Greenhouse Gas Emissions in India's Road Transport Sector

Namita Singh, Trupti Mishra and Rangan Banerjee

Abstract India is one of the fastest growing major economies of the world. The transport sector of India is the third most GHG (Greenhouse gas) emitting sector, where the major contribution comes from the road transport sector. The chapter examines the trend of CO_2 emission from transport sector (1970–2012) and trend of annual vehicle registration in India (2001–2012). The chapter also gives an account of the travel characteristics of India and explains the fleet models applied to obtain the age and technology distribution of vehicles on the road. Different methodologies adopted for GHG estimation can be explained via two independent approaches based on two sets of data such as fuel sold and vehicle kilometers traveled. The study analyzed the Tier 1, Tier 2, and Tier 3 methods for GHG emission estimation given by IPCC and segregates the studies done on India based on these approaches. Uncertainty in CO_2 emission from different studies for Indian transport sector was high initially, but it has reduced in recent studies due to refinement in the input parameters, emission factors, and associated methodologies. The study addresses the gap in the estimation study and discusses the policies in India for reducing emissions from transport sector such as auto-fuel policy, shifting to four-stroke vehicles from two-stroke vehicles, policies for alternative fuels like CNG and biofuels, and incentives provided for the diffusion of electric vehicles in India.

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1 Greenhouse Gas Emissions

1.1 Introduction

Greenhouse gases (GHGs) are responsible for causing global warming on earth. These gases trap the heat in the atmosphere and increase the temperature of the earth. Anthropogenic activities such as deforestation, fossil fuel consumption, and atmospheric emissions majorly from industries and transport sectors have led to greenhouse gas emissions. According to Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report which was published in 2014, human involvement is evident in increasing GHG emissions. Suitable mitigation and adaptation strategies must be adopted to curtail the threat of climate change (Jeyalakshmi et al. 2015).

Greenhouse gases which are responsible for global warming consist of carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), hydrofluorocarbons (HFCs), sulfur hexafluoride (SF_6), and perfluorocarbons (PFCs). Here, CO_2 emission accounts for the major GHG emissions from transport sector which is around 95%. Methane (CH_4) and nitrous oxides (N_2O) consist of 1%, and the leakage from air-conditioning systems of hydrofluorocarbons (HFCs) accounts for the rest of the 3% of GHG emissions. Ozone, aerosol, and carbon monoxide (CO) are also transport sector emissions (Atabani et al. 2011).

Fossil fuel CO_2 emission from the Indian transport sector have increased by approximately 5 times from 50 Mt in 1970 to 242 Mt in 2012 (derived from World Bank Indicator data). Whereas, CH_4 and N_2O emissions have increased by about 45%, and fluorinated gases have increased from 0.4% in 1970 to 2% in 2010. In Asia, China and India are the major economies responsible for the increase in GHG emissions (Nejat et al. 2015). Globally transport sector is responsible for 24% of total CO_2 emissions from fuel combustion in 2015 (which is second most CO_2 emitting sector after electricity and heat, i.e., 42%) (IEA 2017). The current study focuses on GHG emission from the transport sector of India and examines the growth trend of vehicle population on road. The study analyzes the transport (travel) characteristics of India and focuses on the methodologies adopted for the CO_2 emission estimation and the variation in input variables resulting in the uncertainty in CO_2 emission from the transport sector. In the end, the study highlight the policies adopted by the government for emission reduction and the gaps needed to be addressed for robust analysis of GHG emission.

1.2 Greenhouse Gas Emissions from the Transport Sector of India

In India along with economic growth, the urban areas have also increased. This has led to increase in transport infrastructure and transport vehicles. This portion of the chapter will focus on trend analyis of vehicular population on road, which is one of the leading causes of anthropogenic CO_2 emission from the Indian transport sector.

Over the years, the growth rate of CO_2 emission from the overall transport sector of India has increased exponentially as shown in Fig. 1. The growth rate of CO_2 emission from transport sector was not linear from the time period 1970 to 2012. The graph is plotted for the different time periods with different growth rates for a log of CO_2 emission from the transport sector. The data for the growth analysis are obtained for the duration of 1970 to 2012 from World Development Indicators reported by the World Bank. The growth rate of CO_2 emission from the time period 1970 to 1980 was 2.7%, from 1980 to 1990 was 2%, from 1990 to 2000 was 4%, and from 2000 to 2012 was 6.9%. Various reforms for reduction in emissions from transport sector were introduced which should have reduced emission with time such as introduction of four-stroke engine vehicles in mid-1990s, adoption of emission norms like auto-fuel policy like Bharat Stages I, II, and III (which are similar to European emission norms) in India, and introduction of fuels like compressed natural gas (CNG) and liquefied petroleum gas (LPG) in vehicles during the period 2000–2012. But with an increase in private motor vehicles on road, along with an increase in the distances traveled and deterioration of public transport (Ramachandra et al. 2015), the emission has increased with respect to previous decades from urban road transport. The major fuels in these motor vehicles are petrol and diesel, and even though stringent emission norms were introduced in India, lack of their implementation and missing infrastructure has lead to uncontrolled emission from the transport sector.

Emission of greenhouse gases like methane (CH_4) and nitrous oxide (N_2O) is very less from road transport sector of India. Methane emission has increased by fourfold from 1980 to 2000 (from 2.9 to 11.6 kt), but its growth rate has dropped from 8% during 1980–1990 to 6% during 1990–2000. Similarly, for N_2O, road transport contribution in its emission is negligible, but their amount has doubled from 1980 to 2000 (from 0.23 to 0.9 kt). The growth rate during the period 1980–1990 was 8% and during the period 1990–2000 was 6%. Emission reduction in both the gases has been attributed to the introduction of four-stroke engine vehicles in two-wheelers and three-wheelers in the market in the mid-1990s (Singh et al. 2008).

Assume the vehicles registered are the vehicles used on road and are responsible for the increase in emissions. Figure 2 shows the trend in vehicle registered data for two-wheelers, cars, jeeps, taxis (all three considered as four-wheelers), buses, and goods vehicles. Here, the registered vehicle population data for the years 2001–2012 are taken from MORTH (2015), and growth trend for two-wheelers, four-wheelers, buses, and goods vehicles is shown.

The graphs examine the growth in annual vehicle registration for motor vehicles in India. The trend analysis shows the exponential growth in vehicles over the years.

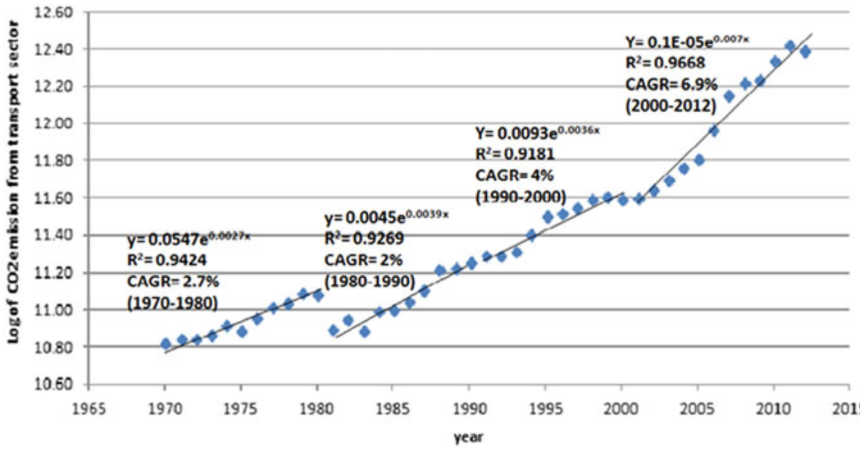

Fig. 1 Growth trend of log of CO_2 emission from transport sector of India for different time period

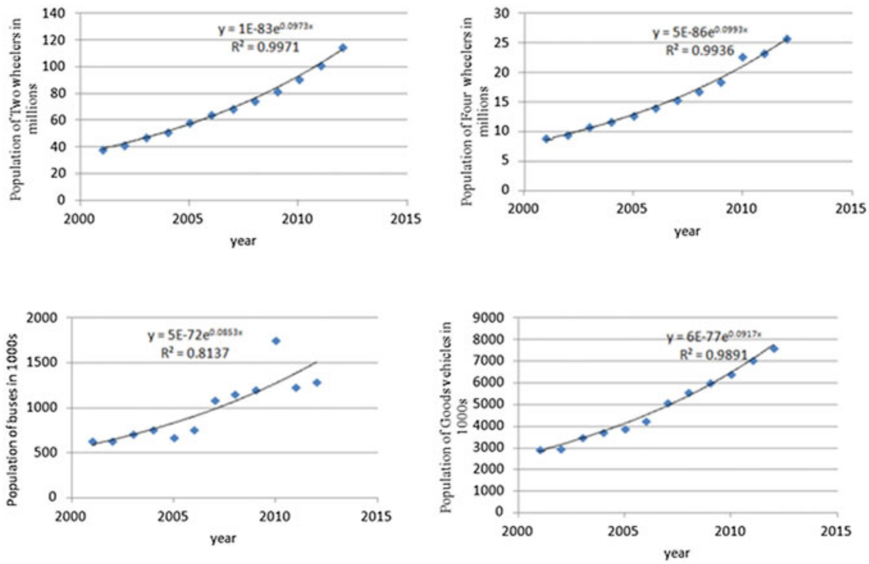

Fig. 2 Growth Trend in annual vehicle registration in India for two-wheelers, four-wheelers, buses, and goods vehicles

For the time period 2001–2012, the growth rates for two-wheelers, four-wheelers, buses, and goods vehicles are 10.5, 10.2, 6.7, and 9.1%, respectively. The registered vehicles are subjected to fleet model which separates the vehicles of different technology based on their age and hence takes care of the phasing out or old vehicles which are no longer on road. The methods applied in the Indian context are Weibull distribution (Baidya and Borken-Kleefeld 2009) and logistic distribution (Pandey and

Venkataraman 2014) to study age distribution of vehicles on road. Understanding the fleet model using logistic function approach, the model required time series vehicle registration data, vehicle sales data, and age distribution of vehicles at a particular year (reference year) to estimate the survival function parameters.

$$V_{c,a}(t) = V_{c,0}(t-a) \times \mathrm{Suf}_{c,a} \tag{1}$$

$$\mathrm{Su}(a) = \frac{1}{1 + \mathrm{e}^{[\propto(1\frac{a}{L50})]}} \tag{2}$$

Here, in Eq. 1, $V_{c,a}$ (t) is the population of the vehicle in year t, having category c and age a. $V_{c,0}$ $(t-a)$ is the new vehicle registered in the year $t-a$, and $\mathrm{Suf}_{c,a}$ is the survival fraction applied to the vehicles present in the given category of a vehicle having aged a. In Eq. 2, survival fraction is the ratio of survival rate Su for vehicles of age a to the vehicles of age 0. Here, α is the shape factor which indicates the start of significant retirement for the vehicles of given category. And $L50$ represents the age by which half of the vehicles of the particular age have retired. The values for α and $L50$ are as follows—α for two-wheelers, three-wheelers (auto rickshaws), four-wheelers, buses, and goods vehicles are −2.9, −2.9, −5.2, −4.5, and −4.5, respectively. Whereas, $L50$ for two-wheelers, three-wheelers (auto rickshaws), four-wheelers, buses, and goods vehicles are 10.1, 10.1, 19.8, 13, and 13 years respectively (Pandey and Venkataraman 2014).

With the increase in vehicle population, energy consumption by vehicles has also increased. From the overall transport sector in India (road, water, air, and rail), approximately 73% of GHG emissions come from road transport sector in 2011 (Gupta and Singh 2016).

1.3 Travel and Energy Demand for Transport Sector of India

In India, urban road passenger transport consists of road passenger and road freight transport travel demand. Road passenger transport is made up of passenger-carrying vehicles such as motorcycle, scooters, cars, and buses, whereas road freight transport demand consists of trucks and heavy diesel vehicles which carry only goods. Similarly, rail transport also consists of passenger and freight travel demand. The growth rate of road passenger transport demand (which is passenger kilometers traveled) is 11% from 1831.6 billion passenger kilometers in 2000 to 6351.2 billion passenger kilometers in 2012. For road freight transport demand, the growth rate is 8% from 467 billion tonnes kilometer in 2000 to 1212.4 billion tonnes kilometers in 2012. Similarly, for rail passenger kilometers, the growth rate is 8% from 430.7 billion passenger kilometers in 2000 to 1046.5 billion passenger kilometers in 2012, whereas for rail freight transport demand, the growth rate is 7% starting from 305.2 billion tonnes kilometers in 2000 to 667.6 billion tonnes kilometers in 2012 (MORTH 2015). Figure 3 shows the travel demand share for the year 2012 for India. It can be

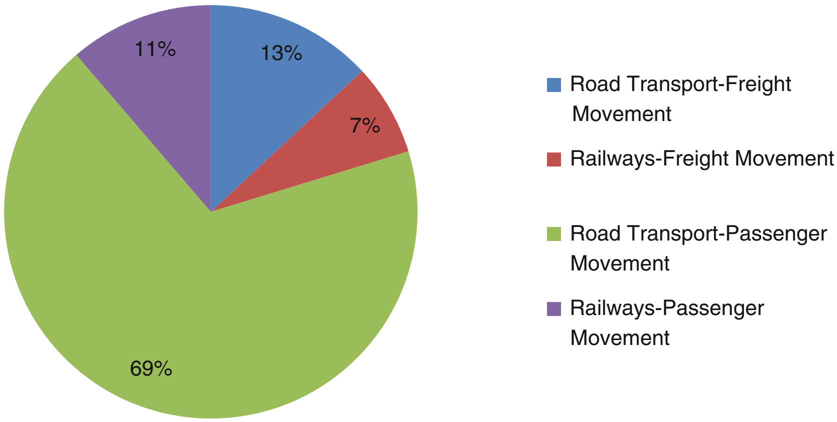

Fig. 3 Share of road and rail transport demand in India for the year 2012

seen that passenger road transport demand (on-road vehicles like two-wheelers, cars, three-wheelers, and buses) dominates the travel demand in India, followed by road freight transport demand (goods carrying vehicles like trucks) which is followed by rail passenger and freight transport demand. Here, travel demand in terms of billion kilometres travelled is indicated by 'movement' of each mode type.

Diesel and petrol are the major transportation fuel for Indian vehicles such as cars, buses, trucks and two-wheelers, and in small percentages, CNG is also used in auto rickshaws, taxis, and buses. The transport sector in India accounts for 70% of diesel consumption (both direct and retail sales) at all India level. Diesel is used in both transport and non-transport sector. Light commercial vehicles (LCHs), heavy commercial vehicles (HCVs), and buses account for about 38%; whereas cars and utility vehicles (UVs) are responsible for about 22% of diesel sales in India. The growth rate of diesel consumption for Indian transport sector is 7% from 1970–71 to 2012–13. For petrol, two-wheelers are reported to have maximum consumption at 61.42% for the duration of 1970–71 to 2012–13. This could be mainly because of growing middle-class income group in the country. Cars in India running on petrol are reported to be around 34%, which is lower than diesel cars. This could be due to the price difference between diesel and petrol, and consumers perceive diesel cars to be economically optimal. Two-wheelers and cars together account for 95% of the total consumption of petrol. The growth rate of petrol consumption in India is 5.7% since 1970–71 to 2012–13 (MOP&NG 2013).

This increase in fuel (petrol and diesel) consumption is responsible for the increase in energy consumption. The concentration of air pollutants and GHG gases emitted from the exhaust of vehicle has increased with increase in vehicle population (Pucher et al. 2005). These air pollutants have an adverse impact on the health of the people. Hence, one can say that urban transportation has also degraded the health of the people along with causing global warming. The ever-increasing demand for conventional fuel (petrol and diesel) has led to research in alternate technology/fuels which can diffuse in the market and replace the petroleum fuels.

Climate change mitigation strategies are actions which limit the rate of long-term climate change. For the transport sector, various policies have been enacted and suggested as mitigation strategies such as auto-fuel policy in India, blending of biofuel in petrol and diesel, phasing out of old and polluting vehicles, diffusion of electric vehicles, and increasing number of buses or improving the public transport sector are few policies or initiatives to mention. In order to see the impact of policies or strategies on transport emission, one need to first calculate the GHG emissions or build an emission inventory for a reference year for a city/country and then calculate the impact of each strategy in terms of emission reduction from the reference year value. The estimation of emission is done by either fuel consumption approach or activity data approach. The methodology adopted is either top-down or bottom-down at the city or country level.

2 Approach Toward Estimating GHG Emissions from Transport Sector

2.1 Emission Estimation Methodology

The GHG emission inventory at the country level for road transport sector consist of methodologies suggested by IPCC (1996). Figure 4 shows the top-down approach and bottom-up approach together for GHG emission estimation from the transport sector. The Tier 1 approach calculates CO_2 emissions by multiplying estimated fuel sold with a default CO_2 emission factor.

The Tier 2 approach is similar to Tier 1 approach, except that country-specific carbon contents of the fuel sold in road transport are used. CH_4 and N_2O emissions are significantly affected by the distribution of emission controls in the fleet. The Tier 3 approach requires detailed, country-specific data to generate activity-based emission factors for vehicle subcategories and may involve national models. Several studies are available for India where Tier 3 approach is used for emission estimation.

In Fig. 4, the input values are represented by dashed arrows and output values are represented by solid arrows. The bottom-up approach consists of information related to vehicle numbers, age distribution of vehicles on the road, fuel used in vehicles, technology subdivision in vehicles, vehicle activity data, fuel efficiency, and emission factors for each vehicle type. The activity data consist of per capita trip rate, vehicle population, average trip length, and relative modal share data for developing travel demand. The occupancy factor is the load capacity of each vehicle type and gives the per capita emission. As mentioned earlier, the fleet model is applied to get the age distribution of vehicles on road applying either logistic distribution or Weibull distribution. In the bottom-up approach, fuel consumption is calculated by data of vehicle population (obtained after applying fleet model) of different vehicle types, fuel share in vehicles, average vehicle kilometer traveled, fuel efficiency of vehicles, and fuel density, whereas in the top-down approach directly fuel consumed data at the aggregate level is used. After obtaining the fuel consumption value, it is multiplied by the emission factor to estimate the GHG emissions. The bottom-up approach is robust and estimates emission at the vehicle/mode level running on different fuel type.

The emission factors applied are either default IPCC emission coefficients or developed at a country level for different vehicle types. Emission of each greenhouse gas is calculated by multiplying fuel consumption (obtained either by bottom-up or top-down approaches) to their respective emission factor. The final outcome varies in the studies depending on the values of input factors and assumptions.

2.2 Emission Estimation Studies Done for Indian Transport Sector

Several studies have been done on India to estimate CO_2 emission from the road transport sector. The study done by Baidya and Borken-Kleefeld (2009) has grouped the studies on the basis of emission estimation method. These methods are as follows:

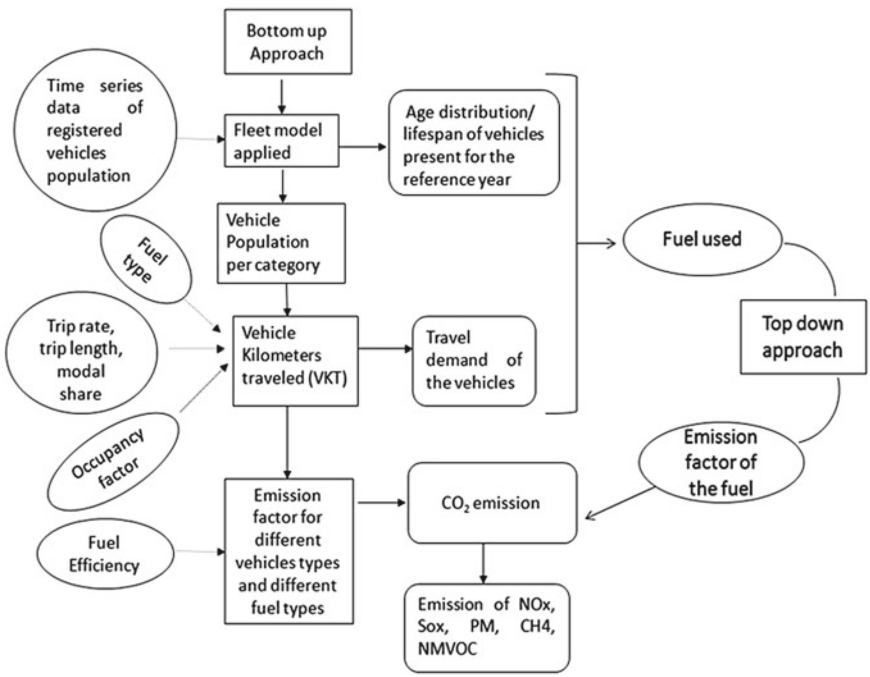

Fig. 4 Bottom-up and top-down approaches for emission estimation

(a) Fuel consumption and total road,
(b) Fuel consumption and vehicle category,
(c) Vehicle kilometer and vehicle category, and
(d) Vehicle kilometer and vehicle subcategory.

In the current study, this is further updated and studies showing emission estimation till the year 2013 are included based on the similar division of groups given by Baidya and Borken-Kleefeld (2009). Table 1 demonstrates the CO_2 emission for the different years from different studies. The studies are listed chronologically where emissions from the year 2013 are listed first and emissions from the year 1980 are listed at the end.

Uncertainty in the final output is dependent on the values of the input parameters, assumptions, type of methodological approaches such as bottom-up or top-down, and emission factors. With the increase in a number of input variables, the uncertainty in the final output increases. Attempts have been made to decrease the uncertainties in the emission estimation by addressing issues such as vehicle activity data like total kilometers traveled and model share and fuel share in different categories of vehicles. The uncertainty in CO_2 emission also results due to variation in emission factors applied in different studies for different vehicle types.

Figure 5 shows the uncertainty in final CO_2 emissions from different studies over different years at 95% confidence interval. For the same year, the difference in input variables results in different CO_2 emission. Uncertainty in CO_2 emission measured from the literature for the year 1990 was 62.36 ($\pm$8) Tg; for the year 1994, it was 73.56 ($\pm$12) Tg; for the year 1995, it was calculated to be 88.85 ($\pm$24); for the year 2000, it came out to be 127.74 ($\pm$49) Tg; and for the year 2005, it was 144 ($\pm$24) Tg. Uncertainty in the final output (CO_2 emission) was high initially, but it has reduced in recent studies due to refinement in the input parameters, emission factors, and associated methodology.

3 Policy Implications in the Indian Transport Sector

3.1 Policies in Transport Sector of India

Effective policy implementation is very important for removing the discrepancies between supply and demand for the transport sector. Policies are the strategies which can be applied to reduce emissions and energy consumption at national or local level. Reducing CO_2 emissions will require some strict actions from the government side. These actions include auto-fuel policy where the objective is to improve the quality of fuel standard and apply strict emission norms for emission reduction by implementing Bharat Stages I, II, III, IV, V, and VI into the motor vehicles. Path of implementation of auto-fuel emission norms for future years has been stated by the Government of India with improvement in vehicle technology. As per India's Intended Nationally Determined Contribution (INDC), it was suggested to increase

Table 1 Studies on Indian transport sector

Study	Tg of CO_2	Year	Group
Singh et al. (2017) (I)	469.07	2013	c
Sadavarte and Venkataraman (2014)	162.00	2010	d
Ramachandra and Shwetmala (2009)	258.10	2003–2004	c
Sadavarte and Venkataraman (2014)	103.00	2005	d
ADB (2006)	220.00	2005	d
Baidya and Borken-Kleefeld (2009) Max	146.85	2005	d
Baidya and Borken-Kleefeld (2009) Ref.	146.33	2005	d
Garg et al. (2006)	143.00	2005	a
Fulton and Eads (2004)	135.38	2005	c
Baidya and Borken-Kleefeld (2009) Min	133.87	2005	d
Baidya and Borkeen-Kleefeld (2009) with CPCB (2000)	133.87	2005	d
IIASA (2008)	133.76	2005	a
Singh et al. (2017)	71.67	2001	c
Sadavarte and Venkataraman (2014)	222.00	2000	d
Van Aardenne et al. (2005)	119.81	2000	a
Garg et al. (2006)	116.00	2000	a
Singh et al (2008) (II)	105.00	2000	a
IIASA (2008)	102.55	2000	a
Borken et al. (2007)	99.59	2000	c
Ohara et al. (2007)	86.37	2000	a
Mittal and Sharma (2003)	42.93	1997	c
Sadavarte and Venkataraman (2014)	82.00	1996	d
Olivier et al. (2002)	98.74	1995	a
Garg et al. (2006)	89.00	1995	a
IIASA (2008)	78.82	1995	a
Ramanathan and Parikh (1999)	79.00	1994	c
MiEF (2004)	71.89	1994	a
Bhattacharya and Mitra (1998)	69.80	1994	b
Garg et al. (2006)	70.00	1990	a
IIASA (2008)	61.67	1990	a
Olivier et al. (2002)	60.46	1990	a
Bhattacharya and Mitra (1998)	57.30	1990	b
Singh et al. (2008) (II)	27.00	1980	a

Singh et al (2017) (I)—(Singh et al 2017); Singh et al (2008) (II)—(Singh et al 2008); Max is the maximum CO_2 emission; Min is the minimum CO_2 emission; Ref. is the CO_2 emission for the reference year; Baidya and Borken-Kleefeld (2009) with CPCB (2000) is CO_2 emission obtained from CPCB emission factors

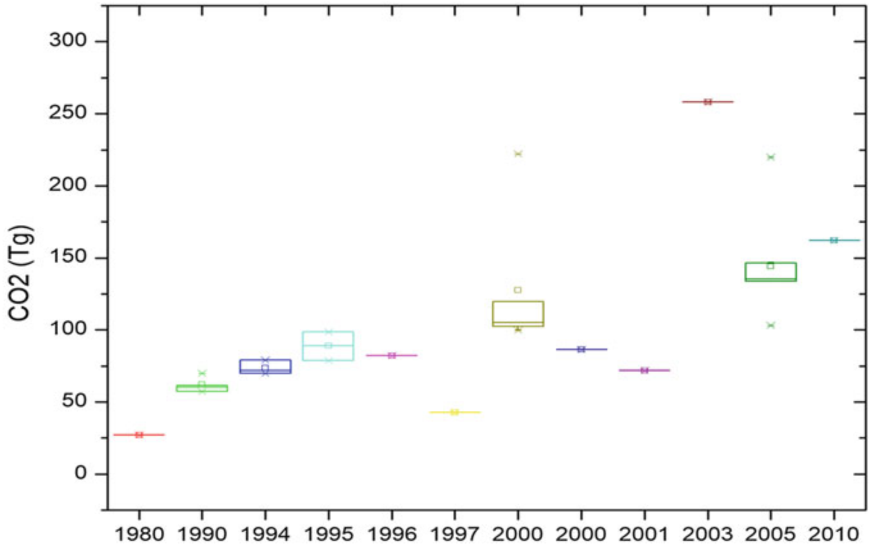

Fig. 5 Uncertainty in CO_2 emissions over the years in the literature

the share of railways (public transport) from 36 to 45% to restrict the emissions. Around 20% blending of biofuels for bioethanol and biodiesel (alternate fuels) by 2017 was suggested by the National Policy on Biofuels. Promotion of electric vehicles (alternate technology) for its diffusion in Indian market is done by providing incentives under Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) in India. The program includes the development of high-performance electric or hybrid vehicles for Indian scenario, decreasing the capital cost for its purchase, developing charging infrastructure, and creating programs for its promotion and awareness in the consumers (Dhar et al. 2017). Studies also suggest improvement in fuel efficiency for cars and two-wheelers, which will sufficiently reduce the tailpipe emissions from the motor vehicles.

3.2 Summary of the Study

The trend analysis of CO_2 emission from Indian transport sector shows exponential growth. The growth rate was 2.7% during the period 1970–1980; it decreased to 2% during the period 1980–1990 and increased to 4% during 1990–2000, which further increased to 6.9% during 2000–2012. This increase is due to increase in motor vehicles on road running on petrol and diesel and also increase in distance traveled by these vehicles. CO_2 is the major GHG emission from the transport sector, whereas the contribution of CH_4 and N_2O is negligible (Singh et al. 2008).

Registered motor vehicles in India have increased during the period 2001–2012. The annual growth rates for two-wheelers, four-wheelers, buses, and goods vehicles were 10.5, 10.2, 6.7, and 9.1%, respectively. The annual growth rate of road passenger and freight traffic demand for the same time period (2001–2011) was 11 and 8%, respectively. Similarly, for rail transport, passenger and freight demand were 8 and 7%, respectively, for the duration 2001–2011. Top-down or bottom-up approaches applied for emission estimation at a national level or local level depend on the availability of the data. Uncertainty in CO_2 emission depends on uncertainty in input variables, the methodological approach applied, and the emission factors used. Uncertainty in the final output (CO_2 emission) was high initially, but it has reduced in recent studies due to refinement in the input parameters, emission factors, and associated methodology.

The gap which can be addressed from the study is the discrepancy in the data for the input variables and emission factors which results in uncertainty in GHG (CO_2) emissions from several studies for the same year. The gap in policy implementation is addressed by acknowledging the lack of awareness in people with respect to incentives and benefits of electric vehicles for the environment and lack of infrastructure which is required for the speedy diffusion of alternate fuels and technologies.

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