FACTORIZING THE CHANGES IN CO₂ EMISSIONS FROM INDIAN ROAD PASSENGER TRANSPORT: A DECOMPOSITION ANALYSIS

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Abstract:

The main aim of this paper is to analyse the role of different factors responsible for CO₂ emission from Indian road passenger transport with the help of Logarithmic Mean Divisia Index over the period of 1971-2011. CO₂ emission increase is decomposed into five major factors - emission coefficient, transport energy intensity, transport activity, economic growth, and population. Findings suggest that economic growth, transport activity and population have a significant positive role in increasing CO₂ emission from road passenger transport, whereas energy intensity plays a negative role in CO₂ emission increase. Emission coefficient has also a negative role in CO₂ emission increase during all the periods except during 1971-81. Therefore, emission coefficient and energy intensity are the two most important factors for policy design and implementation to reduce CO₂ emission from the sector.

Key words: *Decomposition Analysis, Log Mean Divisia Index, Passenger Road Transport, CO₂ Emission, Economic Growth*

1. Introduction

The passenger mobility in India relies heavily on its roads. Road-based passenger mobility, measured as passenger-kilometers (PKm), in India increased from 239.65 billion PKm in 1970-71 to 6351.20 billion PKm in 2011-12, an increase at the rate of 8.3% per year during last four decades. That's why, total number of registered motor vehicles in the country increased from 1.9 million in 1971 to 141.9 million in 2011, an increase at the rate of 11.4% per year during last four decades (MoRTH, 2013). From 1971 to 2011, the share of two wheelers in total registered motor vehicles in India increased from 30.9% to 71.8% whereas share of buses decreased from 5% to 1%. Rapid increase motorized vehicles particularly two wheelers and cars has serious

implications on various issues related to energy and environment. Already, transport sector is the major cause of air pollution in urban areas. It contributes significantly to major environmental challenges both at local as well as global levels. In 2011, transport sector had 14% share in total energy related CO₂ emission in the country, in which road transport had 73% share. The share of road transport in CO₂ emission is increasing over the years due to rapid increase in vehicular population in the country.

Therefore, it is important to identify the underlying factors that causes the increase in CO₂ emission from the sector in order to formulate and implement the emission reduction measures effectively. Understanding the links among the factors such as economic growth, transport activity and CO₂ emissions will give a direction in crafting transport emissions reduction policies. The famous Kaya identity (Kaya and Yokobori, 1997) was developed to see the contribution of GDP and population on CO₂ emissions. It played a crucial role in developing future emissions scenarios in Intergovernmental Panel on Climate Change report (Nakicenovic and Swart, 2000). It is basically an identity which states that total emissions level is the product of four basic forces driving emissions – (1) population, (2) GDP per capita (activity level), (3) energy use per unit of GDP (energy intensity) and (4) carbon emission per unit of energy consumed (fuel mix). Kaya identity is represented as -

$$E = P \times \frac{G}{P} \times \frac{C}{G} \times \frac{E}{C} \quad (1)$$

where E shows CO₂ emission, P is the population, G is the economic output (GDP) and C is total energy consumption. In this way, the identity shows that the total CO₂ or Green House Gases (GHGs) emissions on one side and multiplication of the population, per capita value added, energy consumption per unit value added and emissions per unit energy on the other side (Nakicenovic and Swart, 2000). In this study, the identity is extended in decomposing CO₂ emission from road passenger transport in India.

Kaya identity is further developed as IPAT identity to show the impact of human activity on environment in terms of change in population, affluence (per capita consumption) and technology as human behaviour adaptation has also significant role in reducing CO₂ emission (Chertow, 2000). It states that Environmental (I)mpact can be measured in terms of the (P)opulation, (A)ffluence and (T)echnology.

Quantifying the role of factors in emissions increase over the long run and examining their historical trend, would help to give important insights for policy makers in framing CO₂ emissions reduction strategies and ensure their efficacy. In this paper, decomposition method is used to measure the contribution of major drivers of CO₂ emissions. Decomposition is nothing but a weighted sum of relative changes in different factors. Decomposition analysis was first used in 1970s and since then it has been widely adopted in energy and environment related studies (Ang and Choi, 1997). This paper focuses on time series decomposition and uses Logarithmic Mean Divisia Index (LMDI) to quantify the effects of various factors over different time periods. Therefore, LMDI is used to decompose the changes in CO₂ emissions from Indian road passenger transport over the period of 1971 to 2011 in order to find out the important

factors contributing CO₂ emissions from the sector. Road passenger transport is the main focus of this study because road transport has a major share in total transport emissions and passenger transport is the area where major improvements can be done such as increase in vehicle occupancy ratio, reduction in vehicle ownership, improvement in driving practices, use of green fuels, use of public transport, use of bicycles, etc. The study would help to enhance our understanding of the factors that influence the increase of CO₂ emissions. In the literature, this phenomenon has not been examined much in the context of Indian road passenger transport, we expect that the research findings would have some important implications for policy makers in crafting different policy measures.

Structure of the paper is as follows. Section 2 examines the importance of decomposing the factors responsible for CO₂ emission and reviews the related literature. Section 3 deals with the methodology and model development. Section 4 reports the data structure and trends in road transport CO₂ emission. Section 5 presents the empirical results. Section 6 concludes the paper and discusses policy implications.

2. Role of Different Factors in CO₂ Emission and Decomposition Method in Literature

Boyd et al. (1987) decompose the energy demand for manufacturing sector. They make some comparison between energy intensity decomposition and the formulation of economic indices. It is found in the study that there is a sectoral shift in the sector due to energy demand. Ang (2005) quantifies the change in CO₂ emission from industry with Log Mean Divisia Index. He decomposes the contributions into five different factors which are activity effect of the sector, structure effect defined as industry activity mix, intensity effect, energy mix effect and emission effect. He further suggests that the switch to cleaner fuels in final energy consumption will lead to changes in energy mix. Choi and Ang (2012) further extend Index Decomposition Analysis (IDA) in energy studies by quantifying the contribution of individual attributes to the percentage change in factors such as the real energy intensity index and structural change index.

Lee and Oh (2006) use LMDI approach for cross section decomposition in analysing CO₂ emission increase in case of APEC countries. Further, they evaluate the differences in emission level for three different groups of APEC countries. Findings of the study show that per capita GDP and population are the key factors responsible for CO₂ emission increase in many countries. Implications suggest that energy efficiency and fuel switching are the potential areas for possible cooperation among APEC countries. The study is also an example of cross-section decomposition studies. These studies help to distinguish the relative contribution of different factors which affect energy consumption and related GHG emissions. Many authors examine the

dynamic relationship between carbon emission, energy consumption and economic growth in a single framework for single country (see, for example, Ghosh, 2002; Ang, 2007; Soytaş et al., 2007)

Diakoulaki et al. (2006) decompose the CO₂ emissions during 1990-2002 for Greece. It is done for different sectors such as agriculture, transport, electricity, etc. and then aggregated at country level. They find that economic growth has an important impact on CO₂ emissions. To reduce CO₂ emissions, they emphasize on reducing energy intensity and diverging the fuel mix. Similarly, Hatzigeorgiou et al. (2008) find that the income effect is the biggest contributor to the rise in CO₂ emissions in Greece whereas the energy intensity effect is mainly responsible for the decrease in CO₂ emission. They compare the two results and conclude that energy decomposition analysis is intricate. The relative contributions of different fossil fuels to total energy related CO₂ emission have changed over time. Agnolucci *et al.* (2009) use decomposition analysis in a different context to check the pattern in energy consumption in different scenarios for reduction in carbon emission. Fan and Lei (2016) analyze energy related emissions from Beijing's transport system. With the help of Multivariate Generalized Fisher Index, they find economic growth, energy intensity and population size are the positive drivers in emissions whereas transportation intensity and energy structure are found as the negative drivers.

Lakshmanan and Han (1997) have done the decomposition analysis for transportation sector for USA for the period 1970 to 1991. They find that people's propensity to travel, population, and economic growth are the three main factors in the US transportation energy use and CO₂ emissions. Han and Chatterjee (1997) estimate the effect of GDP growth, industrial structure, fuel mix and energy efficiency on CO₂ emissions of developing countries. GDP growth is found to be the most significant factor in this study.

There are various cross country and country specific studies which include the decomposition of energy consumption in different sectors including transportation. However, there are few studies which focus on decomposing the CO₂ emission from road transport sector (Kwon, 2005; Diakoulaki et al., 2006; Lu et al., 2007; Timilsina and Shrestha, 2009; Papagiannaki and Diakoulaki, 2009). For road transportation, Lu *et al.* (2007) decompose CO₂ emission into emission coefficient, vehicle fuel intensity, vehicle ownership, population intensity, and economic growth for different countries. They also analyse the decoupling effect to see the interrelationship among economic growth, transport energy demand, and CO₂ emission and find that the share of transport sector in aggregate CO₂ emission is increasing. They find that rapid growth of economy and vehicle ownership are the most important factors for the increased CO₂ emission, whereas population contributes significantly to emission decrease. Greene (1992) finds that a reduction in fuel intensity of driving by 10% would lead to an increase in distance driven by 1.3% (at constant fuel price). Therefore, fuel intensity is also among the important factors responsible for CO₂ emission from road transport sector.

Mazzarino (2000) addresses energy consumption and carbon dioxide emissions in the transport sector in Italy over the period of 1980 to 1995. The study shows that GDP growth effect is significant in driving CO₂ emission in Italy. Zachariadis et al. (2001) show the effect of vehicle age and technological innovation on environment. They find a clear deterioration in the emission with the aging of vehicles. It clearly indicates the role of maintenance in order to sustain the fuel efficiency and mileage of the vehicle. Zhang et al. (2009) decompose the energy related CO₂ emission for the period 1991-2006 in China. They use decomposition method, proposed by Sun (1998) and find that CO₂ intensity contributes to CO₂ reduction emission whereas economic activity, measured in terms of GDP, has significant role in CO₂ emission increase from transport. Overall in the economy, they find that energy intensity effect is the most powerful in reducing CO₂ emission. The study of Zhang et al. (2011) is related to the transport sector energy consumption in China. The findings show that energy intensity effect has a dominant role in decreasing energy consumption whereas transport activity effect has significant role in increasing energy consumption. They suggest to improve energy intensity, fuel quality, technology, use of alternative fuels and traffic equipments in order to reduce CO₂ emission. Wang, Zhang, et al. (2011) and Wang, Hayashi, et al. (2011) find that per capita economic activity and modal shift are the key factors responsible for increase in transport sector CO₂ emission whereas energy intensity plays a significant role in decreasing the emission in China.

Decomposition of different factors responsible for CO₂ emission from Indian road transport sector has not received much attention. Timilsina and Shrestha (2009) examine the role of different factors in CO₂ emissions from all modes of transport in case of Asian countries including India. They find that the per capita GDP, population growth, and emission intensity are the important factors in transport sector CO₂ emissions. The study also reviews the role of fiscal instruments and government policies in limiting CO₂ emissions in transport sector. They mention that India and China are the main contributors (almost 80% in the region) in CO₂ emissions in Asia. Ramachandra and Shwetmala (2009) present a state wise analysis of CO₂ emission from road transport sector in India. The analysis shows that six states of the country account for 52% of CO₂ emission from road transport sector. Among the highest contributors are the industrialized states such as Maharashtra (11.8%), Tamil Nadu (10.8%), and Gujarat (9.6%). Nag and Parikh (2000) show that rising per capita income and rapid growth in population lead to more demand and consumption of primary energy sources. At the same time, rapid urbanization and industrialization are responsible for a shift from primary energy to transformed energy sources, mainly electricity and from non-commercial to commercial energy consumption. Therefore, rising per capita income is primarily responsible for CO₂ emission because it leads to high level of car ownership and increased mobility in terms of more number of trips for work and recreation.

For decomposition analyses, a variety of methods and empirical studies have been proposed for different sectors. During earlier period, the focus of these study was

industrial energy demand. Gradually, there have been a shift in research dealing with energy-induced greenhouse gases such as CO₂ emissions in the last decade. Some researchers have also extended the application of decomposition to areas other than energy and environmental domains. As research gap shows there has not much research been done to evaluate the important factors contributing Indian road transport sector CO₂ emissions, this study would help to identify these important factors and guide the future policy actions.

3. Methodology and Model Development

There are different parametric and nonparametric, multiplicative and additive decomposition methods. The four different paradigms to decompose the changes experienced by an indicator are - (a) econometric analysis (b) analysis based on aggregate data (c) index based analysis or index decomposition and (d) structural analysis or structural decomposition). Structural Decomposition and Index Decomposition are two decomposition techniques that have been widely used in energy studies.

Arithmetic Mean Divisia Index, LMDI, Fisher Ideal and Laspeyres Decomposition Index are index based decomposition methods. Among these, LMDI is the most prevalent in recent studies. Ang and Choi (1997) propose LMDI method. Subsequently, Ang et al. (1998) use it in factorizing the changes in energy demand and gas emissions over time. LMDI is an exact decomposition (no residual) method based on Divisia indices with logarithmic mean weights. Ang and Zhang (2000) shows that LMDI is a more effective technique for decomposition because it has an advantage of being a perfect decomposition index with time reversal, subsector additive, theoretically sound and not difficult to understand. Moreover, it is an ideal index number where multiplicative and additive results can be linked easily with simple equations. It can be derived as follows.

Suppose E is the aggregate emission level in an economy which depends on n factors (X₁, X₂ ... X_n), i.e.,

$$E = \sum_{t=1}^n E_t = \sum_t X_{1,t} X_{2,t} X_{3,t} \dots X_{n,t} \quad (2)$$

Aggregate changes in different period can be shown as $E_t^0 = \sum_t X_{1,t}^0 X_{2,t}^0 \dots X_{n,t}^0$ and $E_t^1 = \sum_t X_{1,t}^1 X_{2,t}^1 \dots X_{n,t}^1$ and it can be decomposed in additive and multiplicative form as follows:

$$\Delta E_{tot} = E^1 - E^0 = \Delta E_{x1} + \Delta E_{x2} + \dots + \Delta E_{xn} \quad (3)$$

The multiplicative decomposition shows the relative growth of an indicator between two period

$$D_{tot} = E^1 / E^0 = D_{x1} D_{x2} \dots D_{xn} \quad (4)$$

In above equations, there would be a residual term if decomposition is not perfect.

where E^0 and E^t are the aggregate emission level at initial period and final period, respectively. ΔE and D are the emission level in different periods in additive and multiplicative form, respectively. The 'tot' subscript denotes the total change in CO₂ emission over the period.

Changes in emission level from a sector can be broadly assessed through changes in overall activity effect, activity mix and energy intensity in the sector because these are the major factors which have a direct impact on CO₂ emission. ASIF (Schipper et al., 2000, 2009) approach reveals that energy use in transportation is a function of total activity (A), mode share (S), fuel intensity (I), and fuel type (F). These are the four basic components which drive transport energy consumption and consequently GHG emission. Though other studies (see, table 1) show that CO₂ emission from transport sector can be decomposed into transport activity, travel modes, emission intensity (emission per unit of fuel used), fuel mix, modal structure, energy intensity (fuel used per km traffic performance), the transport volume (passenger km), economic growth, population growth and vehicle ownership.

Table 1. Major factors influencing road transport CO₂ emission in different studies

Author	Region	Year	Major influencing factors
Fan and Lei	Beijing, China	(2016)	Energy intensity, energy structure, output per unit of traffic turnover, transport intensity, economic growth, and population
Wang et al.	China	(2011)	Emission coefficient, transportation services share, modal shifting, intensity, per capita economic activity, and changes in population
Wang et al.	Shanghai, China	(2011)	Economic activity, modal share, passenger transport intensity, CO ₂ emission, and population
Zhang et al.	China	(2011)	Transportation mode, passenger–freight share, energy intensity, and transport activity
Papagiannaki and Diakoulaki	Greece and Denmark	(2009)	Distance effect (average annual mileage), size effect (relative share of cars with different engine capacity), technology effect (relative share of cars with different engine technology), fuel mix, ownership, and population
Timilsina and Shrestha	Asia	(2009)	Fuel mix, modal shift, emission coefficients, energy intensity, GDP, and population,
Kwon	Great Britain	(2005)	Affluence (per capita consumption), carbon intensity, and population
Lu et al.	Taiwan, Germany, Japan and South Korea	(2007)	Emission coefficient, fuel intensity, vehicle ownership, economic growth, and population
Mazzarino	Italy	(2000)	Fuel mix, energy intensity, mode mix, transport intensity, GDP per capita, and population

Lakshmanan and Han	USA	(1997)	People's propensity to travel, mode structure, transport intensity, mode energy intensities, GDP, and population
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After taking into account the important factors, Index Decomposition Identity for the road passenger transport CO₂ emission can be written as:

$$E = \sum_t E_t = \left(\frac{E_t}{FEC_t} \right) \left(\frac{FEC_t}{TA_t} \right) \left(\frac{TA_t}{EG_t} \right) \left(\frac{EG_t}{POP_t} \right) (POP_t) \quad (5)$$

where,

E = the amount of CO₂ emission from road passenger transport

FEC = the fossil fuel energy consumption used in road passenger transport

TA = transport activity (measured in PKm)

EG = Gross Domestic Product (GDP)

Pop = population

The selection of factors is also constrained by the data availability. Therefore, we decompose changes in CO₂ emission from road passenger transport sector (ΔE_t) from 1970 to 2011 into the following effects.

- emission coefficient effect (C)
- the energy intensity effect (I)
- transport activity effect (A)
- economic growth effect (G)
- population effect (P)

Therefore, equation (5) can be re-written

$$E_t = C_t I_t A_t G_t P_t \quad (6)$$

where,

$$C_t = \left(\frac{E_t}{FEC_t} \right), I_t = \left(\frac{FEC_t}{TA_t} \right), A_t = \left(\frac{TA_t}{EG_t} \right), G_t = \left(\frac{EG_t}{POP_t} \right), P_t = (POP_t) \quad (7)$$

This method has been used in the literature (Ang, 2004; Ang and Choi, 1997; Ang and Zhang, 2000) to segregate the sectoral effect or industry level effect. Lee and Oh (2006) and Vinuya *et al.* (2010) use it at economy level. The additive form of above equation can be expressed as:

$$\Delta E_t = [E_t(T) - E_t(0)] = C_{eff} + I_{eff} + A_{eff} + G_{eff} + P_{eff} \quad (8)$$

The above mentioned effects can be calculated by using the following formula of LMDI.

$$C_{eff} = [E_t(T) - E_t(0)] \times \left\{ \frac{\ln[C_t(T)/C_t(0)]}{\ln[E_t(T)/E_t(0)]} \right\} \quad (9)$$

$[E_t(T) - E_t(0)] / [\ln[E_t(T)/E_t(0)]]$ is a log mean of CO₂ emission in the initial year (0) and final year (T). Similarly, other effects ($C_{eff}, I_{eff}, A_{eff}, G_{eff}, P_{eff}$) can also be decomposed for the sector with the help of following equations.

$$I_{eff} = [E_t(T) - E_t(0)] \times \left\{ \frac{\ln[I_t(T)/I_t(0)]}{\ln[E_t(T)/E_t(0)]} \right\} \quad (10)$$

$$A_{eff} = [E_t(T) - E_t(0)] \times \left\{ \frac{\ln[A_t(T)/A_t(0)]}{\ln[E_t(T)/E_t(0)]} \right\} \quad (11)$$

$$G_{eff} = [E_t(T) - E_t(0)] \times \left\{ \frac{\ln[G_t(T)/G_t(0)]}{\ln[E_t(T)/E_t(0)]} \right\} \quad (12)$$

$$P_{eff} = [E_t(T) - E_t(0)] \times \left\{ \frac{\ln[P_t(T)/P_t(0)]}{\ln[E_t(T)/E_t(0)]} \right\} \quad (13)$$

This method is used to derive the contribution of different factors and quantify their relative contribution in CO₂ emission from the road passenger transport sector in India from 1970 to 2011.

4. Data Description and Trends in CO₂ Emission from Road Transport

The time series data of different variables is collected from databases of World Bank Indicator, Road Transport Statistics (2013) published by the Ministry of Road Transport and Highways (MoRTH), Gol, Petroleum Planning and Analysis Cell of the Ministry of Petroleum and Natural Gas, Gol, and Singh (2006). Time series decomposition is done over the period of forty years from 1971 to 2011. Moreover, time period is further split into four decades, 1971-81, 1981-91, 1991-2001 and 2001-11, for decadal analyses. The breakdown of forty years in four decades is done to see whether there are specific changes over the decades.

The important variables, included in the study, are population, GDP (in billion US \$ at constant 2005 prices), output of the road passenger transport or activity level (billion PKm), fossil fuel consumption (diesel and petrol in kilotons of oil equivalent), and CO₂ emissions (kilotons) from road passenger transport. The variables are selected on the basis of literature (table 1) and availability of data in Indian context. Road transport diesel and gasoline consumption are available but these are not available for road passenger transport sector. Therefore, it is estimated on the basis of other information available. As we know that gasoline is used by two wheelers, cars, and other light vehicles only but diesel is used by all kinds of motor vehicles except two wheelers. To segregate passenger diesel consumption from logistic consumption, total diesel consumption is multiplied by the share of diesel consumption in passenger vehicle given by Petroleum Planning and Analysis Cell, Ministry of Petroleum and Natural Gas, Govt. of India. CO₂ emission is calculated on the basis of kg of CO₂ emission per unit of fuel consumption with the help of emission coefficient data extracted from U.S. Energy Information Administration.

Figure 1 shows the trends of CO₂ emission from transport sector with the segregation of subsectors of road transport and road passenger transport over the four decades. Figure reveals that the share of road transport in total transport CO₂ emission has increased over the years, while share of road passenger transport in total road transport CO₂ emission has diminished. All the three curves in Figure 1 are smooth during 1970s, 1980s, and 2000s; however, during 1990s, sudden rise and a bump in CO₂ emission is noticed. This might be related to economic liberalization which started in early 1990s in India. Liberalized government policies, role of private sector in the market, entry of MNCs in Indian consumer market, increased competition, and

expansion of road network and releasing of regulatory measures happened in the decade of nineteen nineties. The sudden change in CO₂ emission from road transport is due to the change in the consumption of light speed diesel (MoSPI, 2011). Few researchers consider this significant change in diesel consumption due to a statistical adjustment and correction in the reporting of the diesel consumption in India. Furthermore, decoupling is also found during the period of 1995 to 2005 of road transport energy consumption and transport demand (Gota and Schipper, 2013).

Figure 2 demonstrates the relationship between fuel consumption and CO₂ emission from road passenger transport. This figure reveals that the CO₂ emission from the sector is increasing rapidly in comparison to fuel consumption. This may be due to increased congestion and poor driving practices. Figure 3 shows the trend of road transport sector CO₂ emission vis-à-vis GDP at constant 2005 prices. As expected, CO₂ emission is increasing with the increase in GDP since transport activity and mobility of people are closely linked with economic activity. Figure 4 shows the increase in road-based passenger mobility, measured in billion passenger-kilometer, from 1971 to 2011. This figure reveals that passenger mobility in India has increased at the rate of 8.5% per year from 239.7 billion PKm in 1971 to 6351.2 billion PKm in 2011.

Figure 1. CO₂ emission from Indian transport sector from 1971 to 2011

Figure 2. Fuel consumption and CO₂ emission from Indian road passenger transport sector

Figure 3. GDP (at constant 2005 prices) and CO₂ emission from road transport sector in India

Figure 4. Road-based passenger mobility in India from 1971 to 2011

5. Results and Analysis

Table 2 presents the breakdown of CO₂ emission from road passenger transport sector over the period of 1971 to 2011 in different components. The contribution of these components with their negative and positive effect on CO₂ emission is presented in the table. Further, four decadal analyses for decomposition of CO₂ emission from road passenger transport in India is also shown. Total change in CO₂ emission is analyzed through emission coefficient effect, energy intensity effect, transport activity effect, economic growth effect and population effect. Table 3 presents the percentage share of these factors in CO₂ emission change. The tables show that economic growth has strong and positive effect on CO₂ emission increase in all the periods. Almost 60% of total increase in CO₂ emission during 1971-2011 is due to increase in GDP. Economic growth effect during 1990s and 2000s is significantly higher than that during 1970s and 1980s. This is in line with the Environmental

Kuznets Curve which shows that at initial stage of development, rapid use of resources leads to increase in CO₂ emission (Stern et al., 1996).

Transport activity has also played a positive role in increasing CO₂ emission during all the periods except during 1990s. During 1971-2011, 48.22% of total increase in CO₂ emission is due to increase in transport activity. Moreover, transport activity effect was more influential during 1970s and 1980s. There was a sudden change in direction of the contribution of transport activity effect during 1990s. In fact, except economic growth and population, all other factors have negative effect on CO₂ emission during 1990s. It is important to note that economic liberalization started in India in early 1990s and Indian economy started to grow at rapid pace since then. Passenger road transport sector also experienced significant change during economic liberalization. During 1990s, a number of multinational automakers were allowed to invest in Indian market. By 2000, there were twelve large automotive companies in the Indian market, most of them offshoots of global companies. Consequently, Indian market got flooded with variety of cars and two wheelers during 1990s and 2000s. During 1990s, when GDP increased rapidly, transport activity which is measured as passenger mobility per unit of economic activity (PKm/GDP) decreased, though CO₂ emission from the sector increased due to proliferation of cars and two wheelers. That's why, transport activity effect was negative during 1990s.

Energy intensity effect was found to be negative on CO₂ emission during all the periods, though effect is more influential during 1990s and 2000s than 1970s and 1980s. From 1971 to 2011, CO₂ emission from passenger road transport sector is reduced by 40.54% due to energy intensity effect. It means that improvement in vehicle technology particularly after economic liberalization has played an important role in restricting CO₂ emission from the sector. In India, most of the new vehicles produced during 1990s and 2000s are more fuel efficient and less polluting than those produced during 1970s and 1980s. That's why, not only energy intensity effect but also emission coefficient effect during 1990s and 2000s are negative.

It is evident from the results that GDP growth is the most significant contributor in CO₂ emission from passenger road transport sector. In addition to income effect, transport activity effect and population effect are also found to be significant in CO₂ emission increase. However, declining energy intensity during different decades particularly during 1990s and 2000s managed to offset a good proportion of the economic growth, transport activity, and population effects. The shift away from fossil fuels especially after 2000 and the decline in emission intensity of fossil fuels also contributed negatively to CO₂ emission growth.

Transportation demand is guided by the fuel prices, propensity to travel and mobility due to increased share of transportation in GDP. There is also an increasing trend in private vehicle ownership in India. Population growth and economic growth are the major sources of more energy consumption and higher demand. In India, high economic growth and per capita income drives the energy demand as people are left with more disposable income.

Gerike et al. (2008) show that demographic change such as decline in the population would not be helpful in solving pollution problem from transport in Germany because mobility and travel demand is increasing. Therefore, they suggest a policy package to reduce adverse environmental impact from transport and promote sustainable transport. In passenger car CO₂ emission analysis of Greece and Denmark, Papagiannaki and Diakoulaki (2009) show that ownership of the car is the most influential factor as compared to other factors. There is also a shift towards bigger or luxury cars with greater energy consumption and therefore, there is regular reduction in annual mileage. It also shows the evident impact of income on CO₂ emission, which we also found in this study. There should be appropriate mechanism to reduce continuous growth in the passenger cars and ownership of the cars which would lead to less passenger kilometre and less consumption of fuel. Lise's (2006) study shows that the largest increase in CO₂ emission is due to scale effect i.e., the expansion in the economy. Due to scale effect, increase in economic growth leads to increase in CO₂ emission. In addition to scale effect, carbon intensity contributes in CO₂ emission. Modal shift effect is also found to be significant in CO₂ emission increase from road transport in these studies. Findings of this study are in line with the findings of above mentioned studies.

Table 2. Decomposition of change in CO₂ emissions from road passenger transport

Period	Emission Coefficient Effect (C)	Energy Intensity Effect (I)	Transport Activity Effect (A)	Economic Growth Effect (G)	Population Effect (P)	Total Change in Emission
1971-1981	317.72	-3085.62	6823.23	1319.57	2835.09	8210.00
1981-1991	-12.34	-3682.97	11271.81	7132.80	5505.09	20214.39
1991-2001	-605.21	-7465.16	-4114.89	17300.19	7700.86	12815.79
2001-2011	-586.49	-25590.52	15288.76	40549.95	9602.53	39264.23
Overall Change						
1971-2011	92.13	-32634.19	38820.67	47810.66	26415.14	80504.41

Table 3. Percentage share of different factors in CO₂ emissions change

Period	Emission Coefficient Effect (C)	Energy Intensity Effect (I)	Transport Activity Effect (A)	Economic Growth Effect (G)	Population Effect (P)
1971-1981	3.87	-37.58	83.11	16.07	34.53
1981-1991	-0.06	-18.22	55.76	35.29	27.23
1991-2001	-4.72	-58.25	-32.11	134.99	60.09

2001-2011	-1.49	-65.18	38.94	103.27	24.46
Overall Change					
1971-2011	0.11	-40.54	48.22	59.39	32.81

6. Conclusion

The road transport sector accounts a major part of energy consumption due to the use of fossil fuels in motor vehicles. There are many factors responsible for increase in transport related CO₂ emissions. To see the contribution of the major factors in CO₂ emission increase, time series decomposition analysis is done over the period of 1971-2011. Changes over the four decades as well as overall change in CO₂ emission from 1971 to 2011 are decomposed through LMDI method of index decomposition. In Indian road passenger transport sector, CO₂ emission is decomposed into five major effects which are emission coefficient, energy intensity, transport activity, economic growth and population effect. Findings suggest that economic growth, population growth and transport activity effects have significant positive role in increasing the CO₂ emission from road passenger transport sector whereas energy intensity has a negative role in CO₂ emission increase. Emission coefficient effect is found to be negligible.

Analysis shows that there is a positive relationship between GDP and CO₂ emission. Per capita GDP growth and transport activity are the two dominant factors responsible for CO₂ emission increase. Moreover, emission coefficient and energy efficiency are the promising areas where focus is required as they help to reduce CO₂ emission. Therefore, there should be focus on technological advancement and sustainable growth; key driving forces such as shift to clean fuels and electric vehicles, increase in load factor, carpooling, etc. should be promoted to reduce CO₂ emission. We hope that our findings will help policy makers in quantifying the important factors in order to design and implement suitable policy options for CO₂ mitigation. For example, fiscal policy should promote clean technology and green transport in order to have sustainable transport system in the country. When GDP is increasing, per capita income will increase. People will have more disposable income to afford clean and efficient technology such as electric vehicles. Fiscal instruments can be used to reduce the consumption of diesel and petrol, while increasing the use of clean fuels. Therefore, government should use a blend of preventive and adoptive strategies such as promotion of clean technology and green transport modes, promotion of energy efficient motor vehicles, promotion of public transportation, subsidy to electric vehicles and use of clean fuels. Fiscal policy instruments should be used along with regulatory measures such as stringent emission standards for new as well as in-use vehicle, mandatory use of clean fuels for para-transit and public transport vehicles, congestion

charge on private vehicles during peak hour, etc. to reduce CO₂ emission from road transport sector and achieve sustainable economic growth.

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7. References

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