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REVIEW ARTICLE

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REVIEW OF METHODOLOGIES FOR THE ESTIMATION OF CO_2 EMISSION FROM TRANSPORT SECTOR

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ABSTRACT

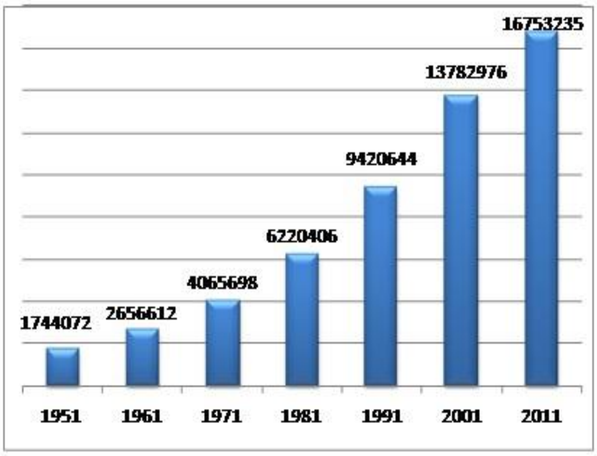
Carbon footprint has become a broadly used term. CO_2 emissions results in the global warming and subsequently climate change. It is one of the most significant of the six greenhouse gases (carbon dioxide, methane, nitrous oxide, hydro fluorocarbons, per fluorocarbons and sulphur hexafluoride). Transportation sector is one of the sources of GHG emissions. All means of transportation, apart from walking and cycling, which are negligible, cause emissions. In 2007, the transport sector emitted 142.04 million tons of CO_2 eq. Road transport, being the dominant mode of transport in the country, emitted 87% of the total CO_2 equivalent emissions from the transport sector. The main objective of this research is to provide the review of carbon emissions from transport sector in India and review of methods available for its estimation.
Keywords: CO_2, emissions, methods.

INTRODUCTION

In recent years there has been a rapid increase in the population of Delhi due to urbanization. According to the Census of India in 2011, population of Delhi has grown from 2.6 million in 1961 to 16.7 million in 2011.The total population growth in this decade was 20.96 percent while in previous decade it was 46.31 percent [6]. The population of Delhi forms 1.38 percent of India in the year 2011. The growth of population in Delhi is shown in Fig 1. Due to ill planned escalation of urban centers large numbers of problems have occurred like traffic congestion, scarcity of water and electricity, declining environment and public health. The developing city has generated the high level of transport demand over the years. Total number of road vehicles in India as per the latest available statistics were 72.7 million whereas vehicular population in Delhi has increased from 0.01 million in 1951 to 3.5 million in 2001 and 7.4 million in 2012 [6]. The increase in registered motor vehicles in Delhi is shown in Fig 2. Among different types of motor vehicles, percentage of two wheelers has shown rapid growth (doubling in every 5 years) and it constitutes 70% of total motor vehicles of India [14].

The registered two wheelers constitute nearly seventy percent of the vehicle population in almost all the cities. Due to higher income levels and greater needs for mobility in the urban areas, more automobiles are owned and operated in them. More than 90 percent of the automobiles are located in urban centres. This trend is observed to be changing in the recent past mainly due to the development of better quality road network connecting rural areas and richer communities of rural areas going in for the automobiles.

Variety of road based transport modes catering to the transport demand ply in large numbers on the road system resulting in traffic and transportation problems in the form of increased traffic congestion, increased air and noise pollution, accidents, delays and subsequently results in emission of green house gases [15]. The six greenhouse gases are CO_2 (carbon dioxide), CH_4 (methane), N_2O (nitrous oxide), HFC's (hydrofluorocarbons), PFC's (perfluorocarbons) and SF_6 (sulphur hexafluoride). Of these, CO_2 is estimated to account for two third of global warming (DETR, 2000). It is present in the atmosphere in significant quantities, representing 99.4% of the six greenhouse gases, by tonnage CO_2 emissions are the most significant of the greenhouse gases. Emission is on the increase due to enhanced trip lengths, shift of modal share towards personalized modes of travel and at signalized intersections (during the stoppage of vehicles during red signal phase). In this study an attempt has been made to provide the review of methods used for measuring emissions.



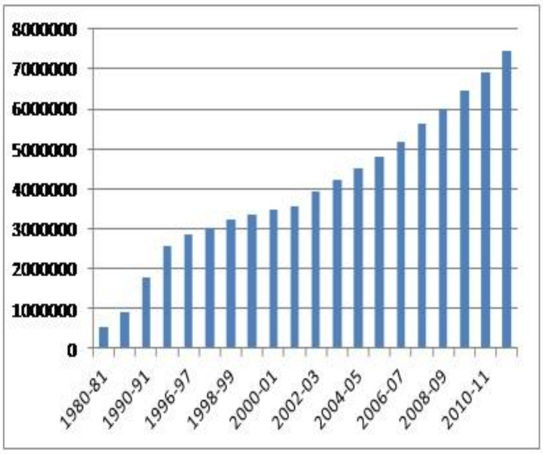


Fig. 1: Growth of Population in Delhi   Fig. 2: Increase in Number of Registered Motor Vehicles in Delhi

CARBON FOOTPRINT OF ROAD TRANSPORT

Between 1994 and 2005, India's greenhouse gas emissions are estimated to have risen approximately by 50 percent [13], ranking fourth globally in overall terms (behind the US, China, and the EU) and contributing around 5.5 per cent of global emissions. The largest, bulk of India's emissions comes from the energy sector. In 1994, energy accounted for about 61 percent of total CO_2 eq. emissions, of which, almost half came from electricity supply, 20 per cent from industrial fuel combustion and around 11 per cent from transport. Road transport accounted for nearly 90 per cent of transport emissions (the remaining 10 percent coming from rail, aviation and shipping). WRI estimates suggest that the overall contribution of the energy sector is rising [21]. Of the other sectors, agriculture accounted for 28 per cent of total emissions in 1994 and around 22 percent in 2005, industrial process emissions contributed around 6-8 percent, waste disposal accounted for 2 per cent (rising to nearly 7 percent in 2005), and land use and land use change accounted for 1 per cent (net carbon storage in 2000). Fig. 3 shows a sectoral breakdown of emissions in 1994.

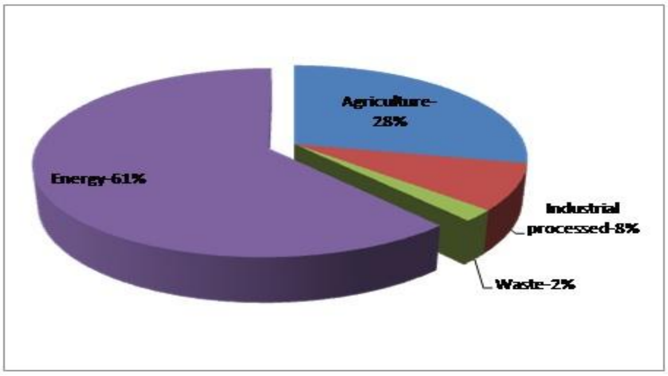


Fig. 3: Emissions by Various Sectors, 1994 (based on data from MoEF, 2004)

The emission intensity of India's economy in 2006, estimated at 0.34 kg CO_2 per US$ GDP (at 'Purchasing Power Parity', 2000 prices), was roughly equal to the emission intensity for EU-27 (0.33 kg CO_2) and below the world average (0.49 kg CO_2) [7].The Indian Network for Climate Change Assessment [8] reports that the net Greenhouse Gas (GHG) emissions from India, that is emissions with LULUCF, in 2007 were 1727.71million tonnes of CO_2 equivalent (eq.) of which CO_2 emissions were 1221.76 million tonnes;

- CH_4 emissions were 20.56 million tonnes; and
- N_2O emissions were 0.24 million tonnes[8]

GHG emissions from energy, industry, agriculture, and waste sectors constituted 58%, 22%, 17% and 3% of the net CO_2 eq. emissions respectively.

- Energy sector emitted 1100.06 million tonnes of CO_2 eq., of which 719.31 million tonnes of CO_2 eq. were emitted from electricity generation and 142.04 million tonnes of CO_2 eq. from the transport sector.
- Industry sector emitted 412.55 million tonnes of CO_2 eq.[8]

India's per capita CO_2 eq. Emissions including LULUCF were 1.5 tonnes/capita in 2007 represents the sector wise GHG emissions for the year 2007 in India. The energy sector emitted 1100.06 million tonnes of CO_2 eq. due to fossil fuel combustion in electricity generation, transport, commercial/institutional establishments, agriculture/fisheries, and energy intensive industries such as petroleum refining and manufacturing of solid fuels, including biomass use in residential sector. Fugitive emissions from mining and extraction of coal, oil and natural gas are also accounted for in the energy sector [8].

The transport sector emissions are reported from road transport, aviation, railways and navigation. In 2007, the transport sector emitted 142.04 million tonnes of CO_2 eq. Road transport, being the dominant mode of transport in the country, emitted 87% of the total CO_2 equivalent emissions from the transport sector. The aviation sector in comparison only emitted 7% of the total CO_2 eq. Emissions. The rest were emitted by railways (5%) and navigation (1%) sectors. The bunker emissions from aviation and navigation have also been estimated but are not counted in the national totals. [8]

NEED AND IMPORTANCE OF THE WORK

Vehicular emissions account for about 60% of the GHG's from various activities in India [16]. India was the third largest emitter of carbon dioxide in 2009 at 1.65 Gt per year, after China (6.9 Gt per year) and the United States (5.2 Gt per year). About 65 percent of India's carbon dioxide emissions in 2009 was from heating, domestic uses and power sector. About 9 percent of India's emissions were from transportation (cars, trains, two wheelers, airplanes, others). With 17 percent of world population, India contributed some 5 percent of human-sourced carbon dioxide emission; compared to China's 24 percent share. On per capita basis, India emitted about 1.4 tonnes of carbon dioxide per person, in comparison to the United States' 17 tonnes per person, and a world average of 5.3 tonnes per person. [5]

Energy consumption also varies with the modes of transport and public transport system has least average energy consumption per passenger kilometre [17]. The urban population of India, which constitutes 28% of the total, is predominantly dependent on road transport. Around 80% of passenger and 60% of freight movement depend on road transport [12]. Traffic composition of six mega cities of India (Delhi, Mumbai, Bangalore, Hyderabad, Chennai and Kolkata) shows that there is significant shift from the share of slow moving vehicles to fast moving vehicles and public transport to private transport [9].

Transportation sector is one of the biggest sources of carbon footprint. Idling of vehicles at signalized intersections results in emission of green house gases (carbon footprint). Thus because of increasing concern about global climate change and health of people, it becomes necessary to estimate "carbon footprint" at signalized intersections. Estimation would help people understand that, because of idling, huge amount of gases are emitted into the atmosphere and they would be able to adopt mitigation measures.

REVIEW OF PROCEDURES FOR MEASURING CARBON FOOTPRINT

A literature review was performed in respect of commonly used traffic models and methods for measuring CO_2 emission. CMEM (COMPREHENSIVE MODAL EMISSION MODEL) is a microscopic emissions model that has been developed at the University of California, Riverside. It is capable of predicting second-by-second fuel consumption and tailpipe emissions of carbon dioxide (CO_2), carbon monoxide (CO), hydrocarbons (HC), and nitrogen oxides (NO_x) based on different modal operations from an in use vehicle fleet. CMEM is based on the power requirement and related fuel consumption, tailpipe emissions of CO_2, CO, HC, and NO_x [10].

The GREET (Greenhouse gases, Regulated Emissions and Energy in Transportation) model has become the standard for use in performing life cycle analyses of transportation fuels. GREET is a publicly available spreadsheet model developed at the Argonne National Laboratory (ANL) that can be downloaded and run from a user's computer. The model is a spreadsheet workbook with several macros that can be used directly or manipulated with a graphical user interface (GUI) packaged with the model download, although the GUI is considered unhelpful by many because it obscures access to the inputs and facilitates input to only a limited set of key assumptions GREET models emissions of the three traditional greenhouse gases (CO_2, CH_4 and N_2O) and the criteria pollutants. Global warming potential values are used to aggregate the three GHG species emissions into a single carbon dioxide equivalent result. Volatile organic compounds (VOC) and carbon monoxide (CO) are counted in their fully oxidized forms as CO_2. (http://www.lifecycleassociates.com/lca-tools/greet-model/)

The model PHEM (Passenger car and Heavy duty Emission model) is capable of calculating fuel consumption and emissions for any vehicles and driving cycles with a high accuracy using engine emission maps and transient correction functions. The model interpolates the fuel consumption and the emissions from steady state engine emission maps for every second of given driving cycles. For interpolating the emissions from the engine map, the actual power demand from the engine and the engine speed are simulated according to the vehicle data given as model input. The simulation of the actual power demand of the engine is based on the driving resistances and the transmission losses. The engine speed is calculated using the transmission ratios and a gear-shift model. The different emission over transient cycles is taken into consideration by "transient correction functions" which adjust the second-by-second emission values according to parameters describing the dynamics of the driving cycle. The results of the model are the engine power, the engine speed, the fuel consumption, and emissions of CO, CO_2, HC, NO_x and particles every second, as well as average values for the entire driving cycle.

VRPTW (Vehicle Routing Problem Delivery Time Windows) software was originally developed with the premise of creating vehicle routes, which minimize the distance travelled. It uses a range of heuristic methods to create the routes, starting with a construction heuristic based on a variation of the Clarke and Wright Savings algorithm [11]. Improvements to this initial construction are attempted using the cross exchange heuristic developed by Taillard (1997) which tries to improve the solution by swapping individual deliveries between neighboring routes, and the I-opt technique developed by Or (1997), which also tries to improve the solution by swapping consecutive groups of deliveries between neighboring routes, and the number of deliveries in the group is reflected by the value of I. Thus a group of two deliveries would mean 2-opt, a group of 3 deliveries would mean 3-opt, etc. CO_2 can be calculated from this software, and also any of the other VRP variants, by applying an average emission value per kilometre or mile, but these have been shown to be inaccurate [19].

COPERT 4 is a software programme that is based on a methodology to estimate vehicle fleet emissions on a country-level. The methodology tries to balance the need for detailed emission calculations on one hand and use of few input data on the other. Three different modes of emissions are taken into account that is hot emissions, cold-start emissions, and emissions due to gasoline evaporation. The latest COPERT 4 version (7.0) also includes non-exhaust PM emissions (tyre, break). It estimates emissions of all major air pollutants (CO, NO_x, VOC, PM, NH_3, SO_2, heavy metals) produced by different vehicle categories (passenger cars, light commercial vehicles, heavy duty trucks, busses, motorcycles, and mopeds) as well as greenhouse gas emissions (CO_2, N_2O, and CH_4). It also provides speciation for NO/NO_2, elemental carbon and organic matter of PM and non-methane VOCs, including PAHs and POPs.

In general, the formula used for calculating an emission [2, 3, 18, 20] is given by:

CO_2 emission = Activity data (kg / km / litres) × Emission factor (CO_2 per unit).

For both activity data and emission factors, a distinction can be made between primary data and secondary data. Primary data are direct measurements within the life cycle of a specific product. For example, the amount of litres of gasoline used per number of kilometers can be directly measured. Secondary data consists of external, averaged data, which are not specific to the product [3].

In Dynamometer Testing (Federal Test Procedure –FTP) the FTP is used to test vehicles for compliance with emission standards. The current test procedure used in the U.S. is referred to as FTP75. The FTP is conducted on a dynamometer for different driving cycles. The FTP is used to measure concentrations of different pollutants, like HC, CO, NO_x and CO_2. Both the evaporative and exhaust emissions are measured by dynamometer testing under several simulated situations. A brief description of methodologies in measuring emissions is given in Table 1.

Table 1: A brief description of methodologies used in measuring emissions

S No.	Title	Author	Year	Name of journal	Methodology
1	Traffic Energy and Emission Reductions at Signalized Intersections	Li et. al.	2009	International Journal of ITS Research, Vol. 7, No. 1	Comprehensive Modal Emission Model
2	Analyzing on-road emissions of light-duty vehicles with Portable Emission Measurement Systems (PEMS)	Weiss et. al.	2011	EUR 24697 EN – 2011	PHEM (Passenger car and Heavy duty Emission model)
3	The Development of an Integrated Routing and Carbon Dioxide Emissions Model for Goods Vehicles	Andrew Palmer	2007	Thesis submitted at Cranfield University	Computer based vehicle routing model VRPTW
4	Energy Use and Emissions Comparison of Idling Reduction Options for Heavy-Duty	Gaines and Hartman	2008	Paper No. 09-3395	GREET model

	Diesel Trucks				
5	Methodology for calculating transport emissions and energy consumption	Hickman	1999	TRL Report SE/491/98: Deliverable for EU project MEET	COPERT II
6	Flow improvements and vehicle emissions: Effects of trip generation and emission control technology	Robert B	2006	Transportation Research Part D 11 (2006) 1–14	VISSIM integrated with CMEM
7	Uncertainty estimates and guidance for road transport emission calculations	Charis Kouridis,	2009	EMISIA SA Report No: 09.RE.014.V2	COPERT 4.
8	Statistical modeling of vehicle emission from inspection/maintenance testing data : an exploratory analysis	Washburn et. al.	2001	Transport research part D : Transport and Environment 6(1) :pp 21-36	Dynamometer testing

CONCLUSION

It is revealed that the best possible method to calculate CO_2 emission could be to multiply activity data by suitably selected values of emission factors. It should be worthwhile to adopt suitable measures in future for reducing the CO_2 emissions due to idling of vehicles at signalized intersection in Delhi on the basis of the CO_2 estimation using such methodologies. In addition it is also emphasized that transport planning in cities must incorporate strategies towards the reduction of CO_2 emission.

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