Estimating Impacts and Cost of Air Pollution Due to Road Infrastructure Projects

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ESTIMATING IMPACTS AND COST OF AIR POLLUTION DUE TO ROAD INFRASTRUCTURE PROJECTS

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Abstract. Economic activities in the world is growing at an enormous pace and thus it is requiring to connect with the areas never touched before, leading to high scale infrastructure development. This is a good thing from a normal human perspective as it is giving opportunity to lower income people to earn the bread on their own but this development has its own consequences. With an objective to improve the connectivity between two points, the infrastructure projects are awarded without significant consideration towards environment. This study presents an estimate of damage produced by vehicle operation in terms of monetary values. This gives an opportunity to the Indian infrastructure planners to take environmental damage cost into account for selecting a suitable alignment between two nodes, which is not a common practice in India. The study included two-fold objective to quantify the emissions from vehicles of a typical national highway traffic in terms of capital cost and to compare the changes in the cost associated with the emissions by shifting vehicle operation from BS IV to BS VI. In order to achieve the objectives, secondary data from an alignment of Maharashtra and Karnataka was utilized. The study adopts a methodology of finding out the difference in the cost between BS IV and BS VI vehicular operation based on standard emission norms and unit costs of pollutants suggested by researchers around the globe. This gives us an approximate estimate of how much damage is posed to the environment and health effects on nearby residents or users of the link by operating a vehicle for one km. Data collected from various reports give an indication of total overhead cost to upgrade the fuel technology and vehicles as per BS VI norms.

Keywords: Air Pollution Cost, Emission Quantification, Energy, Traffic.

1 Introduction

1.1 Background

Enormous growth in industry is leading to urbanization of rural areas and formation of new cities. More road networks are being developed for faster and comfortable travel routes. This is all good from the perspective of economic growth of the country but this is just one side of the entire story. On the other hand, we are emitting huge of amount of greenhouse gases (GHGs) from the industries like vehicle manufacturing, fuel extraction, travels, road construction and traffic congestion. This pollution in short term does not mean much but in the long run it is creating imbalance in the environment. The imbalances can be seen everywhere around the globe e.g., loss of coastal lands due to rise in sea level, melting of permanent glaciers, devastating cyclones in the Bay of Bengal each year, extinction of species, origin of deadly viruses etc. These are just preliminary warnings; the threat in the coming future can be far more dangerous than it is today.

As per International Energy Agency, transportation sector itself contributed approximately 8 Giga tonnes of GHG emissions, which is approximately 1/4th of the entire GHG emission in that year. Out of this, approximately 74% is contributed by road transportation which consists of construction, maintenance and rehabilitation of roads/highways, operation of vehicles etc. Several methodologies/tools such as RoadCO2, COPERT4, MOVES, CHANGER and CO2NSTRUCT are developed around the world to estimate the amount of GHG emitted during each phase of the road infrastructure's life cycle. If the unit cost of each type of pollutant can be determined based on the severity of each pollutant on human health, animals species and environment, then the output from the various tools can be directly used to estimate the mitigation cost. This cost can be imposed on public or concerned industrial bodies to reverse the damage done by transportation sector. The present study focuses on understanding the effects of air pollution on environment and human health by relating it to a monetary values.

1.2 Literature Review

Small and Kazimi (1995) determined the air pollution costs for the city of Los Angeles. The cost of average car towards air pollution was found to be $0.03 considering 1990s class of vehicles. It was observed that the diesel cars and trucks resulted in higher cost towards the air pollution. The study indicated that a substantial cost savings can be achieved by changes in vehicle and fuel technology. Chatterjee et al. (2007) divided the cost into two parts, one for the cost incurred for technological advancement of the vehicles and compatible fuel production and the other required to operate and upgrade the vehicle by the user. Kuik et al. (2008) conducted meta-analysis on 62 papers and estimated the marginal abatement cost as € 74-227 for 2025 and € 132-381 per tonne for a target reduction of CO2 to 350 ppmv. Maibach et al. (2008) considered the current impact on the environment such as sea level rise, common health issues due to pollution, damage to the ecosystem and biodiversity, extreme weather events such as flood, drought, cyclones and collapse of Amazon forests. The estimated damage cost came out to be € 50-100 t/CO2 to maintain a safe gap between threshold limit of catastrophic events. Litman (2009) evaluated the carbon tax as an energy conservation strategy, which would also result in consumption of the fossil fuels. Various fossil fuels were provided a certain amount of carbon tax, which the user has to pay for the consumption. The collected tax money was utilized in economic up-liftment of low income groups, where it was first introduced in British Columbia. Litman et al. (2018) divided this environmental cost in two parts for simplified view: Damage Cost and Control Cost. Damage cost reflects monetary valuation of damage done to environment and risks while control cost reflects the amount that can be incurred to reduce emissions. These costs are estimated considering various factors such as discount rate, current global factors, uncertainty of the extent of the damage, vehicle type and road condition etc. Čokorilo et al. (2019) developed a methodology to calculate the exhaust emission cost with the help of traffic data, vehicle and fuel type, length of road network and unit cost of each pollutant. For the base year, total exhaust emission cost was estimated to be € 354,238,894 per year for the chosen road segment. .

1.3 Significance of Research

The way we are expanding ourselves to the edge of the advancements, environment should not be neglected in the process. Developed nations are putting an effort to find a way to reduce the damage. India can also follow the same path and start from developing a methodology to estimate the unit cost of each pollutants to estimate the damage cost. This data can also be helpful in selecting the best alignment while designing a road network from both perspective environment as well as development cost. Further, this cost can be included in the total transportation cost in order to assess the damage to the environment, which will help the policy makers to make decision on various aspects.

2 Methodology

2.1 Vehicle Emission Standards

Government of India formed Bharat Stage Emission Standards (BSES) to regulate the air pollution created by motor vehicles. Central Pollution Control Board (CPCB) under the Ministry of Environment sets the standard policy and its implementation plan throughout the nation.

The emission standard was first introduced in 2000 on the basis of European emission standards. Bharat Standard (BS) IV emission standard has been enforced to the entire states on 1st April, 2017 with a deadline to vehicle manufacturers to jump to BS VI standard 1st April, 2020. New emission standards come with a motivation to have a stricter control over the air pollutants ejected from tail-pipe in comparison to its previous version. The Indian emission standard roll-out is shown in Table 1.

Table 1. Indian Emission Standard Roll-out Timeline for 4-wheelers (DieselNet.com)

Standard	*Reference*	*Year*	*Region*
India 2000	Euro 1	2000	Nationwide
Bharat Stage II	Euro 2	2001	NCR*, Mumbai, Kolkata, Chennai
		2003	NCR and 14 Cities#
		2005	Nationwide
Bharat Stage III	Euro 3	2005-04	NCR*, 14 Cities#
		2010	Nationwide
Bharat Stage IV	Euro 4	2010	NCR, 14 Cities#
		2017	Nationwide
Bharat Stage V	Euro 5	Skipped	

Bharat Stage VI	Euro 6	2018 2019 2020	Delhi NCR* Nationwide

* National Capital Region (Delhi)
\# Mumbai, Kolkata, Chennai, Bengaluru, Hyderabad, Ahmedabad, Pune, Surat, Kanpur, Lucknow, Jamshedpur, Agra and Guwahati

The current work uses the secondary data from the traffic survey of a national highway in plain terrain in the region of Maharashtra and Karnataka to arrive at an abatement cost. The abatement cost is divided into two parts: *vehicle operation cost* or *exhaust emission cost* and *technology advancement cost* as shown in Fig. 1.

The *vehicle operation cost* is calculated with the help of the cost estimation model developed by Čokorilo et al. (2017) because of some similarity between India and Serbia and suitability of the model. This model makes use of network length and traffic data, fuel emission technology and type of vehicle which is very helpful in estimating the amount of pollution that can be generated due to traffic operation.

Technology advancement cost can be directly obtained from the financial reports of various oil refining companies.

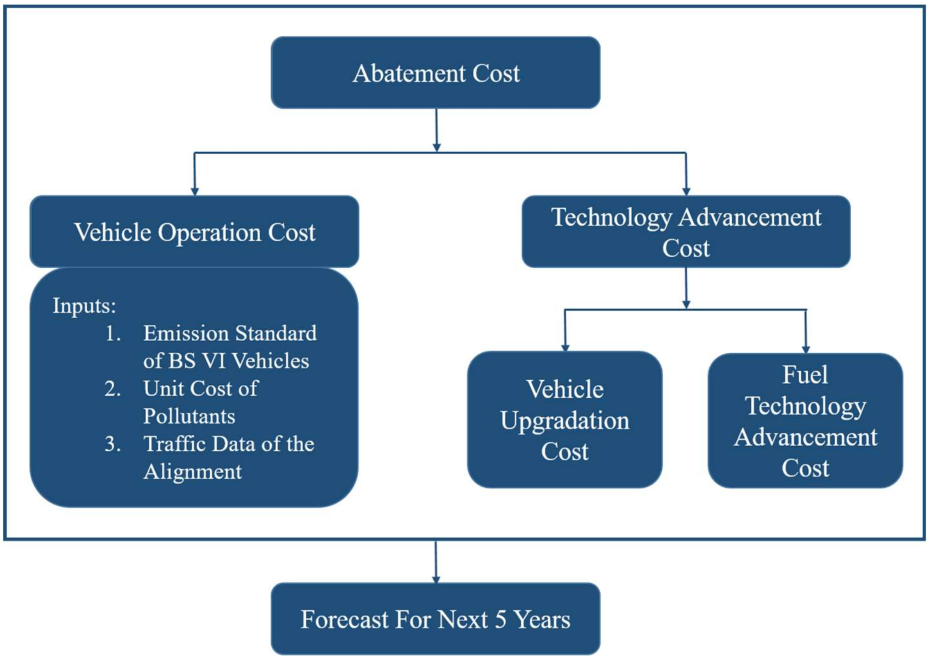

Fig. 1. Methodology to Estimate EEC

2.2 Exhaust Emission Cost (EEC) Estimation Method

The EEC is estimated with the help of Eq. (1) as per Čokorilo et al. (2017):

$$EEC = \sum_{i,j,k} const * DT_{i,j} * FC_{i,j} * f_{(FC)_{i,j}} * \rho_f * L_j * EF_{i,k} * f_{EF_{i,j,k}} * UC_k \qquad (1)$$

Where, EEC = Exhaust emission cost for the road network (₹/year)

DT = Average Annual Daily Traffic (AADT) per vehicle category (vehicle/day)

FC = Fuel consumption of vehicle (L/km)

f_{FC} = Correction factor of fuel consumption (1-1.25 for passenger vehicles and 1-1.8 for freight vehicles)

ρ_f = Density of fuel (petrol = 0.71 kg/L, diesel = 0.835 kg/L, LPG = 0.56 kg/L)

const = 3.65 x 10^{-4}

L = Length of road section (km)

EF = Emission factors ($g_{pollutant}/kg_{fuel}$)

f_{EF} = Factor of change in the emission of pollutants, depending on the different engine mode

UC = Unit cost of pollutant (€/tonne)

i = Index of vehicle category

j = Index of road section

k = Index of pollutants

The EEC is calculated for BS IV and BS VI vehicles as these two engine technologies are currently in use in India. The difference in the amount would suggest that shifting from one technology to the other the amount of environmental cost that can be saved in terms of emission cost. Further this data is projected for next 5 years to determine increment of the cost over the time span. A period of 5 years is considered as beyond five years, the growth rate of vehicles may change depending on various factors associated with politics, natural disaster, economic changes, etc.

Traffic forecast is done with the help of econometric modelling taking historical national state domestic product (NSDP) data and vehicle counts in the states considered for this study.

2.3 Traffic Growth Rate Estimation

Traffic growth rate for two alignments is estimated with the help of econometric modelling as per IRC:108-2015.

$$lnP = c + m * ln(Economic\ Indicator) \quad (2)$$

Where P is the traffic count, m is the coefficient of traffic demand elasticity.

$$Traffic\ Growth\ Rate = Elasticity * Growth\ Rate\ of\ Economic\ Indicator \quad (3)$$

$$Growth\ Rate\ of\ Economic\ Indicator = \frac{(Current\ Year\ Value - Previous\ Year\ Value)}{Previous\ Year\ Value} \text{ X } 100\ \% \quad (4)$$

$$P_n = P_0(1 + r)^n \quad (5)$$

Where P_n and P_0 is the traffic population in n^{th} year and in the base year respectively, r is the traffic growth rate in the state.

3 Result and Discussion

3.1 Vehicle Operation Cost

National State Domestic Product (NSDP) is chosen as the economic indicator for this study for a period of 9 years from 2006 to 2014 for Maharashtra state and 2009 to 2015 for Karnataka state as shown in Table 2 and 3, respectively.

Table 2. Historical Vehicle Count and NSDP (in INR Crore) Data of Maharashtra (Ministry of Statistics and Programme Implementation)

Year	*2 Wheelers*	*Cars*	*Buses*	*Trucks*	*NSDP*
2006	8573679	1648379	71187	316502	481983
2007	9394869	1822458	77042	344267	538081
2008	10212360	1979191	79073	366642	546533
2009	11181762	2182969	83816	374705	599338
2010	12429011	2440404	89861	389941	667625
2011	13921763	2750167	100097	411418	695904
2012	15457123	2592565	110121	402366	749137
2013	16910395	2834847	120886	47128	805593
2014	18603835	3113773	120750	491582	852451

Table 3. Historical Vehicle Count and NSDP (in INR Crore) Data of Karnataka ((Ministry of Statistics and Programme Implementation)

Year	**2 Wheelers**	**Cars**	**Buses**	**Trucks**	**NSDP**
2009	4796587	892160	44308	366597	278534
2010	6404905	1005291	53874	377495	300747

2011	7033045	1131201	58012	415491	368338
2012	7737366	1269430	62501	454582	406821
2013	8575104	1420767	69718	506340	462395
2014	9533892	1572521	75529	555255	516516
2015	10644368	1741831	80911	606352	581741

Average growth rate of the economic indicator is the statistical mean of year-on-year growth of NSDP, yearly growth is calculated with the help of Eq. (4). Eq. (2) can be used to estimate the traffic demand elasticity which is further used in Eq. (3) to determine average traffic growth rate. The regression statistics and growth rates of different vehicle categories are shown in Table 4 and 5 for Maharashtra and Karnataka state, respectively. Average growth rate of NSDP of Maharashtra was estimated to be 7.44% and 13.15% for Karnataka.

Table 4. Econometric Model Output for Maharashtra

Regression Statistics	*2-Wheelers*	*Cars*	*Buses*	*Trucks*
Multiple R	0.995	0.979	0.987	0.963
R Square	0.990	0.958	0.973	0.928
Adjusted R Square	0.989	0.952	0.970	0.918
Standard Error	0.028	0.047	0.035	0.040
Observations	9	9	9	9
Elasticity	1.372	1.082	1.001	0.688
Intercept	-2.012	0.185	-1.959	3.676
Traffic Growth Rate (%)	10.21	8.05	7.45	5.12

Table 5. Econometric Model Output for Karnataka

Regression Statistics	*2-Wheelers*	*Cars*	*Buses*	*Trucks*
Multiple R	0.924	0.955	0.928	0.964
R Square	0.854	0.912	0.860	0.928
Adjusted R Square	0.824	0.894	0.832	0.914
Standard Error	0.112	0.079	0.085	0.056
Observations	7	7	7	7
Intercept	7.123	5.883	4.205	6.485
Elasticity	0.673	0.630	0.528	0.506
Traffic Growth Rate (%)	8.85	8.28	6.94	6.65

Table 6. AADT of Maharashtra (NH 361) and Karnataka (NH 648)

	AADT (veh/day)	
Vehicle	**Karnataka**	**Maharashtra**
PC Petrol	2929	2493
PC Diesel	517	440
Buses	285	550
Trucks	2858	3531
TWs	6047	1763
Total	**12636**	**8777**

Table 6 shows the traffic volume at the stretch of selected highway in the region of Maharashtra (NH 361) and Karnataka (NH 648) and Table 7 shows the forecasted traffic population if the traffic grows by the growth rate predicted by econometric model output (as shown in Table 4 and 5) in the year 2025.

Table 7. Base year and forecasted year traffic data

P_0 *(veh/day)*		P_5 *(veh/day)*	
Maharashtra	***Karnataka***	***Maharashtra***	***Karnataka***
8777	12506	12724	18711

Unit cost (Table 8) was estimated by Čokorilo et al. (2017) to estimate the EEC using Eq. (1).

Table 8. Unit Cost of Pollutants (Čokorilo et al., 2017)

Pollutant	Unit cost (₹/kg)
CO	8.09
NOx	763.97
NMVOC	42.79
CH_4	75.54
PM	1954.86
CO_2	2.70
SOx	699.13

Based on the unit cost shown in Table 8, the exhaust emission cost due to BS IV and BS VI emission categories is shown in Table 9. The year wise total EEC for Maharashtra and Karnataka is shown in Fig. 2 and Fig. 3 respectively.

Table 9. Exhaust Emission Cost (in INR) due to Various Fuel Emission Technologies

Emission Technology	State / Year / Vehicle Type	Maharashtra Base year 2020	Maharashtra Forecasted year 2025	Karnataka Base year 2020	Karnataka Forecasted year 2025
BS IV	Cars	1028533.44	1514754.57	1208438.90	1798729.82
	Buses and Trucks	926283.10	1207532.34	713380.98	985516.34
	2-Wheelers	881456.82	877517.14	3023351.90	4619881.83
	Total	***2836273.36***	***3599804.05***	***4945171.78***	***7404127.99***
BS VI	Cars	995340.86	1465870.78	1169444.24	1740687.27
	Buses and Trucks	673132.53	877517.14	518415.96	716177.49
	2-Wheelers	652561.70	1061027.38	2238253.32	3420199.22
	Total	***2321035.09***	***3404415.30***	***3926113.52***	***5877063.98***

Traffic growth is forecasted for 5 consecutive years from 2020 and the exhaust emission cost is calculated per unit km length per year of the selected highway link. Results indicate that the EEC varies linearly for the next 5 years for both Maharashtra and Karnataka region (Fig. 2 and 3) assuming the calculated growth rate of vehicles in this study. The vehicle category wise EEC for the state of Maharashtra and Karnataka is shown from Fig. 4 to 9. A saving of ₹33.19 thousand/km, 2.53 lakh/km and 2.19 lakh/km can be made by switching from BS IV to BS VI vehicles for Maharashtra region while a saving of ₹1.39 lakh/km, ₹2.43 lakh/km and ₹10.53 lakh/km can be saved in the base year 2020 for Karnataka region for cars, buses and trucks and 2-wheelers respectively.

For the projected period the difference in the EEC by shifting from BS IV to BS VI technology grew by 7.45%, 5.15% and 9.26% for cars, buses and trucks and 2-wheelers, respectively for Maharashtra while for Karnataka the difference grew by 7.65%, 6.26% and 8.13% for cars, buses and trucks and 2-wheelers, respectively.

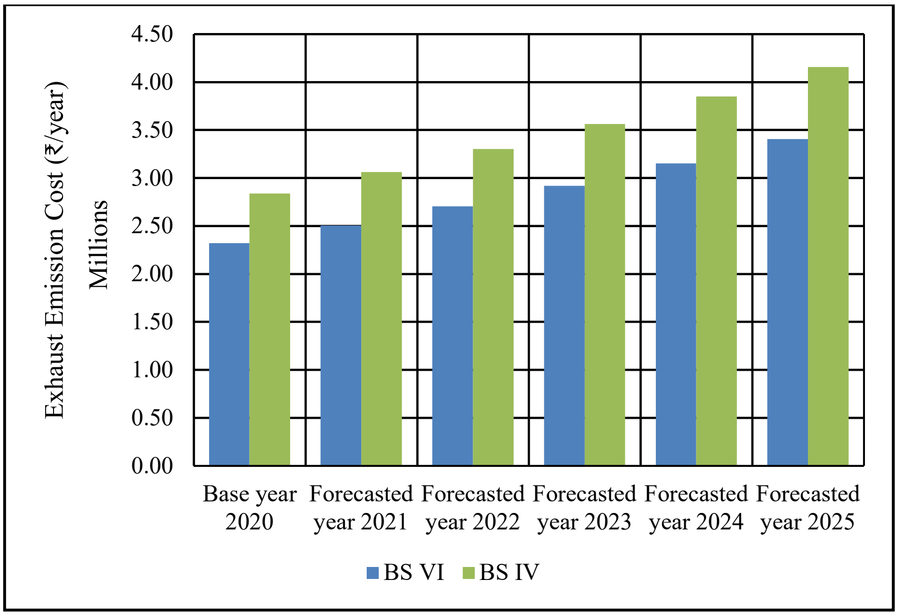

Fig. 2. Total Exhaust Emission Cost for Base and Forecasted Year in Maharashtra Region

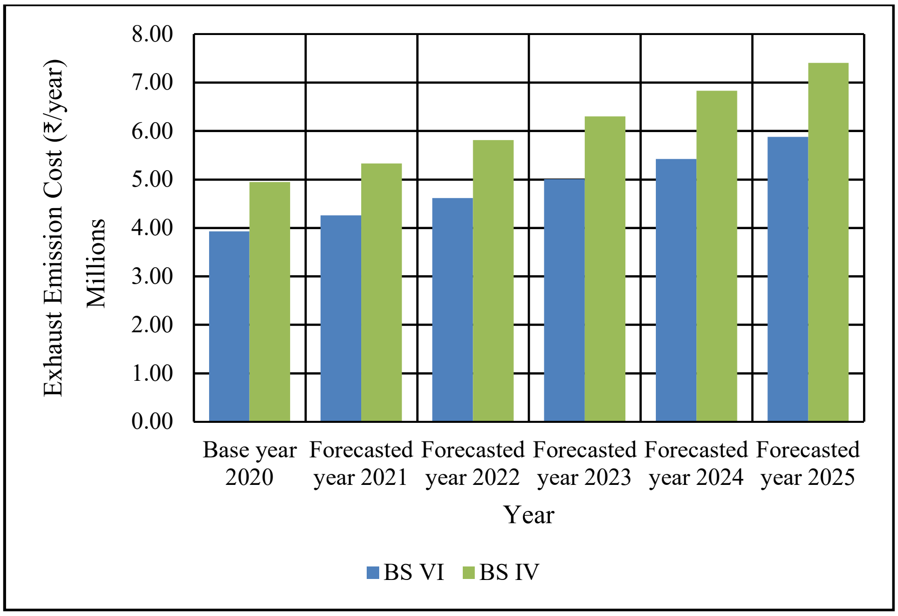

Fig. 3. Total Exhaust Emission Cost for Base and Forecasted Year in Karnataka Region

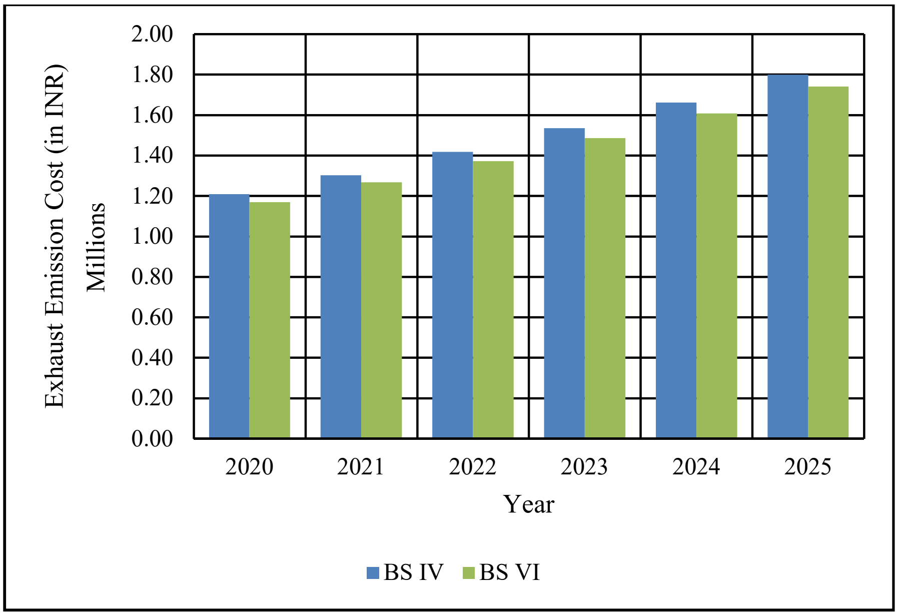

Fig. 4. Year Wise EEC for Cars in Karnataka

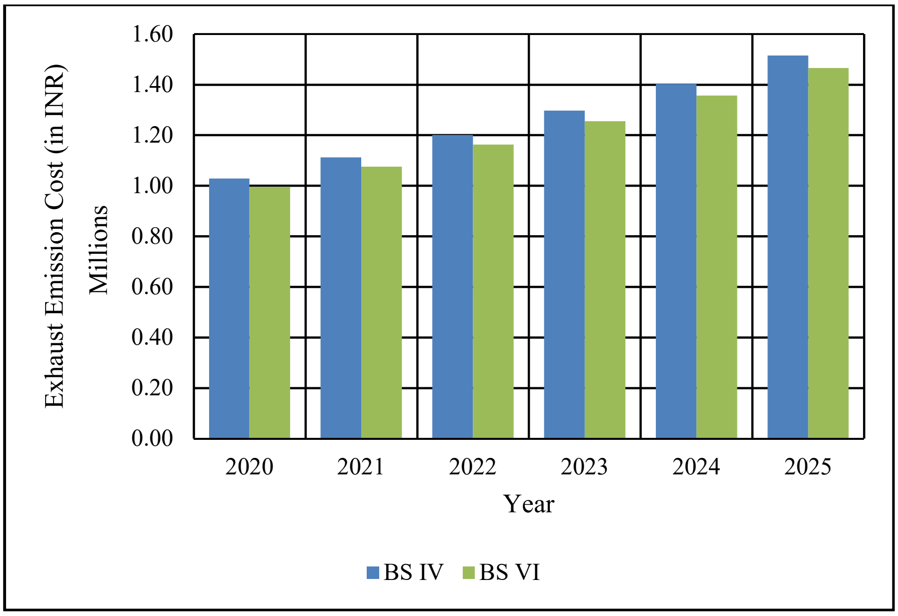

Fig. 5. Year Wise EEC for Cars in Maharashtra

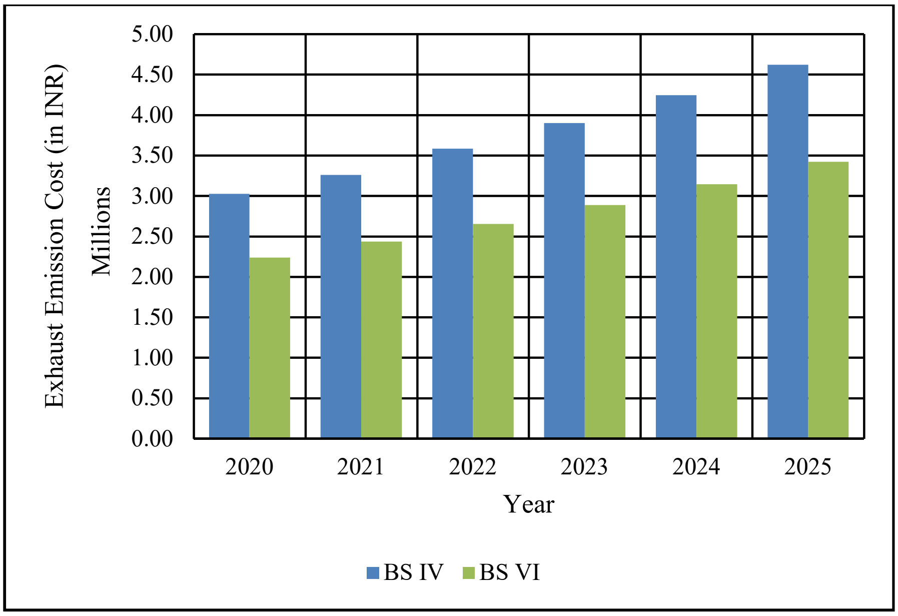

Fig. 6. Year Wise EEC for 2-wheelers in Karnataka

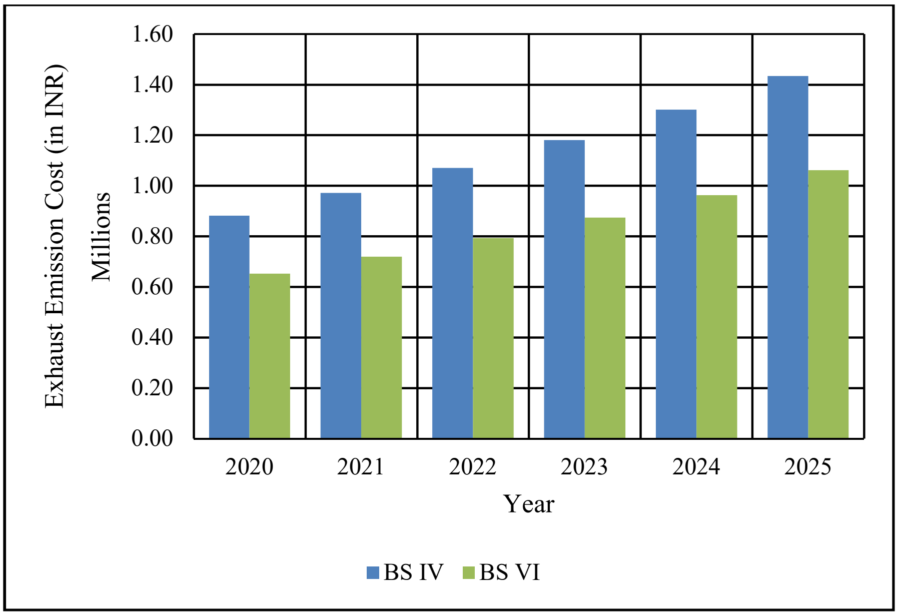

Fig. 7. Year Wise EEC for 2-wheelers in Maharashtra

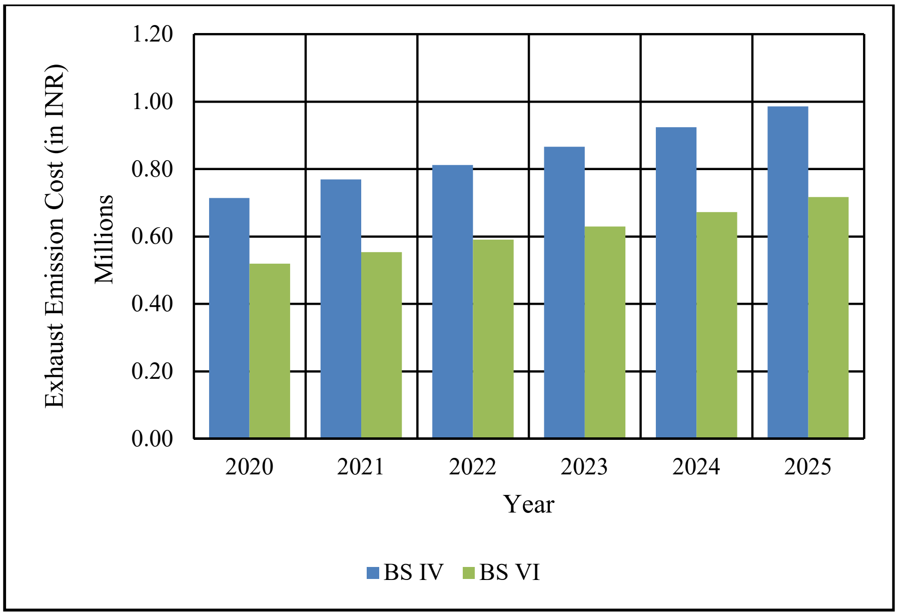

Fig. 8. Year Wise EEC for Buses and Trucks in Karnataka

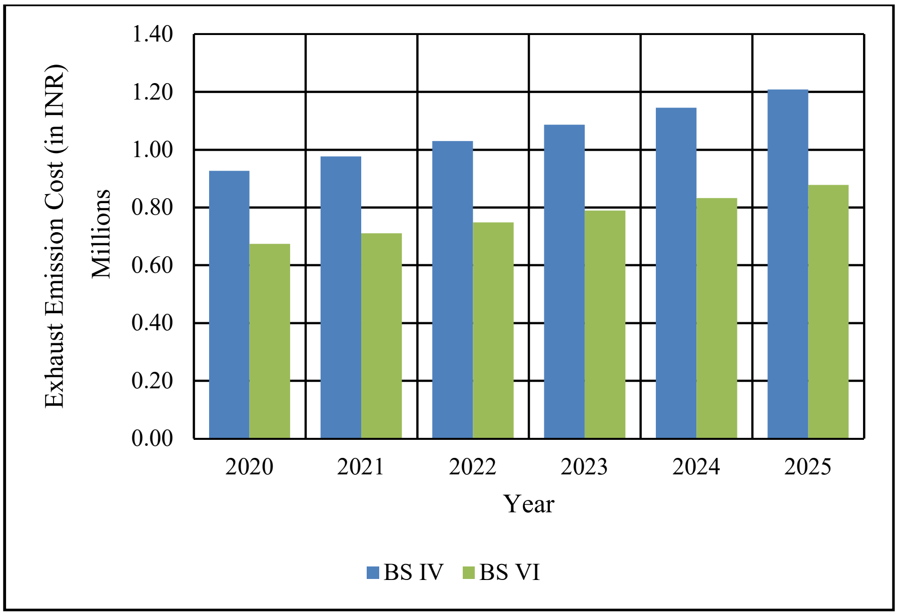

Fig. 9. Year Wise EEC for Buses and Trucks in Maharashtra

Results indicate that the EEC difference between BS IV and BS VI is negligible for cars for the entire projected years (Fig. 4 and 5) but the same is not true for buses and trucks (Fig. 6 and 7) and 2-wheelers (Fig. 8 and 9). This is mainly because car engine emission standards are already heavily regulated and buses and trucks emit high amount of poisonous NOx gases which pose huge threat to human life hence their unit cost is kept high, this ultimately leads to very high environmental cost for operation of buses and trucks. Further, the 2-wheelers amount for a high cost associated with air pollution. Therefore, adopting electric 2-wheelers may considerably bring down this cost in the near future. Note that we cannot compare here, which state is resulting in higher EEC or lower EEC considering various factors such as AADT obtained, local factors, etc.

3.2 Technology Advancement Cost

Technology advancement cost consists of vehicle up-gradation cost and fuel technology advancement cost. These costs are one-time cost that needs to be borne by either owner of the vehicle with the help of lending institutions or their own money or by government by subsidizing the shifting cost. These costs can vary on the basis of company, vehicle class and financing schemes of the lending institutions.

As per Live Mint (2015), Sanjeev Singh, chairman of IOCL reported that the oil refineries around the country spent a sum of ₹35000 crore to upgrade their machinery across the nation to produce fuels as per the norms of BS VI from April 1, 2020.

As per the methodology worked out by Chatterjee et al. (2007), the state of Maharashtra and Karnataka would need a sum of ₹97.71 crore and ₹82.60 crore per year, respectively for next 5 years at 10% discount rate to finance all the vehicle owners to switch to new technology vehicles in the base year.

4 Conclusions

This study included two-fold objective:

- To quantify the emissions from vehicles of a typical national highway traffic in terms of capital cost.
- To compare the changes in the cost associated with the emissions by shifting vehicle operation from BS IV to BS VI.

It was observed that upgrading the vehicles from BS IV to BS VI would cost around ₹97.71 and ₹82.60 crore per year for a period of 5 years for Maharashtra and Karnataka, respectively. Upgrading fuel technology for BS VI standard vehicles have costed around ₹35000 crore for oil refineries as per the statements of Sanjeev Singh, chairman of IOCL. These technological advancement cost would be borne by the road users either with the help of bank or independently.

India formally switched to BS VI vehicles from 1st April 2020 skipping BS V category of vehicles. Therefore, currently most of the vehicles on the road are either BS IV standard vehicle or BS VI standard vehicle. There is a significant improvement in tail-pipe emission technology in the new standard vehicles. The operation of all BS IV vehicles on the highway traffic considered in this study would create damage worth ₹28.36 lakh while BS VI vehicles would create a damage of ₹23.21 lakh for each km of distance travelled per year. This study suggests that upgrading to new norms can save a sum of ₹33.19 thousand/km from passenger car operation, ₹2.53 lakh/km from buses and trucks operation and ₹2.29 lakh/km from two-wheelers operation i.e., approximately ₹5 lakh/km can be saved annually if all vehicles using this alignment located in Maharashtra switch to the latest emission standard for the vehicles and the same for an alignment located in Karnataka was found to be approximately ₹10.19 lakh/km from all vehicles (passenger car: ₹38.99 thousand/km, buses and trucks: ₹1.95 lakh/km and two-wheelers: ₹7.85 lakh/km). Based on the study, it is interesting to note that the two-wheelers resulted in a significant reduction in air pollution cost or in other words, their contribution towards air pollution will be significant. The savings while using car and two-wheelers would be significant if we consider the traffic data from an urban road as the traffic data considered in this study was obtained from a national highway. Therefore, this result can help policy makers in promoting electrical vehicles, which are already gaining attention of many automobile owners.

The exhaust emission cost increases linearly primarily because of the nature of the model presented by Čokorilo et al. (2017). This model can help the regulatory bodies to evaluate the trend and determine the right time to switch from current emission standard to a new one which can aggressively cut down the air pollution.

4.1 Scope of Future Work

From literature survey it was found that this kind of cost estimation methodology is still far away from being realized especially in India. The researchers should definitely look into this direction to propose a suitable methodology to estimate unit costs of various gases from vehicles for Indian conditions as the air pollution problem has already started creating a havoc on the eco-system. Moreover, air pollution is considered as the first significant threat towards the environment and human health.

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