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Assessment of emissions from transport sector in Delhi

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This study presents emissions of different pollutants from transport sector in Delhi. Results show that emissions of pollutants have increased during 2001-2009 as follows: CO_2, 4395-6423; CH_4, 1.03-3.32; N_2O, 0.04-0.05; CO, 238-329; NO_x, 44-64; and NMVOC, 44-60 Gg. However, CO_2 emissions per unit of vehicle types for gasoline driven vehicles show a decrease as follows: two wheelers, 2.7; and cars, 4.3%; while in case of diesel driven vehicles, this reduction is 1.6%, indicating impact of better vehicle technologies introduced. However, CO_2 emissions from per unit of CNG vehicles have been found to increase by 2.4% during this period due to increased consumption of CNG per unit of CNG vehicles.

Keywords: Activity data, Emission factor, Emission inventory, Greenhouse gases (GHGs), Transport sector

Introduction

Increasing industrialization, urbanization and transportation are the main causes of emissions of Greenhouse gases (GHGs) and other air pollutants that are responsible for deteriorated air quality and climate change. Major pollutants emitted from transport sector are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), carbon monoxide (CO), oxides of nitrogen (NO_x), sulphur dioxide (SO_2), particulate matter (PM) and non methane volatile organic compounds (NMVOC). Transport sector has become one of the major anthropogenic contributors of these air pollutants into atmosphere[1]. These pollutants have significant adverse human health effects in Asia[2]. However, most of the human health impact assessments are based on the levels of PM_{10} in the atmosphere in urban areas[3].

In India, Delhi is one of the most affluent urban centers[4] (area, 1483 km^2; population, 16.75 million) and ranked second among the most densely populated metropolitan cities[5] after Mumbai (population density, 9340 persons/ km^2). Rapid urbanization and economic growth have resulted in increased consumption of fossil fuels and other natural resources, which are responsible for increased emissions of GHGs and other pollutants. In Delhi[6], vehicles have been estimated to contribute maximum (67%) to the total pollution load, followed by power plants (13%), industries (12%) and domestic sector (8%). Delhi itself accounts for about 8% of the total registered vehicles in India and has more registered vehicles than those registered in other three metros (Mumbai, Kolkata and Chennai) taken together[7]. In Delhi, registered motor vehicles[8], which were 3551690 units in 2001, have increased to 6451883 units in 2009, registering a growth rate of 81% (Fig. 1). Because of increased number of vehicles and consequent increased consumption of fuels in road transport sector in Delhi, emission of GHGs and other pollutants have also increased significantly[9] from 1990-91 to 1999 as follows: CO_2 from gasoline driven vehicles, 766-1187; and CO_2 from diesel driven vehicles, 577-9779 Gg. In another study[10], CO_2 emissions from transport sector has increased from 27% to 39% during 1999-2000 and NO_x, CO and NMVOC emission contributed over 80% in total emissions from transport sector as compared to thermal power plant. For per unit area emissions of CO_2, CO, CH_4, HC, NO_x, PM and SO_2, Delhi has been estimated at fourth place among five major metropolitan cities of India (Chennai, Bangalore, Kolkata, Delhi and Hyderabad)[11]. From a number of policy measures implemented in transport sector for improving Delhi's air quality, reduction in sulfur content of diesel and petrol (gasoline) have helped to reduce SO_2 emissions in Delhi[12], and implementation of Euro-1 in 2000 has showed

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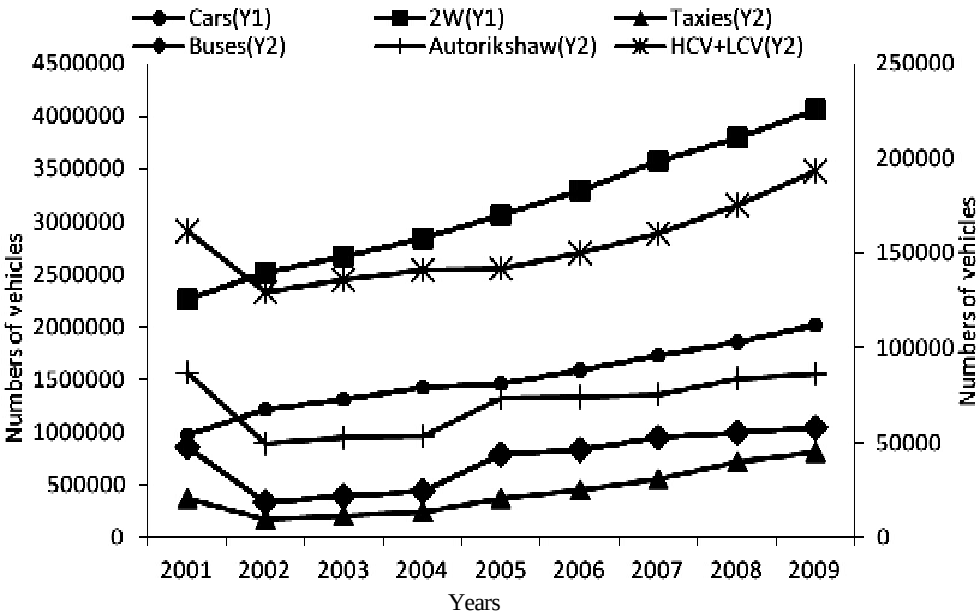

Fig. 1—Number of registered vehicles in Delhi during 2001-2009

Table 1—Diesel and gasoline consumption in different categories of vehicles during 2001-2009

Years	Diesel consumption, kt			Gasoline consumption, kt		
	Total consumption	HCV/MCV	LCV	Total consumption	2 Wheelers	Cars
2001	764.2	534.9	229.2	569.5	341.7	227.8
2002	726.2	508.3	217.8	595.5	357.3	238.2
2003	773.1	541.2	231.9	610	366	244
2004	834.7	584.3	250.9	632.2	379.3	252.9
2005	823.0	576.1	246.9	666.7	400.0	266.7
2006	899.6	629.7	269.9	696.2	417.7	278.5
2007	963.9	674.7	289.1	737.5	442.5	295
2008	884.9	619.4	265.5	758.7	455.2	303.5
2009	787.5	551	236.2	795.7	477.4	318.3

the reduction in total emissions of CO, HC, NO_x and VOCs for all the classes of vehicle[9]. Similarly, after implementation of compressed natural gas (CNG), decreasing trend was found in polycyclic aromatic hydrocarbons (PAHs), SO_2 and CO in ambient air, while NO_x level increased in comparison to that of pre CNG implementation period[13,14].

This study presents emission inventories of different pollutants from transport sector in Delhi, besides assessment of CO_2 emission efficiencies of different vehicle types in Delhi during 2001-2009.

Experimental Section

Inventories for emissions of pollutants from transport sector can be computed on the basis of types of vehicles and quantities of fuel consumed. Diesel is primarily used in public passenger and cargo vehicles, while two wheelers and cars mainly use gasoline. In Delhi, most of the buses, omnibuses and taxies use CNG since 2001. An emission inventory for different pollutants emitted from transport sector has been prepared using IPCC 2006 guidelines[15] as $E_i = AD_i * EF_i$, where E_i is emissions of pollutant i, AD_i is activity data of pollutant i and EF_i is emission factor of pollutant i. Activity data (fuel consumption and number of vehicles) for Delhi's transport sector during 2001-2009 have been taken from Delhi Government website (www.delhigovt.nic.in) and Delhi Statistical Handbook[8] (Table 1). Default emission factors provided by IPCC[16] were used for estimation of emissions (Table 2).

Table 2—Carbon emission factor (CEF) and emission factors of other pollutants for different fuel types

Fuel	CEF	CH_4	N_2O	CO	NOx	NMVOC
	tC/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ	kg/TJ
Diesel	20.2	5	0.6	1000	800	200
Gasoline	18.9	20	0.6	8000	600	1500
CNG	15.3	92	0.1	400	600	5

For estimation of emissions from transport sector, there are two basic approaches (top-down & bottom-up) provided by IPCC guidelines. In top-down approach, total consumption of gasoline and diesel in transport sector is used, while in bottom-up approach, emissions are estimated using the fuel consumed in different kinds of vehicles. In this study, top-down approach of IPCC methodology has been used to estimate emissions from transport sector in Delhi. Using a reported[17] approach to apportion fuel consumption, it is assumed that 70% of the total diesel sold has been consumed in road transport sector, out of which, 70% are consumed by medium and heavy-duty commercial vehicles (MCV/HCV) and the rest 30% by light duty commercial vehicles (LCV). Similarly, for gasoline, it is assumed that out of the total gasoline consumption, 60% is consumed by two wheelers (2W) and 40% by car/taxies[17].

Results

Vehicular Emissions in Delhi during 2001-2009

GHGs

From different vehicles, CO_2 (Fig. 2a), CH_4 (Fig. 2b) and N_2O (Fig. 2c) emissions, respectively, have increased as follows: 2W, 1050-1467, 0.306-0.428, 0.009-0.013; cars, 700-978, 0.204-0.285, 0.006-0.009; HCV, 1699-1751, 0.116-0.119, 0.013-0.014; and LCV, 728-750, 0.050-0.051, 0.005-0.006 Gg.

CO, NO_x and NMVOC

From different vehicles, CO (Fig. 2d), NOx (Fig. 2e) and NMVOC (Fig. 2f) emissions, respectively, have increased as follows: 2W, 122-171, 9-12, 22.9-32.0; cars, 81-114, 6.1-8.6, 15.3-21.4; HCV, 23-24, 18.5-19.1,4.6-4.8; and LCV, 9.9-10.0, 7.9-8.2, 1.9-2.0 Gg.

Emissions from Consumption of CNG

After introduction of CNG in Delhi's transport sector as replacement of diesel in public road transport, the fleet of CNG vehicles in Delhi has increased from 26350 units in 2001 to 344868 units in 2009, while CNG consumption has increased from 77.47 kt in 2001 to 526.98 kt in 2009. Emissions from CNG consumption during 2001-2009 have increased as follows (Fig. 3): CO_2, 216.85-1475.09; CH_4, 0.359-2.44; N_2O, 0.0004-0.0023; CO, 1.56-10.62; NO_x, 2.34-15.94; and NMVOC, 0.019-0.133 Gg.

Discussion

Emissions of CO_2 increased by 46% during 2001-2009, while an earlier study[9] showed a growth of 65% during 1990-91 to 1999-2000. During 2001-2009 from the transport sector in Delhi, increase in emissions of other pollutants was found to be: CH_4, 221; N_2O, 25; CO, 38; NO_x 46; and NMVOC, 34%. Emissions of pollutants (CO_2, NO_x and N_2O) are higher from diesel driven vehicles as compared to gasoline driven vehicles. On the other hand, emissions of pollutants (CO, CH_4 and NMVOC) are higher from gasoline driven vehicles compared to diesel driven vehicles. Pollutants' emissions from diesel driven vehicles (LCV & HCV) showed decreasing trend post 2007 period. Emissions from gasoline vehicles showed increasing trend due to increased consumption. It indicates the preference for personalize mode of the transport over public transport. The increasing consumption of CNG shows preference for cleaner fuel in transport sector, which however, is also responsible for estimated increase in CH_4 emission (221%) during 2001-2009.

Looking into trends of emissions per unit vehicle types for different vehicles deduced for 2001-2009 (Fig. 4), CO_2 emissions showed negative compound annual growth rate (CAGR) from cars (4.32%), 2W (2.71%), and diesel vehicles (1.63%), while CNG vehicles showed a positive CAGR (2.43%). Thus introduction of better technologies in diesel and gasoline driven vehicles curtailed pollutants emissions per unit vehicles, which would, otherwise, have been quite high due to increasing vehicle population and fuel consumption. Increase in emissions in CNG vehicles is probably because CNG consumption has increased in greater proportion compared to the increase in number of CNG driven vehicles.

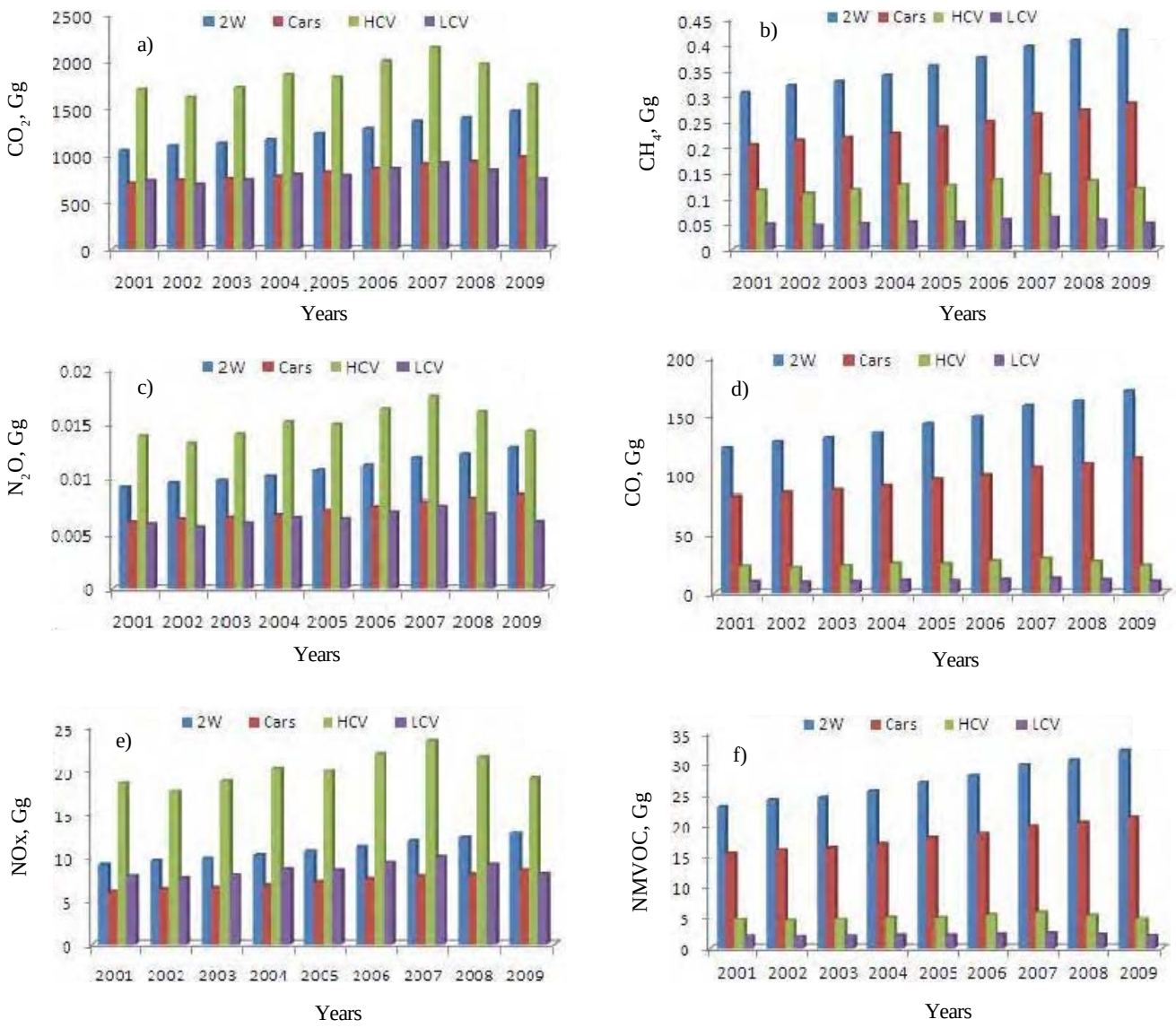

Fig. 2—Pollutants' emissions from different vehicles categories: a) CO_2; b) CH_4; c) N_2O; d) CO; e) NOx; and f) NMVOC

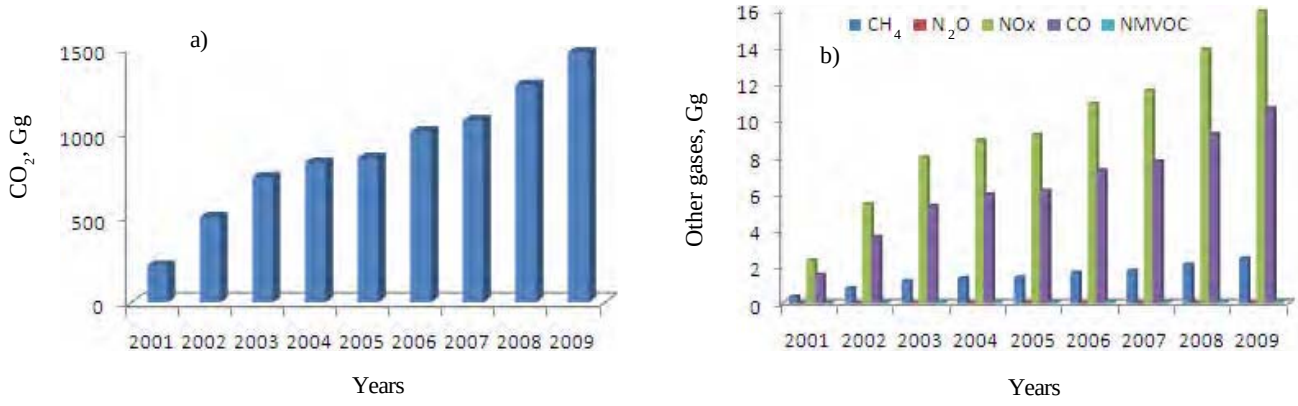

Fig. 3—Pollutants' emissions from CNG consumption: a) CO_2; and b) CH_4, N_2O, NOx, CO & NMVOC

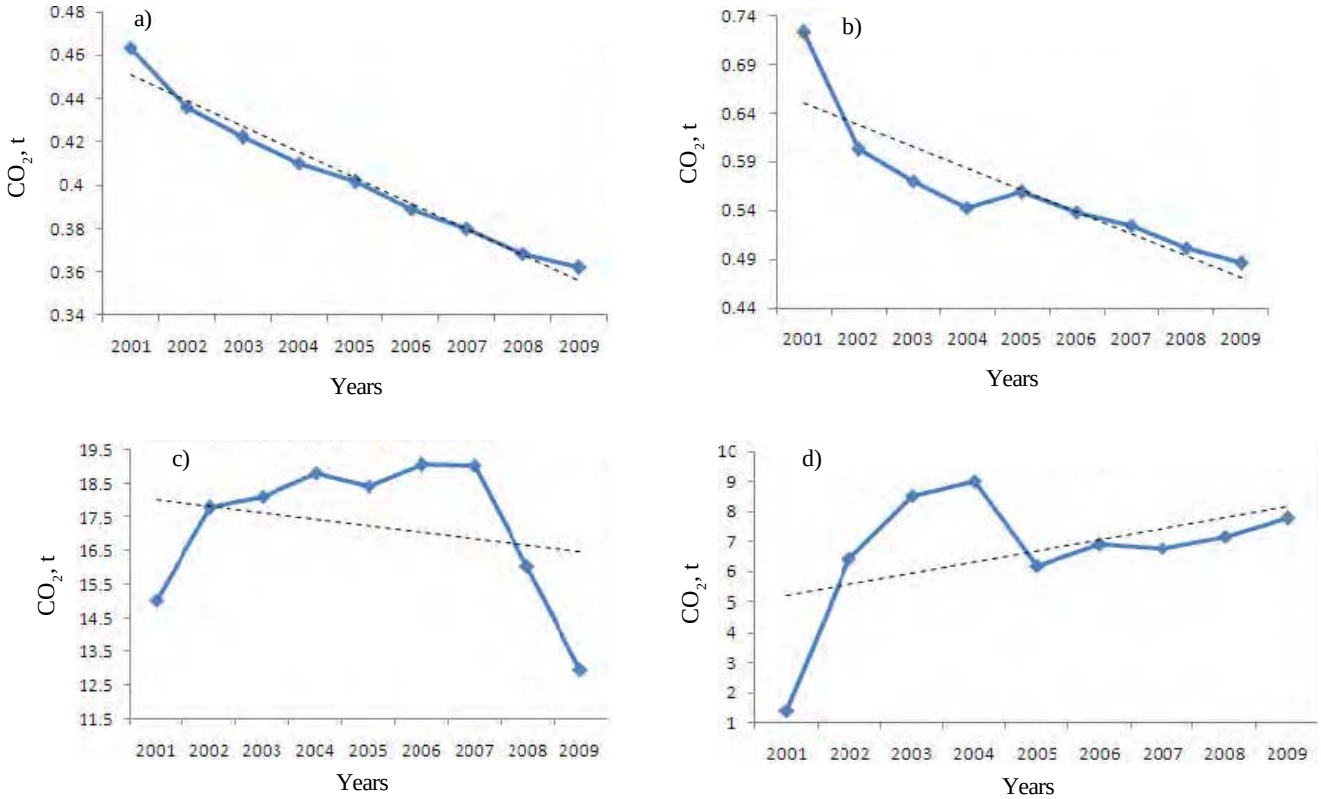

Fig. 4—CO_2 emission efficiencies of different vehicles categories: a) 2 Wheelers; b) Cars; c) Diesel vehicles; and d) CNG vehicles

Conclusions

The number of vehicles in Delhi has registered a growth of 81% during 2001-2009, resulting in increased emissions of GHGs and other pollutants from transport sector. Diesel driven vehicles contributed more in emissions of CO_2, NO_x and N_2O as compared to gasoline driven vehicles in Delhi till 2007 but after that, emissions from diesel driven vehicles showed reducing trend in 2008 and 2009, because of decreased consumption of diesel in Delhi. Improvements in vehicle technologies seem to be effective in curtailing emissions of pollutants as evident from the reduction in emissions of CO_2 per unit of vehicles for almost all categories of vehicles. However, increasing vehicle population is offsetting this reduction, resulting in the increase in net emissions. CNG vehicles showed increasing trend in per unit CO_2 emissions due to increased CNG consumption.

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