shown the potential in reducing the consumption of diesel and autogas (LPG) by 11,654 and 3,256 liter per day, respectively.

Keywords Electric vehicles · Subsidy · Road transport sector · Solar photovoltaic · Charging stations · Pollution

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Introduction

Road transport is an important sector in the development of a nation. In India, among the total freight and passenger load, 60 and 80 % of the loads, respectively, are shared by road transport (Ramachandra and Shwetmala 2009). It has been a major consumer of liquid fuel mainly in the form of diesel, petrol, and gas. The indigenous production of crude oil being insufficient to meet the demand, the country has to import about 80 % (Times of India, January 31, 2011) of its total consumption. Government of India subsidizes (Rs. 43,580 crores as per the Union Budget and Economics, 2012–2013, Ministry of Finance, Government of India) petroleum products to alleviate the suffering of the common man. To worsen matters, the consumption of liquid fuel in transport sector has been increasing rapidly along with increase in population and industrialization. For the reduction of subsidy burden, Government of India has recently decided to decrease the subsidy from diesel for bulk consumers, thus affecting the public road transport costs, rail fares, and even infrastructure related activity. The continuous increase in the price of fuel, gradually depleting sources of natural reserves and increasing pollution level have added to the concerns of the country. If the use of conventional liquid fuel in the passenger road transport sector can be reduced or substituted by a non-conventional energy source, then considerable amount of foreign exchange can be saved making a positive impact. For the present study, battery-operated electric vehicles have been considered as substitute for conventional vehicles in the passenger road transport sector. The objectives of the present study were to examine: (i) the feasibility of setting up an infrastructure for electric vehicles in Kolkata; (ii) the probable financial savings that this infrastructure can offer, if implemented; and (iii) the probable environmental impact if the infrastructure is established. The study has also been extended for some major metropolitans in India.

Literature review and transport scenario

In India, the total number of registered motor vehicles was 141.8 million by the end of the fiscal year 2010–2011 (Road Transport Year Book 2012). There has been a steady rise in the number of registered motor vehicles at a CAGR (Compound Annual Growth Rate) of 9.9 % for the period 2001–2011. Among the total vehicle population, personalized mode (constituting mainly two-wheelers and cars) accounted for more than 80 % of the motor vehicle population in the country compared to their share of over 60 % in 1951 (Table 1). Looking further, the preponderance of two-wheelers (72 %) can clearly be observed and is followed by 13.6 % of passenger vehicles (including jeeps and taxis). A heterogeneous category which includes three-wheelers [Light Motor Vehicle (LMV)], trailers, tractors, etc., had a share of 9.2 %. But unlike the personalized mode, the share of buses in total registered vehicles has declined from 11.1 % in 1951 to 1.1 % in 2011 (Road Transport Year Book 2012). Also, the share of goods vehicles at 5.0 % has shrunk since 1951. This decline in the number of public transport has reflected the slow growth of buses in the vehicle population (Table 1). Again it has been observed that the contribution of road transport sector in GDP has reached 4.7 % in 2010–2011, surpassing the previous share of 3.9 % as in 2001–2002. Figure 1 shows city-wise distribution of total registered vehicles in India.

The increase in economic activities of the country leads to the increase in number of transport in restricted area of metropolitan cities. For example, the share of road vehicles in Kolkata city was about 34 % of that of the total number of registered motor vehicles in the state of West Bengal (Ramachandra and Shwetmala 2009). A picture of the pollution emission and fuel consumption by the road transport sector in Kolkata can thus be estimated. Transport sector has been contributing 22 % of the total CO_2 emissions worldwide (Schepper et al. 2014). Thus, there is an urgent requirement for technological advancement to address both the issues of conventional fuel consumption and pollution emission. An efficient way for the improvement of fuel consumption by the conventional vehicles is to set proper fuel economy standards that should be maintained by the manufacturers before the market penetration of the vehicles (Mohammadnejad et al. 2013). The study has shown that by improving the fuel economy standards for the vehicles in Iran the expected saving of fuel for a span of 5 years was about 3.81 billion liters. Again the estimated emission reduction was around 7.35 million ton, 2.54, and 1.2 tons for CO_2, CO, and NO_x, respectively. But in case of improving the emission standards, an important role is played by the increase in the number of vehicles. In case of emission standards, the vehicles are manufactured in a way such that they are able to comply with the required

Table 1 Composition of vehicle population in India

Year end March	Two-wheeler	Cars, jeeps taxis, etc.	Buses	Goods vehicle	Other vehicles	Total
	% of total vehicle population					Million
1951	8.8	52.0	11.1	26.8	1.3	0.31
1961	13.2	46.6	8.6	25.3	6.3	0.66
1971	30.9	36.6	5.0	18.4	9.1	1.86
1981	48.6	21.5	3.0	10.3	16.6	5.39
1991	66.4	13.8	1.5	6.3	11.9	21.37
2001	70.1	12.8	1.2	5.4	10.5	54.99
2002	70.6	12.9	1.1	5.0	10.4	58.92
2003	70.9	12.8	1.1	5.2	10.0	67.01
2004	71.4	13.0	1.1	5.2	9.4	72.72
2005	72.1	12.7	1.1	4.9	9.1	81.5
2006	72.2	12.9	1.1	4.9	8.8	89.61
2007	71.5	13.1	1.4	5.3	8.7	96.69
2008	71.5	13.2	1.4	5.3	8.6	105.33
2009	71.7	13.3	1.3	5.3	8.4	115.0
2010	71.7	13.5	1.2	5.0	8.6	127.7
2011	71.8	13.6	1.1	5.0	8.5	141.8

Source Road Transport Yearbook 2012

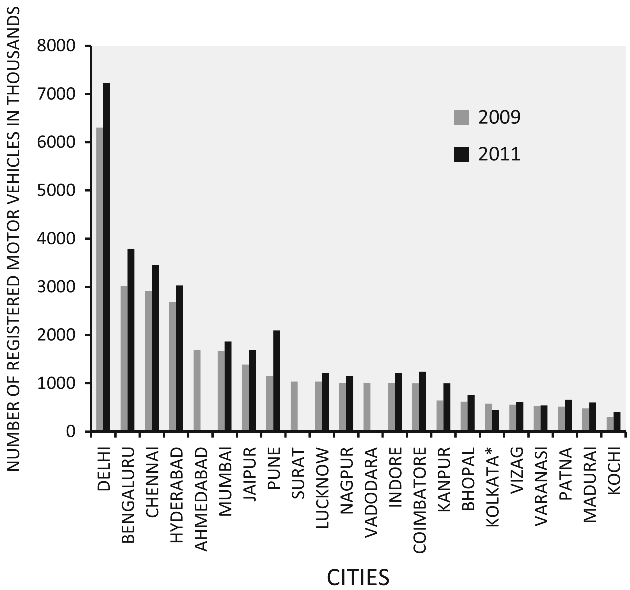

Fig. 1 Registered motor vehicles in metropolitan cities in thousands

standards; however, the importance of the standards is lost within a few years due to the gradual technological advancements and increase in vehicle number (Mahlia et al. 2013). A new standard has to be set after a certain span. Thus, the use of a cleaner energy may help in reducing environmental pollution and also address the issue of checking the use of fossil fuels. Transport sector, in all developing countries, is important, demanding the concentration to be upon energy efficient technologies, such as battery electric vehicles (BEV), alternative fuels, energy efficient designs, etc. (Najjar 2008). The incorporation of BEV in the transport system powered by the conventional grid has been suggested as an alternative to address the pollution reduction issue and is also economically acceptable (Schepper et al. 2014). The study has shown that for GHG mitigation program the introduction of BEVs powered by existing grid has the lowest economic costs whereas the life cycle GHG emission can be reduced by 37 % if a system of solar energy powered BEV model is adopted.

In this study, the passenger road transport system in Kolkata has been taken into consideration i.e., public transport consisting buses, taxis, and auto-rickshaws (LMV 3 wheelers). By the end of March, 2009, the number of registered buses and taxis plying on the streets of Kolkata has been 6,938 and 32,826 (Road Transport Year Book 2011), respectively. But in the two years term, it was observed that, by March end, 2011, the numbers have decreased to 4,249 and 30,840, respectively. The primary reason behind the decrease in the number of buses and taxis has been the cancelation of vehicles having registrations prior to 01.01.1993 (Road Transport Year Book 2012) as per the law enforced by the Government. But the number of buses is likely to increase, as the state Government and private bus owners gets through a stalemate over the issue of increase in bus fare. This demand of hike in the fare structure is due to the increase in the price of diesel and also the cost of vehicle and its spare parts. The number of registered auto-rickshaws in the city was 26,959 by the month of May, 2012 (Times of India, May 10, 2012).

Methodology and calculations

The energy consumption pattern has been studied for different types of public transport vehicles in Kolkata. The data for this purpose have been collected by conducting primary surveys. About 100 individuals including drivers, conductors, helpers, and vehicle owners have been surveyed through personal interviews to gather the required information. Ten random fuel stations have been selected to collect data regarding fuel stations. The owners, managers, and workers of the fuel stations have been interviewed with pre-formatted questionnaires.

Pertaining to the present condition of passenger transport in Kolkata, the rising fuel cost and environmental concern, a nominal share of the conventional public road transportation modes has been considered for replacement by battery-operated counterparts. For the same purpose, the primary objective has been to ensure the similar service by

Table 2 Average distance covered and fuel consumption of vehicles run on conventional fuel in Kolkata

Vehicle type	Average distance between destinations (km)	Average number of trips per day	Average distance covered per day per vehicle (km)	Fuel type	Average fuel consumption per day per vehicle (l)	Energy cost (Rs. /day)
Bus	20	4	160	Diesel	50	3,005
Taxi	n/a	n/a	150	Diesel	12	721.2
Auto-rickshaw	5.03	10	100	LPG	6.04	318

Source (Dutta 2012)

Table 3 Energy consumed and energy cost for electric vehicles in Kolkata

Vehicle type	Battery rating (Ah)	Average distance covered per day per vehicle (km)	Average energy consumption per day per vehicle (kWh)	Cost of electricity by solar PV tech at Rs. 12.77 per kWh (Rs./day)
Bus	600	160	192	2,451.84
Taxi	320	150	36	459.72
Auto-rickshaw	150	100	6	76.62

BEV as offered by the conventional transportation modes, at reasonable expenditure. Thus, the battery ratings for the electric vehicles have to be optimized. The data on distance traveled and energy consumed for the present conventional vehicles have been studied. The average distance covered and fuel consumption for buses, taxis, and auto-rickshaws on daily basis have been shown in Table 2.

A variety of electric vehicles has been available in the market. The range of an electric vehicle has to be determined firstly by the battery stack installed and the load applied. In most cases, a lithium-ion battery stack has been used as the power supply for vehicle propulsion. Now-a-days, lithium-ion phosphate or lithium-titanate battery stacks have gained popularity for better performance of the electric vehicle and lower running cost of the vehicles (http://www.byd.com). These batteries have been acceptable mostly for their use in electric vehicle application as these can be reused very efficiently by laser removal of SEI (solid electrolyte interface). These batteries have shown the property to regain their capacity almost at their initial conditions and have found their use even for other secondary performances. Thus, Li-ion batteries have been found to be very efficient if proper end of life strategy is adopted (Ramoni and Zhang 2013).

The calculation procedures for evaluating the energy consumption pattern for both conventional and alternative public transport systems and infrastructure required for the alternative system have been shown.

Calculation of cost of energy consumed by vehicles using conventional fuel:

(a) Average distance covered by a vehicle in a half trip (between starting point and destination) = A km
(b) Average number of trips per day = B
(c) Average distance covered by a vehicle per day = $2 * A * B = C$ km
(d) Average fuel consumption per day per vehicle = D liter
(e) Cost of fuel = Rs. E
(f) Cost of energy consumed = $D * E$ = Rs. F.

Calculation of cost of energy consumed by BEV:

(a) Energy consumed by one battery-operated electric vehicle per day = G kWh
(b) Average cost of charging battery using renewable energy sources = Rs. H
(c) Cost of energy consumed = $G * H$ = Rs. J.

Calculation of energy requirement for charging K % of vehicle fleet:

(a) Total number of vehicles in a particular fleet = L
(b) K % of vehicle fleet = $\left(\frac{K}{100}\right) * L = M$
(c) Energy requirement for charging of fleet = $G * M = N$. kWh

Calculation of number of remodeled fuel stations:

(a) Average area of a fuel station = U m^2
(b) Polycrystalline solar module of rating 265 Wp (http://www.photovoltaik-web.de/media/media/mod_solarmoduledb/Datenblaetter/Vikram-Solar_Eldora-ELV-265_ELV-280.pdf) has been considered. The efficiency of such a module is about 13.8 %.The standard size of the module is 1,955*982*36 mm^3.
(c) At Kolkata, the value of latitude angle is 22.5697°N. According to NASA Surface Meteorology and Solar Energy, the average annual radiation on a surface facing south with a 22° tilt is 4.93 kWh/m^2.
(d) The shadow area calculated for each module for the given tilt angle is 2.082 m^2.
(e) Let V % of the area of a fuel station is used for electricity generation through solar photovoltaic system. Available area per fuel station = $\frac{V*U}{100} = I$ m^2.
(f) Hence, total number of modules that can be installed = $\left(\frac{I}{2.082}\right) = X$.
(g) Installation capacity for a fuel station = $\frac{X*265}{1000}$ kWp.
(h) Area of modules exposed to solar radiation = $(X * 1.955 * 0.982) = Y$ m^2.
(i) Average units of electricity generated from a fuel station = $\frac{Y*13.8*4.93}{100} = Z$ kWh/day
(j) Therefore, the number of remodeled fuel stations required = $\frac{\sum N}{Z}$.

Calculation of economic impact:

(a) Amount of conventional fuel saved if K % of vehicle fleet is replaced by battery-operated electric vehicles = $M * D = P$ l

(b) Reduction in expenditure for buying fuel $= P * E =$ Rs. Q

(c) Cost of energy consumed by K % of vehicle fleet using conventional fuel $= \sum(F * M) =$ Rs. R

(d) Cost of energy consumed by K % of battery-operated electric vehicle fleet $= \sum(G * M) =$ Rs. S

(e) Financial savings if K % of vehicle fleet is replaced with battery-operated electric vehicles $= R - S =$ Rs. T

Feasibility of electric vehicle infrastructure

The electric vehicles that have been selected to replace the conventional mode of transportation have been expected to meet the criteria in regard to the service to be delivered. The best suited electric vehicle available in the market has been compared with that of the conventional ones.

(i) For buses with a seating capacity of 31 passengers, generally a 600 Ah battery has been used (http://www.byd.com). These buses has the capability to cover a distance of about 249 km (155 miles) on a single charge in urban conditions, whereas the daily distance traveled by a bus in Kolkata has been about 160 km (Table 2). These buses can attain a maximum speed of 100 kmh^{-1}.
The charging time for the battery has been 3 h but can be reduced if fast charging is implemented. The daily energy consumption of a bus traveling a distance of 160 km has been around 192 kWh. The average cost of charging the battery using solar photovoltaic technology has been found to be about Rs. 12.77 per kWh (Patra 2012), and Rs. 2,451.84 for energy consumption per day of an electric bus. A bus running on diesel has been consuming about 50 l per day (Table 2), at a cost of Rs. 3,005. Thus, replacing a bus using conventional fuel with an electric bus has been found to be quite feasible economically.

(ii) In case of an electric taxi, generally a 40–120 kWh (http://www.e-moss.com/products/electric-taxi) battery pack has been used depending on the range the taxi travels (100–300 km). These taxis can attain a top speed of 85–120 kmh^{-1} depending on battery size. However, a 320 Ah battery has been found sufficient to supply the energy demand for the streets of Kolkata. Approximate energy consumed per day per electric taxi for traveling a distance of 150 km (Table 2) has been about 36 kWh. Considering Rs. 12.77 per kWh as the charging cost using solar energy, energy consumption cost has been Rs. 450.72 per day per vehicle. A taxi running on diesel has been consuming about 12 l of diesel per day at a cost of Rs. 721.20. Therefore, the idea of replacing a taxi using conventional fuel with an electric taxi has been found feasible.

(iii) The average distance traveled per day by an auto-rickshaw on the streets of Kolkata has been about 100 km (Table 2). For this purpose, a 150 Ah battery has been found sufficient, and the approximate energy consumed per day has been 6 kWh (http://xgddc.en.alibaba.com/product/387013173210462555/electric_rickshaw.html?tracelog=cgsotherproduct1). The cost of energy consumed has been Rs. 76.62 per day per vehicle using solar energy for charging @ Rs. 12.77 per kWh. An auto-rickshaw using LPG consumes about 6 l of autogas per day at a cost of about Rs. 318. Therefore, replacing an auto-rickshaw using conventional fuel with an electric auto-rickshaw has eminent feasibility.
The details of energy consumed and cost of energy for battery-operated electric vehicles using renewable energy source for charging have been shown in Table 3.

Charging strategies

The cost comparison for charging the batteries of electric vehicles by various electricity sources consisting of solar photovoltaic technology, solar pv and biomass gasifier hybrid technology, and conventional grid supply, has been tabulated in Table 4.

However, for smooth running of battery-operated electric vehicles, the required infrastructure of charging stations has to be established. Making the system more profitable and feasible, from both economic and technical aspect, battery-swapping technology can be implemented, thus eliminating the time consumed by the buses for charging. The daily electricity requirement for charging the electric vehicles (2 % replaced vehicles) is 41,766 kWh (Table 5).

Electricity for charging the batteries has to be supplied by the charging stations. This process can be implemented in various ways, either by establishing new charging stations or remodeling the existing fuel stations to incorporate the charging infrastructure.

Table 4 Cost comparison to run electric vehicles charged from different sources of electricity

Vehicle type	Energy consumption per vehicle per day (kWh)	Cost of electricity per vehicle per day by conventional grid @ Rs 7.95/kWh# (Rs.)	Cost of electricity per vehicle per day by solar PV tech @ Rs. 12.77/kWh (Rs.)	Cost of electricity per vehicle per day by solar bmg* hybrid @ Rs 10/kWh (Rs)
Bus	192	1,526.40	2,451.84	1,920
Taxi	36	286.20	459.72	360
Auto-rickshaw	6	47.70	76.62	60

* Biomass gasifier

\# CESC Ltd., Kolkata

Table 5 Comparison of energy requirement for charging

Vehicle type	Total kWh required for charging the electric vehicles per day		
	2 % of the fleet	4 % of the fleet	6 % of the fleet
Bus	16,320	32,640	48,960
Taxi	22,212	44,424	66,636
Auto-rickshaw	3,234	6,468	9,702
Total	41,766	83,532	1,25,298

Charging stations

One of the major factors for the electric vehicle deployment is the availability of battery-charging infrastructure. As discussed, the present fuel stations have been taken as potential destinations for installation of charging infrastructure with both conventional and non-conventional sources. The data collected from different fuel stations provide the average area required by a fuel station, which is about 1,337.8 m^2. If 70 % of this area is considered for installing solar panels, then the average electricity generation for each fuel station is about 585 kWh per day. Therefore, to supply the required demand for 2 % replaced vehicles, at least 71 such remodeled fuel stations or charging stations or a combination of both (with the same area as that of fuel station) will be required. In case of poor insolation due to weather conditions, BMG (Biomass gasifier) systems (Patra 2012) can be used as a backup to keep the system active.

Economic impact

To calculate the financial savings that the infrastructure can offer, it has been assumed that 2 % of the buses, taxis, and auto-rickshaws using conventional fuel (diesel) are replaced by battery-operated electric vehicles. Each case has been individually discussed below.

(i) *Bus* Kolkata has 4,249 buses, of which 2 %, i.e., 85 have been considered for replacement. Buses have an average consumption rate of 50 l of diesel a day per vehicle thus the quantity of diesel saved if one bus is replaced with an electric vehicle is 50 l. Therefore, the amount of diesel saved in a day for 2 % replacement of buses is 4,250 l. Hence, there is a saving of Rs. 2,55,425 on buying diesel per day.

(ii) *Taxi* Kolkata has 30,840 taxis, of which 2 %, i.e., 617 taxis are replaced. A taxi consumes 12 l of diesel a day and the amount of diesel saved per day for 2 % replacement of taxis is 7,404 l. Hence, the saving on buying diesel is Rs. 4,44,980.40 per day.

(iii) *Auto-rickshaws* Kolkata has 26,959 auto-rickshaws, of which 2 %, i.e., 539 are replaced. LPG consumption of an auto-rickshaw a day is about 6 l. Therefore, the amount of LPG saved per day for 2 % replacement of auto-rickshaws is 3,256 l. Hence, the saving on LPG is Rs. 1,71,428.40 per day.

In other words, the consumption of diesel can be reduced by 42, 53,710 l and LPG by 11, 88,440 l a year by replacing 2 % of conventional vehicles with battery-operated electric vehicles in Kolkata. If the infrastructure of electric vehicles can be further established in other metropolitans and states, there will be a decline in the consumption of diesel and LPG, leading to the reduction in the crude oil import. This in turn can contribute to reserve the foreign exchanges, having a positive impact on Indian economy. This reduction in the import of crude oil may also lead to the reduction in subsidy that the government bears on certain petroleum products. The benefits offered by this infrastructure can be increased even more by replacing a greater number of conventional vehicles by the battery-operated electric vehicles.

The combined running cost of electric vehicles (buses, taxis, and auto-rickshaws) using solar photovoltaic for charging comes out to Rs. 5,33,351 per day, whereas with conventional fuel it is Rs. 8,71,833 per day. Therefore, replacement of 2 % of conventional vehicle fleet may lead to about 38 % economic benefits. The benefits will increase if the percentage of replacement of vehicles is increased. The application of hybrid power generation systems for the purpose of battery charging, such as solar photovoltaic and biomass gasifier hybrid technology (Table 4) may decrease the running cost of the electric vehicles in comparison to solar photovoltaic system.

Environmental impact

Environmental pollution has been one of the major concerns in recent times. Transport sector has played the role as one of the major contributors of air pollutants. The major air pollutants released from an automobile are CO_2, SO_2, NO_2, CO, CH_4, HC (hydrocarbon), and PM (particulate matter). Table 6 shows the pollutants emitted in major cities in India (http://www.cpcb.nic.in/divisionsofheadoffice/upcd/Profiles.pdf).

The amount of pollutants emitted by buses and taxis in India in a year has been shown in Table 7 (Central Pollution Control Board 2010). In case of Kolkata, the road transport sector has an emission level of 129.54 t of CO, 65.59 t of NO_X, 51.02 t of HC, and 10.13 t of PM a day (http://www.cpcb.nic.in/divisionsofheadoffice/upcd/Profiles.pdf).

These pollutants have been formed mainly due to the combustion of the fuel used for vehicle propulsion (in this case, diesel). The combustion of 1 l of diesel emits 2.71 kg of CO_2, 8.9 g of SO_2, and 2.9 g of NO_2 (Ghosh et al. 2004).

The emission factors for various pollutants such as CO_2, SO_2, NO_x, CO, CH_4, HC, and PM, for buses and taxis (in g km^{-1}) have been 515.2 and 208.3, 1.42 and 10.3, 12 and 0.5, 3.6 and 0.9, 0.09 and 0.01, 0.87 and 0.13, 0.56 and 0.07, respectively (Ramachandra and Shwetmala 2009). By replacing 2 % diesel-using vehicles by battery-operated electric vehicles in Kolkata, diesel consumption can be reduced by 11,654 l per day. Therefore, the quantity of CO_2 emission is reduced per day by 26.27 t, SO_2 by 0.972 t, and NO_x by 0.209 t (Table 8).

The emission of pollutants from the transport sector can be reduced further by replacing more vehicles using conventional fuel with battery-operated electric vehicles. A comparison of reduction of pollutants emitted, when greater number of vehicles is replaced, has been shown in Table 9.

Majority of the pollutants emitted by the transport sector (automobiles) contain carbon. This has been mainly due to

Table 6 Pollutants emitted in major cities

City	Pollutants emitted (t per day)			
	CO	NO_X	HC	PM
Delhi	425.83	119.67	200.87	12.26
Mumbai	172.68	55.06	72.89	9.02
Kolkata	129.54	65.59	51.02	10.13
Chennai	133.77	30.07	66.63	5.39
Bangalore	199.90	44.17	103.32	8.14
Hyderabad	138.74	51.44	60.40	7.31

Source Urban Pollution Control Division

Table 7 Pollutants emitted by buses and taxis in India

Vehicle type	Pollutants emitted per year (Gg)						
	CO_2	SO_2	NO_X	CO	CH_4	HC	PM
Bus	28,748.16	79.24	679.73	207.26	5.02	51.72	31.36
Taxi	2,376.08	117	5.68	10.23	0.11	1.48	0.80

Source Central Pollution Control Board, March 2010

Table 8 Reduction in emission of pollutants in Kolkata

Vehicle type	Reduction in the emission of pollutants for 2 % replacement of vehicles (t per day)						
	CO_2	SO_2	NO_x	CO	CH_4	HC	PM
Bus	7.0005	0.019	0.163	0.048	0.001	0.012	0.007
Taxi	19.27	0.95	0.042	0.083	0.0009	0.012	0.0065
Total	26.27	0.972	0.209	0.132	0.0021	0.024	0.014

Table 9 Reduction in pollutants emitted with percentage of vehicles replaced by electric vehicles in Kolkata

Percentage of vehicles replaced	Reduction in pollutants emitted (t per day)						
	CO_2	SO_2	NO_x	CO	CH_4	HC	PM
2 %	26.27	0.972	0.209	0.132	0.0021	0.024	0.014
4 %	52.54	1.944	0.418	0.264	0.0043	0.048	0.03
6 %	78.81	2.916	0.627	0.396	0.0064	0.072	0.042

the incomplete combustion of fossil fuels (diesel, petrol, LPG, etc.). Now, if the vehicles using conventional fuels can be replaced by battery-operated electric vehicles, the carbon-containing pollutants released into the atmosphere can be reduced. This can benefit in the context of carbon trading. If the amount of carbon emitted into the atmosphere can be reduced significantly the government can sell credits of CO_2 to countries which have exceeded their permissible carbon limits (as per the norms in the Kyoto Protocol), thereby gaining economic benefits.

Application of BEV infrastructure model in other major cities in India

The proposed electric vehicle infrastructure model has the potential to check the issues of increasing petroleum-based fuel consumption and pollutants emission. Thus, this model has been considered for the other metropolitan cities as well for calculating the electrical energy requirement and the possible environmental impact. Some of the major cities in India have been considered for this case. However, the fuel consumption and travel pattern for the vehicles have been considered to be same as that of the case study. The energy requirement for the purpose of charging the electric vehicles and the possible environmental impact due to the alternative infrastructure for different cities has been shown in Tables 10 and 11.

Table 10 Electrical energy required for charging of electric vehicles for different cities in India

Cities	Number of registered vehicles			Electrical energy required to charge 2 % of fleet per day (kWh)
	Bus	Taxi	Auto-rickshaw	
Delhi	45,757	62,839	190,693	243,834.1
Mumbai	12,841	50,914	108,715	99,013.32
Chennai	37,205	72,446	101,868	207,252.5
Bengaluru	28,261	41,190	121,241	152,728
Hyderabad	25,311	29,548	93,004	129,629.3

Source Road Transport Yearbook 2012

Table 11 Reduction in emission of pollutants in different cities in India

Cities	Reduction in the emission of pollutants for 2 % replacement of vehicles (t per day)						
	CO_2	SO_2	NO_x	CO	CH_4	HC	PM
Delhi	114.7	2.15	1.8	0.7	0.015	0.15	0.0952
Mumbai	52.9	1.63	0.57	0.3	0.0052	0.055	0.0337
Chennai	106.6	2.4	1.5	0.6	0.0129	0.132	0.082
Bengaluru	72.3	1.4	1.1	0.4	0.0094	0.0947	0.0593
Hyderabad	60.2	1.03	1.01	0.3	0.0082	0.082	0.0516

It can be observed from the results that by replacing the conventional road transport vehicles by BEV, the air quality can be improved throughout the country. Such models, if implemented globally, may address the present issue of maintaining air quality as well as reducing the use of fossil fuels.

Conclusions

The study has shown that the electric vehicle infrastructure may be implemented along with the conventional road transport system and it has the potential to be beneficiary from both economic and environmental aspects. The study on the conditions of Kolkata has shown that this system can be implemented at a national level. The reduction in the amount of diesel and LPG consumption per day by replacing 2 % of the present passenger road transportation mode shows the feasibility of implementing parallel electric vehicle infrastructure. There is a major reduction in emission of pollutants from transport sector if we can come down in favor of this alternative. The calculations involving some of the major metropolitans in India have clearly reviewed the importance of technological advancement required in the transport sector, to check the fuel economy of the country as well as meeting the pollution standards. Due to the rising competition in the international market, there has been a gradual decline in the price of solar modules. This may certainly reduce the cost of generation of electricity bringing down the operating cost for running the alternate system. However, there has to be a valuable initiative from the side of the Government. This system has the benefits of: (i) reducing the consumption of conventional energy sources, (ii) commercializing the use of renewable energy in a larger context, (iii) reducing the ever-increasing problem of environmental pollution, (iv) reducing the financial burden by checking the quantity of crude oil imports, and (v) earning financial benefits through carbon trading.

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