WORKING PAPER

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TRANSPORT EMISSIONS AND **INDIA'S DIESEL MYSTERY**

Comparing Top-Down and Bottom-Up Carbon Estimates

Executive Summary

In India, official statistics on fuel consumption in the road transport sector indicate a possible decoupling of road transport energy consumption and transport demand from 1995 to 2005. In that period, transport sector fuel consumption does not show any increase, while over the same period the number of registered vehicles increased threefold, freight activity (ton-km) increased by more than two times, while gross domestic product (GDP) per capita increased by more than 5% annually.

But is this really good news?

Report by:
Sudhir Gota, Lee Schipper Scholar (2013), Bangalore

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The main objective of this research is to reconcile official fuel consumption data (i.e. top-down) with bottom-up quantifications and identify potential discrepancies. Using bottom-up studies conducted by different researchers and by developing a baseline with different scenarios, various issues are identified for improvement.

It was found that official statistics on road transport fuel consumption do not provide enough explanation for and insights on the growing travel demand. The main issue with the top-down data was the allocation of diesel into different sectors, and this was the main source of variation between top-down and bottom-up estimates. Bottom-up scenarios developed in this analysis suggest that official fuel consumption data seems to overestimate diesel consumption before 1995 and underestimate fuel consumption after 1995, and both these variations are very high in magnitude.

The trends and scenarios in this research explain and establish the need to use bottom-up modelling for policy making and to prioritize diesel vehicle data collection to improve bottom-up transport modelling in India.

INTRODUCTION

Over the past decade in India, the growth rate of transport demand has exceeded the growth rate of gross domestic product (GDP) (Clean Air Asia 2012). This growth in travel demand has huge implications for energy use and carbon emissions. India's transport sector is powered by diesel, accounting for 60%–90% of transport fuel consumption (Singh et al. 2008, MoEF 2012). The latest research from the United Nations Environment Programme (UNEP) projects a sixfold increase in transport fuel consumption in India from 2010 to 2050, under business as usual growth (Dhar, Pathak, and Shukla 2013), while the International Energy Outlook 2013 estimates that India's transportation energy use would grow at the fastest rate in the world, averaging 5.1% per year, compared with the world average of 1.1% per year (U.S. EIA 2013).

India has taken a voluntary pledge to reduce its emissions intensity by 20%–25% by 2020, from 2005 levels (Planning Commission 2011). However, in order to plan for future energy efficiency improvements or low carbon transport, it is essential to understand the past performance of the road transport sector in terms of fuel consumption and carbon emissions.

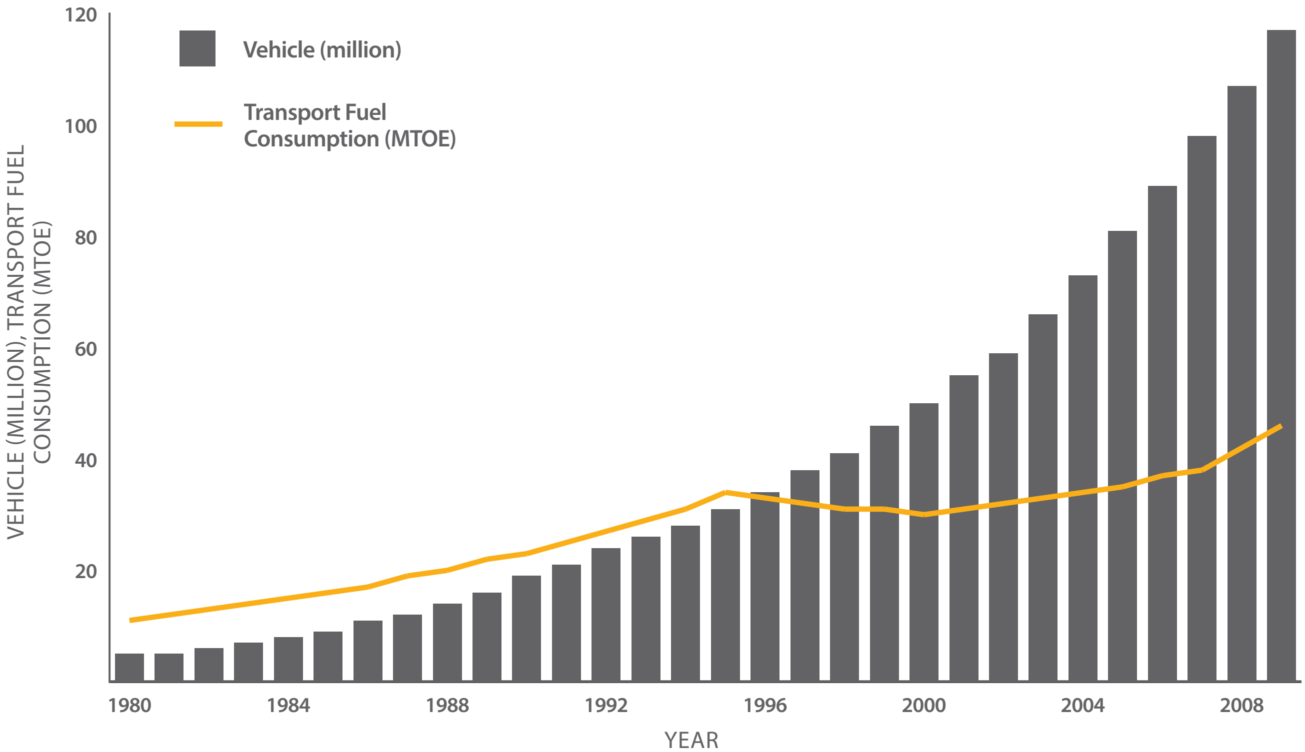
Review of official statistics on road transport fuel consumption over the last three decades provides some interesting facts on energy consumption and vehicle ownership. Transport sector fuel consumption from 1995 to 2005 does not show any increase: 33 million tons of oil equivalent (MTOE) in 1995 to 31 MTOE in 2005 (Figure 1). Over the same period, the number of vehicles increased threefold, freight activity (ton-km) increased by more than two times, and GDP per capita increased by more than 5% annually (MoSPI 2011, MoSPI 2012, Planning Commission 2006).

The Indian Planning Commission considers the reduction in fuel consumption growth in the road transport sector to be due to improved efficiency of vehicles, increased fuel prices, and better road conditions (Planning Commission 2006).

Is road transport fuel consumption starting to decouple from vehicle ownership and activity levels in India?

This paper investigates whether the road transport sector in India is showing signs of decoupling energy consumption and travel demand, or if there are inconsistencies in the official estimates that do not reflect realities on the ground. To determine this, an assessment of top-down[1] estimates based on fuel consumption is contrasted with bottom-up assessment[2] and use of the ASIF[3] framework, based on vehicle kilometers traveled (VKT) as well as the relevant drivers for change in VKT. It concludes with recommendations on how to improve bottom-up estimates in India.

Figure 1 Official Estimates of Fuel Consumption and Registered Vehicles, 1980-2009



Source: Author analysis based on data from MoSPI 2011 and MORTH 2013.
Note: MTOE stands for "million tons of oil equivalent".

TOP-DOWN ESTIMATES

Fuel sales data from fuel suppliers provides valuable insights on fuel consumption in the transport sector.

This data is often collected by a national agency and disseminated through a national energy balance table. Fuel consumption data represents the total fuel consumed by different transport modes (road, rail, waterways) and is further separated by different fuel types. Since fuel for the road sector is taxed, often at many levels (national, state, city), this fuel consumption data is considered to be highly accurate. In India, the Ministry of Petroleum and Natural Gas (MoPNG) is mandated to collect and report fuel production, import, and consumption statistics. A dedicated cell established within MoPNG, the Petroleum Planning and Analysis Cell (PPAC), is mandated to collect and report this information.

Statistics from India's Ministry of Statistics and Programme Implementation (MoSPI 2010, MoSPI 2011, MoSPI 2012) establish that from 1995 to 2005, transport sector fuel consumption has not shown any growth (i.e. stagnant consumption), from 33 million tons (MT) in 1995 to 31 MT in 2005 (Figure 1). In the same period, gasoline and diesel consumption show contrasting growth patterns. While gasoline consumption has nearly doubled at an annual growth rate of 6% (from 4.68 MT to 8.65 MT), diesel consumption in transport has decreased at an annual rate of 2%. Since the transport sector is mainly powered by diesel (60%–90%), analyzing diesel consumption over the past two decades holds the key to understand if the road transport sector in India is showing signs of a decoupling between energy consumption and travel demand.

A key statistical shift in diesel consumption occurs from 1995 to1996 (Figure 2), during which we see a 28% drop in consumption. It took nearly thirteen years for consumption levels to recover, as diesel consumption growth increased marginally. During the same period, nearly 25,000 new commercial heavy-duty diesel vehicles were added to the national fleet annually (SIAM 2010).

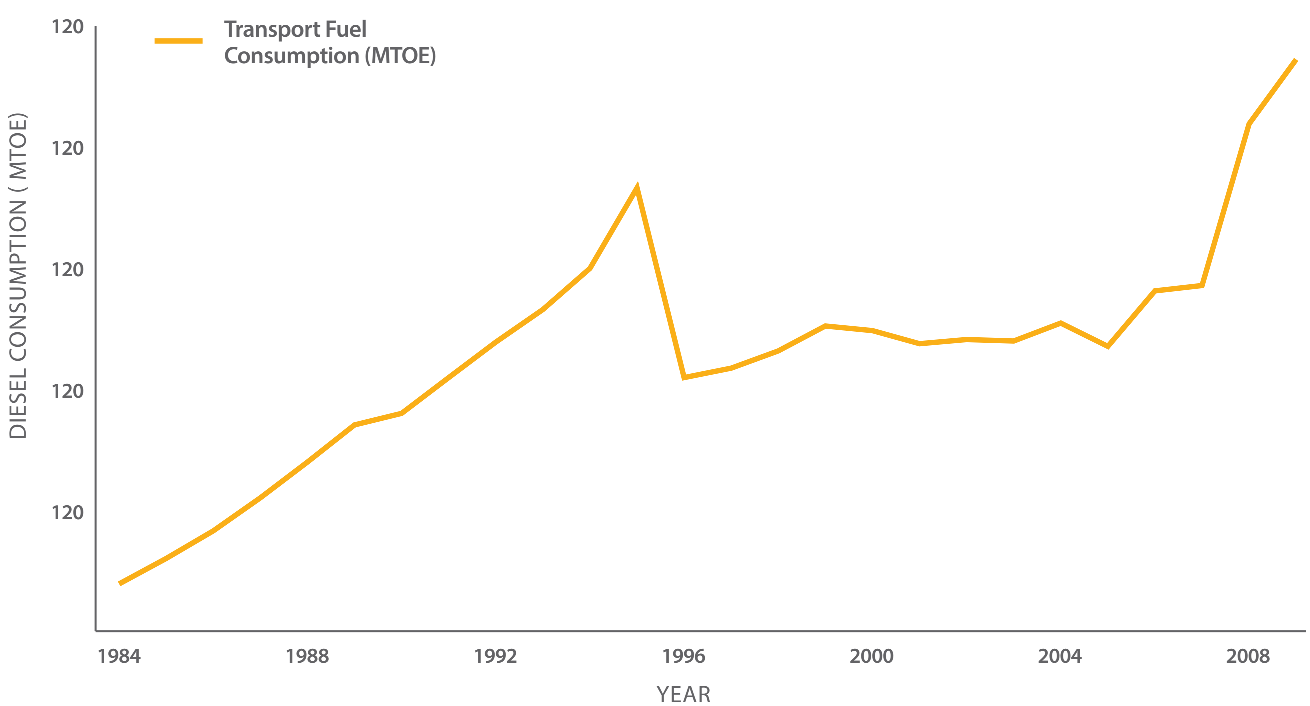
To explain this unexpected drop, researchers have come to following conclusions:

1. Timilsina and Shrestha (2009, 35) reported that the change in diesel consumption may be a statistical adjustment in the reporting of diesel consumption and further suggest, "It is thus likely that both [carbon emission] growth and transportation energy intensity for India ought to be revised downwards from 1980 to 1995 [to reflect this adjustment]." They found that the transport energy intensity (energy consumption per GDP output) in India was steadily decreasing from 1980 to 2005. If there was no such improvement in energy intensity, emissions could have increased by an additional 143% between 1980 and 2005. In addition to this improvement in energy intensity, positive trends in modal mix have resulted in a 14.3% decrease in emission growth.

2. The International Energy Agency (IEA), in its 2004 energy outlook projections, reflected more moderate transport growth and subsequent fuel consumption and scaled down its earlier estimates and projections of oil consumption in India (IEA 2004). The 2000 Outlook (IEA 2000) reported 1997 transport CO_2 emissions at 124 MT while the 2004 Outlook (IEA 2004) reported 2002 transport CO_2 emissions at 94 MT. The 2020 road transport CO_2 emissions projections in Outlook 2000 (IEA 2000) were reduced by approximately 40% in Outlook 2004 (IEA 2004). Though the IEA did not disclose why it reduced the consumption and projection by 40%, the main reason can be attributed to considering revised diesel consumption levels as a statistical adjustment (see Table 1).

Similar to the IEA, the U.S. Energy Information Administration (U.S. EIA 2005) in its 2005 International Energy Outlook (IEO) reduced 2020 energy consumption projections of India by 45% from IEO 2002 (U.S. EIA 2002).

Figure 2 Official Estimates of Diesel Consumption (MTOE) in Road Transport in India, 1984-2009



Source: Author analysis based on data from MoSPI 2011.
Note: MTOE stands for "million tons of oil equivalent".

Table 1 World Energy Outlook 2020 Projections for Road Transport CO_2 Emissions in India

Study	India 2020 Road Transport CO_2 (MT)
IEA World Energy Outlook 2000	407
IEA World Energy Outlook 2004	157
IEA World Energy Outlook 2008	238
IEA World Energy Outlook 2012	239

Sources: IEA 2000, 2004, 2008, 2012.
Note: MT stands for "million tons".

3. De la Rue du Can et al. (2009, 33) reports that in 1996, a serious break in diesel consumption trends was observed. They suggest, "In reality, no major activity disturbance or technology breakthrough can explain such a decline over a one year period. It is believed that a major restructuring in statistics accounting explains this trend, however, no official document or note was found to justify this argument. Hence we assumed that more recent statistics on diesel consumption for the transport sector reflect the real consumption, we back calculated with the vehicle stock the historical diesel consumption."

The majority of researchers and institutions have considered the significant drop in India's diesel consumption as a statistical correction and have reduced their future projections to reflect stagnant diesel consumption growth. The government of India has also considered the low growth in diesel fuel consumption to be a reality, based on its submissions to United Nations Framework Convention on Climate Change (UNFCCC).

However, this stagnant growth contrasts with India's rapid increase in vehicle numbers, economic activity, and the slow or non-existent implementation of comprehensive sustainable transport policies. In terms of transport CO_2 intensity with respect to economy (kg CO_2 per GDP USD), the intensity increases from 1980 to 1995 (0.16 to 0.22) and decreases from 1995 to 2005 (0.22 to 0.11). This decrease is at a rate of -6.6% annually. From 2005 to 2010, transport CO_2 intensity has stabilized at around 0.12. No other country has shown such a dramatic improvement in intensity (Clean Air Asia 2012; Façanha, Blumberg, and Miller 2012).

BOTTOM-UP APPROACH

In 1998, Lee Schipper and Culine Marie-Lilliu (1999) developed the "ASIF" framework, which is an acronym for "activity," "mode share," "intensity," and "fuel mix." This framework shifted the transport discussion from top-down statistics to a more transparent system of calculating emissions, thus establishing the business case for low-carbon transport in Asia. In this framework, emissions (G) in the transport sector are dependent on the level of travel activity (A) in passenger kilometers (or ton-km for freight) across all modes; the mode share (S); the fuel intensity of each mode (I) in liters per passenger-km (or ton-km for freight); and the carbon content of the fuel or emission factor (F), in grams of carbon or pollutant per liter of fuel consumed.

$$G = A * S * I * F$$

Thus, the main factors influencing carbon emissions in transport are:

Activity and mode share (A, S) describe how and how much people or freight travel. They are measured in terms of passenger–km or ton-km and disaggregated by mode type, including non-motorized transport. Passenger-km (or ton-km) are calculated using number of vehicles, number of trips, distances travelled and occupancy (or loading) of vehicles.

Fuel intensity (I) of a mode is generally measured in energy units per passenger-km i.e. liters of fuel per passenger-km or megajoules (MJ) per passenger-km. Measurement depends on the vehicle fuel intensity, occupancy driving behaviour, engine technology, weight, aerodynamic design, and congestion on the road.

Carbon content of fuel (F) is the amount of carbon released per unit of energy consumed.

The relative importance of each of the connected components to total changes in emissions varies with demand and policy interventions. Not all parameters would respond similarly to a given stimulus and each component may directly or indirectly influence other components. For example, increased fuel efficiency may lead to more travel demand, and increased occupancy of vehicles may reduce total vehicle kilometers. In India, "A" and "S" factors have undergone significant transformation when compared with "I" and "F" factors. Of all the ASIF components in India, the carbon content of fuel (F) has not changed in the road transport sector and thus has been neglected in subsequent discussions.[4] The main requirement of bottom-up modelling is to get the number of vehicles, fuel efficiency per kilometer per year, and kilometer driven per vehicle per year all distinguished by fuel. This is a major challenge in a country like India where limited resources are spent on collecting periodic data.

DRIVERS FOR BOTTOM-UP EMISSION GROWTH

Transport sector demand in India is growing rapidly with economic growth, urbanization, increased investment in infrastructure, industrialization, etc. High income growth over the past decade has translated into increased vehicle ownership and use. Vehicle registrations have increased from 5 million in 1981 to 142 million in 2011 (MoSPI 2012) While the total number of vehicles is high, ownership levels (measured as motorization levels) are low (114 vehicles per 1,000 people). Currently, 72% of the vehicle fleet consists of only two-wheelers. Cars constitute the fastest growing vehicle segment on the road, with 10.6% annual growth from 2001 to 2011. Experts expect an acceleration in the increase in vehicle ownership levels in the coming decades, with its growth nearly twice as fast as per-capita income growth in India (Dargay, Gately, and Sommer 2007) or almost four times faster than population growth (MoUD 2008).

It is interesting to note that passenger and freight transport demand exceeds vehicle growth levels. The Eleventh Five Year Plan of the Planning Commission estimates that between 2000 and 2010, passenger kilometer travel (passenger-km) increased at an annual rate of 15%, from 2076 billion passenger-km to 5578 billion passenger-km, and freight travel increased 8% annually, from 494 billion ton-km to 1115 billion ton-km (Planning Commission 2006). The Ministry of Urban Development (MoUD) estimates that urban transport demand (in passenger-km) has increased at an annual rate of 7% from 1994 to 2007 (MoUD 2008).

This increase has been facilitated by the massive expansion of national highways linking different cities in India, as well as by high economic growth and comparatively smaller growth in Indian railways. India has around 3.3 million kilometers of road network, the second largest in the world. Over the past two decades, road infrastructure has expanded at an annual rate of 3.4%. The rapid expansion of highways has shifted transport services away from railways. In 1980, road networks carried 38% of freight and 72% of passenger traffic; they now carry nearly 60% of freight and 87% of passenger traffic (Planning Commission 2013). Clearly, not only has transport demand increased, but modal mix has also shifted towards the more carbon-intensive road transport sector.

FINDINGS

Bottom-up Investigation Results

Bottom-up investigations by different studies reveal a completely different story when compared with top-down estimates. Bottom-up estimates (Table 2) indicate that from 2000 to 2010, the annual growth rate of road transport CO_2 emissions ranged from 6% to 14%, while, top-down estimates from fuel sales indicate a 3.4% annual growth rate (MoSPI 2012). There is a significant gap between what government statistics suggest and what bottom-up estimates reveal.

There is wide variation among the bottom-up emission estimates, and the predominant cause of variation is the error in computing diesel consumption. It is interesting to note that gasoline consumption explains around 20%–33% of the total variation, as seen in Table 3.

Table 3 provides diesel consumption estimates based on various top-down and bottom-up studies. All the bottom-up studies show an increase in diesel consumption. It is very interesting to note that while the official annual growth rate of diesel consumption decreased from 8% in the period 1985–1995 to -2% in the period 1995–2005, the diesel vehicle ownership

Table 2 Annual Growth Rate of Road Transport CO2 Emissions

Study	Time period	Annual growth rate of road transport CO_2 emissions (%)
Clean Air Asia 2012	2000-2010	8
Baidya 2008	2000-2005	6.6
CII and A.T. Kearney 2013	2000-2010	6.1
Façanha, Blumberg, and Miller2012	2000-2010	6.7
Fulton, Cazzola, and Cuenot 2009	2000-2010	6.6
TERI 2006	2001-2006	14.5
TERI 2010	2000-2010	8
Schipper, Fabian, and Leather 2009	2005-2008	8
MoSPI 2011	2000-2010	3.4

Sources: Clean Air Asia 2012; Baidya 2008; CII and A.T. Kearney 2013; Façanha, Blumberg, and Miller 2012; Fulton, Cazzola, and Cuenot 2009; TERI 2006; TERI 2010; Schipper, Fabian, and Leather 2009; MoSPI 2011

rates increased from 7% in 1985–1995 to 11% in 1995–2005. Clearly, increases in vehicle ownership cannot lead to reduction in fuel consumption values until and unless vehicle activity reduction and fuel efficiency values have shown radical improvements.

In order to investigate this discrepancy, a baseline for diesel consumption from 1985 to 2010 is established using vehicle statistics from Ministry of Road Transport and Highways (MORTH) annual reports, literature review, assumptions as detailed in Table 4 below, and using the ASIF framework. Vehicle registration data comes from the MORTH handbook (MORTH 2013). Vehicle activity (km) and fuel efficiency (kilometer per liter (km/l) data have been considered based on review of different studies in India. Further, scenarios are built by varying the parameters as described below.

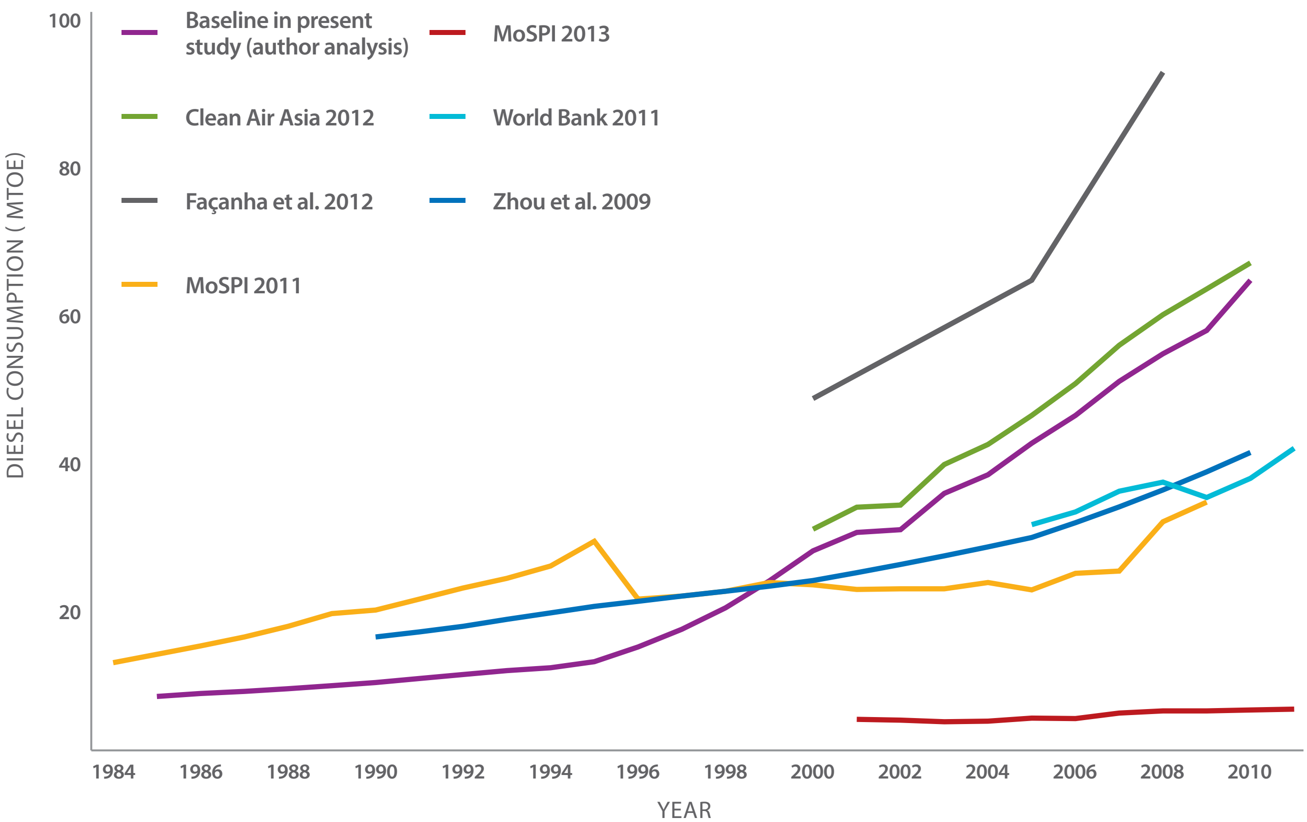
The baseline established in Figure 3 assumes constant vehicle activity and fuel efficiency values over the years, due to the lack of credible data. The constructed baseline falls below the official fuel consumption values (MoSPI 2011) until 1999, and after this it gains a sufficient lead when compared to official consumption values by 2010. There is significant variation with official values both pre-1999 and post-1999. The diesel consumption growth rates for 1985–1995 and 1995–2005 are 5% and 13%, respectively. This finding contradicts official diesel consumption annual growth rates of 8% in the period 1985–1995 and -2% in 1995–2005.

Table 3 Comparison of Top-Down and Bottom-Up Estimates of Road Transport CO2 Emissions

Year	Top-down road transport CO_2 emissions (MT) from total fuel sales	Bottom-up road transport total CO_2 emissions (MT) estimates range		Bottom-up road transport CO_2 emissions from gasoline (MT) estimates range		Ratio of gasoline variation to total variation (%)
		Low	High	Low	High	
2000	86	81	138	18	37	33
2005	90	120	219	24	43	19
2010	145	161	315	40	82	27

Sources: Clean Air Asia 2012; Baidya 2008; CII and A.T. Kearney 2013; Façanha, Blumberg, and Miller 2012; Fulton, Cazzola, and Cuenot 2009; TERI 2006; TERI 2010; Schipper, Fabian, and Leather 2009; MoSPI 2011.
Note: MT stands for "million tons".

Figure 3 Diesel Consumption in Road Transport in India, 1984-2011



Source: Clean Air Asia 2012; Façanha, Blumberg, and Miller 2012; MoSPI 2011; MoSPI 2013; Zhou and McNeil 2009; World Bank 2011; Baseline in present study (author analysis).
Note: MTOE stands for "million tons of oil equivalent".

Table 4 Variation of Average Vehicle Travel and Average Fuel Efficiency of Diesel Vehicles

Modes	Average vehicle travel/year (km)				Average fuel efficiency (km/l)			
	Max	Min	Average	**Baseline**	Max	Min	Average	**Baseline**
Three-wheeler	44,000	14,850	31,425	**30,000**	43	20	35	**35**
Car	35,000	7,500	13,306	**12,000**	18	8	13	**16**
Bus	126,700	30,000	74,302	**50,000**	6	3	4	**4.5**
Light Commercial Vehicle	60,000	19,400	31,859	**25,000**	13	7	10	**10**
Truck	108,000	30,000	56,299	**50,000**	5	2	3	**4**

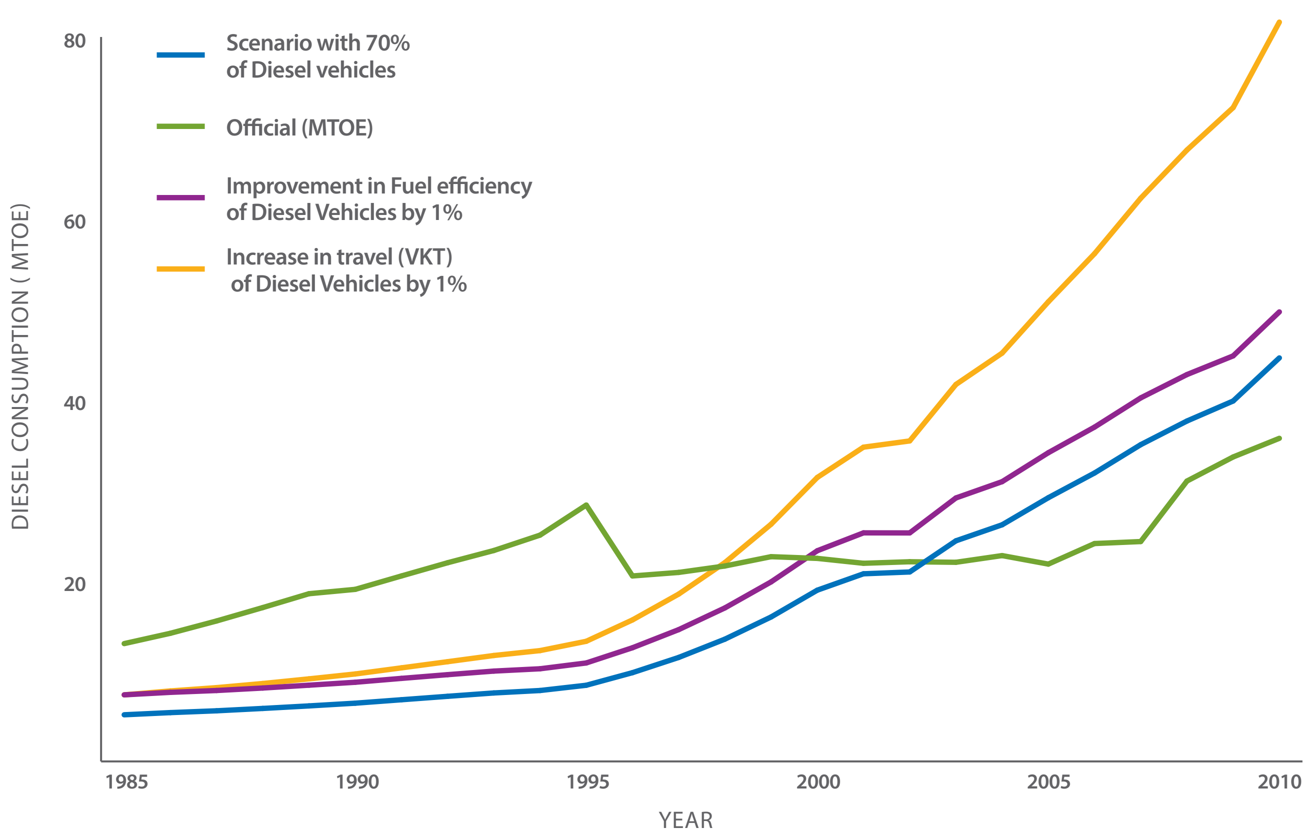
Sources: Clean Air Asia 2012; Singh et al. 2008; Façanha, Blumberg, and Miller 2012; Schipper, Fabian, and Leather 2009; Baidya 2008; Guttikunda and Jawahar 2012; Arora, Vyas, and Johnson 2011; ADB 2006; Planning Commission 2011; SIAM 2010; Zhou and McNeil 2009; World Bank 2011; Baseline in present study (author analysis)

An alternate scenario is also considered, in which it is assumed that only 70% of vehicles registered are available on roads. This assumption stems from the research by Baidya and Borken-Kleefeld and others (Baidya and Borken-Kleefeld 2009; Centre for Science and Environment 2012; Schipper, Fabian, and Leather 2009; Zhou and McNeil 2009), which established that only two-thirds or a maximum of three-quarters of registered vehicles are actually circulating on the road. Based on the revised calculations, the variation still exists, predominantly before 2002 and from 2002 to 2007. The diesel consumption growth rates for 1985–1995, 1995–2005, and 2005–2010 are 5%, 13%, and 9%. Since the majority of diesel vehicles (light-duty and heavy duty vehicles) are commercial vehicles, they are registered annually and thus, there should not be a great discrepancy between registered vehicles and vehicles on the road.

If the vehicle activity levels increased annually (by say 1%), the variation after 1999 would increase further (Figure 4). Considering a scenario in which the vehicle activity levels do not increase, but fuel efficiency of vehicles improves by 1% annually from 1985, the variation in pre-1999 levels increases further. It is to be noted that India has not yet implemented fuel economy standards and thus drastic improvement in fuel efficiency of vehicles cannot be expected. Clearly, it is very difficult to replicate official diesel consumption values with bottom-up measurements and official consumption values seem to be unreliable.

De la Rue du Can et al. (2009) have considered the official statistics to be reflective of fuel consumption and have compared official fuel consumption data with bottom-up diesel consumption values from 1990 to 2005. In order to match the official consumption values,

Figure 4 Diesel Consumption Scenario Variations in Road Transport



Source: Author analysis based on MoSPI 2011.
Notes: MTOE stands for "million tons of oil equivalent"; VKT stands for "vehicle kilometers traveled".

Table 5 Variation in Diesel Consumption Share by Different Modes of Road Transport

Modes	Diesel Consumption in Road Transport (%)					
	Clean Air Asia 2012	SIAM 2010	Façanha, Blumberg, and Miller 2012	Baseline in present study Max	Zhou and McNeil 2009	MoPNG 2014
Car	2	10	4	3	8	19
Bus	24	11	19	22	25	14
Truck	74	72	76	74	68	40

Sources: Clean Air Asia 2012; Singh et al. 2008; Façanha, Blumberg, and Miller 2012; Schipper, Fabian, and Leather 2009; Baidya 2008; Guttikunda and Jawahar 2012; Arora, Vyas, and Johnson 2011; ADB 2006; Planning Commission 2011; SIAM 2010; Zhou and McNeil 2009; World Bank 2011; Baseline in present study (author analysis)

the energy efficiency of vehicles would have needed to increase by 1% to 4% annually, while the travel distance for each mode would have needed to decrease by 1% to 2% annually from 1990 onwards. This is impossible to achieve without the implementation of aggressive Avoid-Shift-Improve policies and strategies (Dalkmann and Brannigan 2007).

Based on the scenarios, official fuel consumption data seems to overestimate diesel consumption before 1995 and underestimate fuel consumption after 1995. Both of these variations are very high in magnitude.

Interestingly, among diesel vehicles there is no consistency in consumption patterns in different bottom-up studies as shown in Table 5. Clearly, with annual diesel fuel subsidies in India amounting to US$10 billion, the lack of clear insight on diesel consumption among various modes may delay implementation of energy efficient policies and removal of subsidies (Business Standard 2013).

Determining the efficiency of passenger and freight travel can help determine how realistic each of these bottom-up diesel consumption estimates might be. Efficiency of passenger and freight travel can be derived – as per Planning Commission estimates – by combining official top-down CO_2 and fuel estimates with bottom-up travel demand estimates of 8572 billion passenger-km and 1115 billion ton-km (Planning Commission 2013). For passenger and freight transport, this yields an efficiency of 4 grams of CO_2/ passenger-km and 87 grams of CO_2/ton-km respectively. A value of 4 grams of CO_2 per passenger kilometer is impossible to achieve via road transport even if all trips were taken on buses. As for freight, review of international literature on grams of CO_2/ton-km of road freight provides a range between 130 to 350 grams per ton-km (Clean Air Asia 2012; Façanha, Blumberg, and Miller 2012). Clearly, Indian freight cannot have achieved the very high efficiency of 87 g/ton-km when the freight industry is plagued with a high number of empty trips, low truck capacity, poor road geometrics, and fragmented industry.

Considering the issues involved, India's transport sector efficiency cannot be so high. Transport CO_2 emissions or fuel consumption as suggested by official statistics do not correlate with on-the-ground realities.

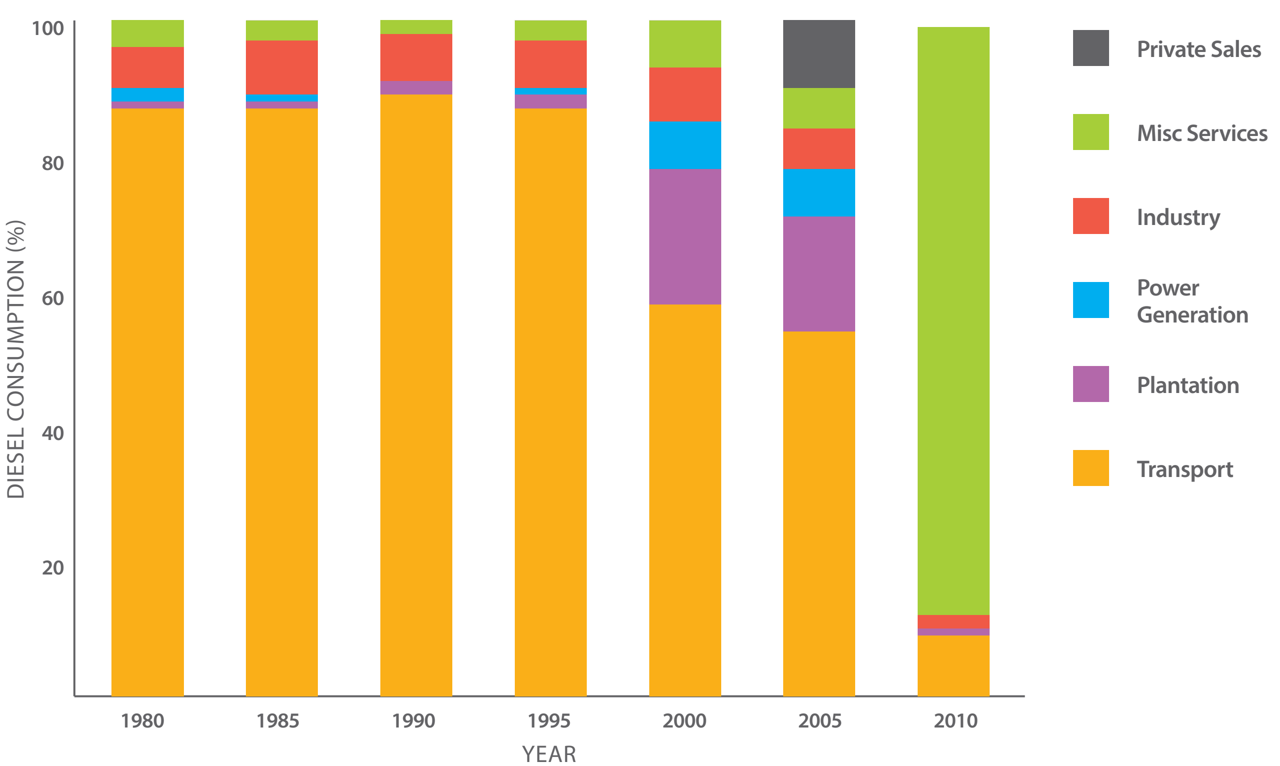
Top-down Investigation Results

In a top-down approach, there is always the possibility of misallocating deliveries between main source categories, neglecting the impact of fuel adulteration and smuggling, or of fuel consumption not being reflected on fuel tax receipts due to tax evasion (Baidya and Borken-Kleefeld 2009, Gawande and Kaware 2013). In India, misallocation of diesel consumption into different sectors could be a serious factor causing variation in diesel consumption in the transportation sector.

Figure 5 shows the historical share of diesel consumption in different sectors. The transport sector's share of diesel consumption decreased from 87% in 1995 to 58% in 2000, 54% in 2005 and 9% in 2010. The problem lies not only in the share as a percentage of total fuel consumption (Figure 5), but also in the volume (Figure 6). The latest official updates of energy statistics in 2012 and 2013 (MoSPI 2012, MoSPI 2013) have readjusted the 2001–2011 official diesel consumption values, which are five to six times lower than previous estimates. These changes of statistics in 2012 and 2013 have been carried out only for the road transport sector and not for railways and waterways. The 2011 road transport diesel consumption value has been readjusted downward to around 5 million tons from an earlier 33 million tons. The CO_2 emissions from diesel consumption dropped from around 100 million tons to around 15 million tons. Since the Indian transport industry is mainly powered by diesel, drastic modification in diesel consumption values would mean drastic reduction in India's transport emissions.

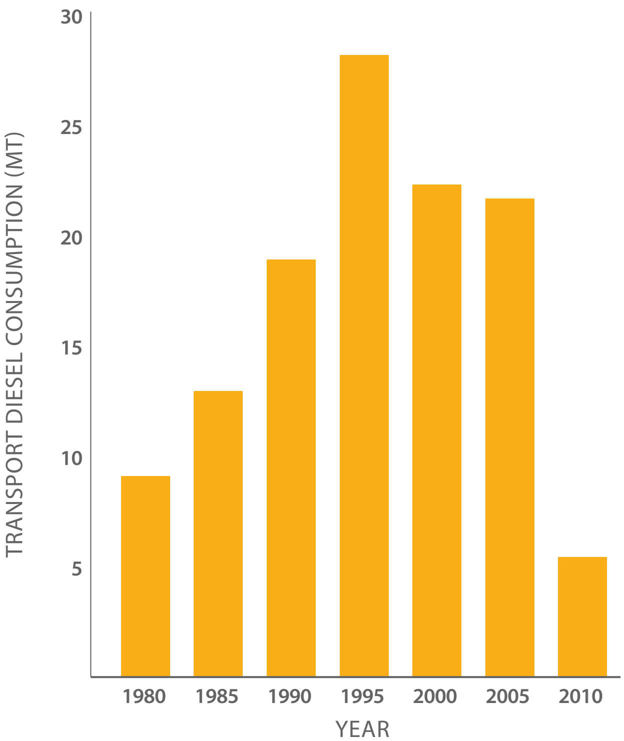
Thus, official diesel consumption values need to be revised. The Indian Government needs to consider using a bottom-up approach with better data in order to estimate fuel consumption for target-setting and tracking purposes, and for planning policies. Ideally, the top-down approach would be more accurate than the bottom-up approach as there are fewer assumptions and data requirements. However, Indian top-down estimates really do not reflect increases in travel demand, nor do they provide any insights on the transport modes (for instance, the fuel sold can be consumed by any kind of motorized mode of transport, and isolating the impact of each mode is impossible). With the top-down approach, authorities cannot really differentiate good news from bad. Thus,

Figure 5 Official Energy Statistics Indicating Share of Diesel Consumption By Sector



Source: MoSPI 1991, 2011, 2012, 2013.

Figure 6 Transport Sector Diesel Consumption, Official Statistics



Source: MoSPI 1991, 2011, 2012, 2013.
Note: MT stands for "million tons".

bottom-up measurements provide the answers for decision-making. They allow measurement of policies, strategies, projects, contribution of different modes, etc. There is urgent need to use and improve bottom-up estimates in India.

IMPROVING BOTTOM-UP ESTIMATES

If detailed vehicle activity data is available, it is considered a "best practice" to perform a validation of total fuel sales against fuel used based on passenger and vehicle kilometers travelled. This often leads to adjustment of travel activity, as fuel sales are considered to be accurate while travel activity is most unreliable in the ASIF framework. For example, in the Global Change Assessment model (Mishra et al. 2013) travel demand is reduced by 41% and 29% for passenger and freight travel activity in India to match official fuel consumption data. Clearly, if the official fuel consumption data is misreported or misallocated, reduction in travel demand may lead to unrealistic estimates and may not provide valuable insights for planning and investments.

In order to improve bottom-up quantifications, availability of national household travel surveys, origin-destination surveys, and commodity flow surveys is a must. These surveys provide valuable insights on travel activity patterns. Further, on-road measurements of vehicle fuel efficiency and occupancy, or load-factor observations or surveys are also required to properly estimate fuel consumption and emissions. Presently, all the above information is absent and there is a complete lack of regular and reliable data on passenger and freight movement.

It is interesting to note that the data on different components of ASIF belong to different ministries or authorities, i.e. transport, energy (MoPNG), finance, home affairs, urban development and environmental ministries. MoPNG provides fuel consumption statistics while the Ministry of Environment and Forests (MoEF) has the mandate to estimate and report emissions from the transport sector. The Ministry of Road Transport & Highways (MORTH) maintains the national database on the road transport sector and provides basic information on transport activity, taxation and infrastructure. The mandate to improve urban transport data is on the Ministry of Urban Development and the Institute of Urban Transport, which manages the affairs of the National Urban Transport Information Centre. This center was established in 2006 to compile data on urban transport in scientifically designed formats and to maintain it methodically. Further, for urban transport, under the Jawaharlal Nehru Urban Renewal Mission, there was a provision of grant assistance to state governments of about 40% of the cost of studies on issues related to traffic and transportation in urban areas. This led to manifold increase in transport data collection at the city level.

In terms of the number of vehicle on the road, private vehicles registrations are valid for fifteen years in India, and thus the exact number of vehicles on the road can be different from the number of vehicles registered. In 2005, the difference in vehicle ownership (vehicles on road) considered in different studies was as high as 33 million vehicles (Clean Air Asia 2012;

Singh et al. 2008; MoEF 2012; MoSPI 2012; Façanha, Blumberg, and Miller 2012; Schipper, Fabian, and Leather 2009; Baidya 2008; Guttikunda and Jawahar 2012; Arora, Vyas, and Johnson 2011; ADB 2006; Zhou and McNeil 2009; World Bank 2011).

Since vehicle taxation is not levied annually for private vehicles, there is almost no clear way to distinguish between vehicles registered and actually in-use. However, commercial vehicles registration data (especially registered buses and trucks) is relatively more accurate as the registration renewal process is carried out annually. But researchers often consider truck and bus data to be highly unreliable (Schipper, Fabian, and Leather 2009; Baidya 2009; Centre for Science and Environment 2012), a factor that needs more investigation.

In terms of vehicle activity, trucks and buses have maximum variation among different studies. Average vehicle travel per year for trucks and buses can vary from 30,000 km to 120,000 km (as shown in Table 4). Since data is not available, researchers have to resort to expert judgment in estimating average vehicle travel and this sometimes can contribute to substantial variations. For example, the Indian Planning Commission in its Twelfth Five Year Plan estimates that a bus on average conducts 7.7 million passenger-kilometers of travel per year (Planning Commission and MORTH 2011). Assuming a normal occupancy of 40 would mean that a bus needs to travel 192,000 km per year in order to provide for 7.7 million annual passenger-km, which is practically impossible.

For accurate bottom-up quantifications, the transport data needs to be disaggregated. For example, many researchers consider "cars" as a single variable and allocate travel activity to it. But in reality, cars can mean mini cars, taxis, or SUVs, and can be powered by gasoline, diesel, CNG, etc. Different types of cars can have different travel patterns and different fuel efficiencies. For example, the Society of Indian Automobile Manufacturers (SIAM) considers commercial light duty vehicles (LDVs), such as jeeps and LCVs modified for passengers, to travel about 43,000 km annually, and personal utility vehicles to travel around 20,000 km. It also estimates that diesel-fueled personal cars travel around 11,000 km annually while diesel taxis travel about 24,000 km annually. For all these classifications, if a single variable is proposed and activity allocated based on one single use, errors would be magnified. Aggregating different modes into a single mode reduces the accuracy of bottom-up estimates.

Planning Commission (2006) estimates of travel demand do not consider non-motorized transport (NMT) modes such as walking and cycling when quantifying passenger kilometer travel (passenger-km). Passenger-km is considered as "the sum of the length of journeys travelled by all passengers carried by a vehicle." This is a significant barrier to understanding NMT usage and to establishing its role in reducing carbon emissions, and thus establishing the need for low-carbon policies related to walking.

The type of data collected and generated is often influenced by its need. Currently, Indian authorities have not conducted adequate surveys and investigations exclusively for bottom-up modeling. With increasing focus on low-carbon transport, India will increasingly need to make informed decisions on various transport-related policies and investments required to reduce carbon emissions.

Lack of data on vehicles segregated by fuel-type is also causing serious distortions in official estimates. For example, the IEA World Energy Outlook 1998 (IEA 1998) suggested that 80% of road vehicles in India ran on diesel fuel while in 2000 Clean Air Asia (2012) suggested that nearly 11% of road vehicles ran on diesel fuel. Since 72% of the vehicle fleet consists of only two-wheelers, diesel vehicle fleet share should be extremely low. Currently, there is no annual survey at the national level to determine the fuel split of vehicles.

For improving bottom-up modelling, the exclusive focus on diesel vehicles provides a great opportunity to improve estimates in the short term. Diesel vehicles currently constitute less than 10% of the total fleet but consume around 60% to 90% of total fuel (Singh et al. 2008, MoEF 2012). Since the majority of diesel vehicles are commercial in nature, there is a huge opportunity to introduce a systematic collection of data on the number of vehicles on the road, vehicle activity, and fuel efficiency.

The problem is not only with the data or assumptions but sometimes even with the approach adopted. Recently India appointed an expert committee to evaluate options to reduce the country's emissions intensity from 2005–2020. This committee published a report called "Interim Report of the Expert Group on Low Carbon Strategies for Inclusive Growth" (Planning Commission 2011). In the transport sector, the report's methodology is to calculate the individual impacts of policy measures such as mode shift, fuel efficiency of vehicles, etc. and add up the individual savings to determine the total impact under different scenarios, such as "determined effort" and "aggressive effort." For example, the report recommends that assuming 8% GDP growth and under scenarios of "determined effort" and "aggressive effort," the total emissions reductions would be 42 million and 63 million tons of CO_2.

The problem with this approach is that it simply adds up the impact of each policy and calculates total savings, which is a violation of ASIF principle. In transport CO_2 computations, implementation of one policy would impact the other policies (for example improving fuel efficiency of vehicles would reduce the impact of mode shift). Calculating the impact of each policy individually and summing up the individual impact to calculate the net savings is not scientifically correct. With this approach the error would be very large. The total emissions reductions with the available policy packages would certainly be less than what has been projected, thus reducing the impact of the plan.

CONCLUSION

Transport sector fuel consumption statistics from 1995 to 2005 do not show any increase in fuel consumption (MoSPI 2011, MoSPI 2012, Planning Commission 2006), while over the same period, the number of vehicle registrations has increased threefold according to data from MORTH. The Indian Planning Commission has considered this reduction in fuel consumption growth in the road transport sector to be realistic, due to improved vehicle efficiency, increased fuel prices, and better road conditions. The purpose of this research was to determine if the road transport sector in India is really showing signs of a decoupling of energy consumption and travel demand, or if there are inconsistencies in the official estimates, which would therefore not be reflective of realities on the ground.

Based on the detailed analysis, the use of top-down data on fuel consumption in the road transport sector in India may have led to serious errors. The current official statistics on road transport fuel consumption do not provide enough justification of growing travel demand or insights on the implications of growing travel demand on fuel consumption and carbon emissions. Misallocation of diesel consumption into different sectors could be the main issue with top-down assessment. There is a significant gap between what government statistics suggest and what bottom-up estimates indicate. Bottom-up estimates indicate that from 2000–2010, the annual growth rate of CO_2 emissions in the road transport sector ranged from 6% to 14%.

There is wide variation among the bottom-up emissions estimates. The predominant cause of variation is diesel consumption. Gasoline consumption explains only 20% to 33% of the variation as seen in Table 3. The total number of motor vehicles and the total distance travelled are the key variables in determining total fuel consumption and carbon emissions. Unfortunately, until this information is collected and updated annually, the quality of the bottom-up measurements cannot be improved.

The trends and scenarios in this research explain and establish the need to prioritize diesel vehicle data collection to improve bottom-up modeling. In India, annual diesel fuel subsidies cost society around US$10 billion and the lack of clear insight on diesel consumption among various modes may delay fuel and energy efficiency policy implementation. Improving diesel consumption data will provide quick wins in reducing variation among bottom-up modeling estimates and provide better insights on energy efficiency in the transport sector. In the long term, the establishment of national transport household surveys as a supplement to the national census should be prioritized. Clearly, mobility for people and freight in a country with 1.2 billion people cannot be planned adequately without sufficient resources allocated to data generation and analysis. Analysis of top-down and bottom-up data in India provides some interesting perspectives on the quality of both top-down and bottom-up quantifications. There is a need for similar reviews in other countries that may have mismatches between top-down allocations and bottom-up estimations.

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Endnotes

1. Top down estimates refer to quantification of CO_2 emissions by using fuel sales data.
2. Bottom-up processes involve computing fuel consumption based on travel activity (ASIF framework).
3. ASIF (Activity-Structure-Intensity-Fuel) is a known bottom-up quantification framework which translates transport activity into fuel consumption in a step wise manner.
4. Carbon content of fuel will change when the fuel split changes dramatically, such as through the use of liquefied petroleum gas (LPG) or ethanol. In Asia, carbon content of fuel has not radically changed over last two to three decades.

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About the Author

Sudhir Gota works as an Independent Consultant and an adviser to Clean Air Asia and Smart Freight Center. He specializes on environmental issues related to transport and has extensive experience in transport data crunching and green freight.
Contact: sudhirgota@gmail.com

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EMBARQ
10 G Street, NE, Suite 800
Washington, DC 20002
USA
+1 (202) 729-7600

Brasil
EMBARQ BRASIL
Av. Independência, 1299 / 401
Porto Alegre, RS
BRASIL, 90035-077
+55 (51) 33126324

中国
EMBARQ CHINA
Unit 0902, Chaowai SOHO Tower A
Yi No. 6
Chaowai Dajie, Chaoyang District
Beijing 100020, China
+86 10 5900 2566

India
EMBARQ INDIA
Godrej and Boyce Premises
Gaswork Lane, Lalbaug
Parel, Mumbai 400012
+91 22 24713565

México
EMBARQ MÉXICO
Calle Belisario Dominguez #8,
Planta Alta
Colonia Villa Coyoacán, C.P. 04000
Delegacion Coyoacán, México D.F.
+52 (55) 3096-5742

Türkiye
EMBARQ TÜRKIYE
Sürdürülebilir Ulaşım Derneği
Gümüşsuyu Mah. İnönü Cad.
No:29 Saadet Apt. Kat:6 D:7
Taksim, Beyoğlu, İstanbul
Tel: 0 (212) 243 53 05