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Assessment of Historic Trend in Mobility and Energy Use in India Transportation Sector Using Bottom-up Approach

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Abstract

Transportation mobility in India has increased significantly in the past decades. From1970 to 2000, motorized mobility (passenger-km) has risen by 888%, compared with an 88% population growth (Singh,2006). This contributed to many energy and environmental issues, and an energy strategy incorporates efficiency improvement and other measures needs to be designed. Unfortunately, existing energy data do not provide information on driving forces behind energy use and sometime show large inconsistencies. Many previous studies address only a single transportation mode such as passenger road travel; did not include comprehensive data collection or analysis has yet been done, or lack detail on energy demand by each mode and fuel mix.

The current study will fill a considerable gap in current efforts, develop a data base on all transport modes including passenger air and water, and freight in order to facilitate the development of energy scenarios and assess significance of technology potential in a global climate change model.

An extensive literature review and data collection has been done to establish the database with breakdown of mobility, intensity, distance, and fuel mix of all transportation modes. Energy consumption was estimated and compared with aggregated transport consumption reported in IEA India transportation energy data. Different scenarios were estimated based on different assumptions on freight road mobility. Based on the bottom-up analysis, we estimated that the energy consumption from 1990 to 2000 increased at an annual growth rate of 7% for the mid-range road freight growth case and 12% for the high road freight growth case corresponding to the scenarios in mobility, while the IEA data only shows a 1.7% growth rate in those years.

Keywords: India, transport, energy demand, decomposition, bottom-up analysis, data

1. Introduction

This study of the transport energy sector in India is part of a larger effort at LBNL(Lawrence Berkeley National Laboratory) to provide sector, country and ultimately global analysis of energy use patterns at the level of sub-sectors and end uses. There are two motivations for this effort. First, as the negative environmental impacts (both local and global) of energy consumption become more urgent, there is a need to evaluate current and future sources of energy-related effects at a greater level of accuracy and detail. Secondly, a disaggregated analysis is highly desirable in order to guide mitigation efforts, including policies towards increased efficiency.

LBNL has a long history in the investigation of energy use patterns in developing countries, particularly in China. Most recently, these efforts have focused on end-use level analysis of historical and projected energy consumption in all Chinese energy sectors. A natural next step is to turn to India.

By now, the dramatic increase in energy consumption in China accompanying that country's phenomenal economic performance in the past two decades has become a somewhat alarming reference point for the negative environmental consequences associated with rapid growth in developing countries. Chinese energy consumption growth in all sectors, following changing lifestyle patterns as well as booming industrial production. In economic terms, India seems poised to be the next emerging giant, in both economic and energetic terms. We hope that this paper will constitute one of the first in a series of steps shedding light on some of the details of recent trends in order to inform the development of effective policies to address the negative impacts of energy demand growth.

The analysis focuses on the transport sector. To date, there have been a variety of studies covering various sub-sectors and use patterns, but none which attempts to integrate all available data into a comprehensive picture of the sector. This paper therefore fills an important gap, and we hope that it will provide a useful basis for forecasts of future sector growth and effective mitigation strategies.

The analysis emphasizes the use of a bottom-up methodology in order to articulate the underlying drivers of energy consumption in the transport sector. These include shifts in mode and fuel, freight volume as a function of economic growth, and the uptake of personal vehicles and increase of passenger miles as new modes of transportation become affordable to a wider population. The following section describes the methodology developed for this study (as well as other current LBNL efforts). In addition to detailing results, the paper compares with other aggregate estimates.

2. Methodology

Population and GDP are two fundamental drivers that influence person and freight mobility demand. Between 1971 and 2004, India population increased at an annual average growth rate of 2.0% and GDP grew at an average rate of 5.0% (WB, 2004). According to the IEA energy balance for India, transport energy consumption represents 10% of total non-biomass primary energy demand, industry 30%, building 13% and energy transformation 47%. Energy consumption in the transport sector represents still a small proportion compared to industrialized countries where it is close to 25% (IEA, 2004). In India, motorization is still low but car ownership is increasing fast as GDP increases. Figure 1 shows the evolution of car ownership per inhabitant as income increases. GDP (constant 2000 US$) grew at annual average of 3.1% between 1975 and 1980, of 11.4% between 1980 and 1990 and of 13.2% between 1990 and 2002 (WB, 2008), whereas the car ownership per capita increased at annual average of 25% between 1975 and 1980, of 13% between 1980 and 1990 and of 7.4% between 1990 and 2002.
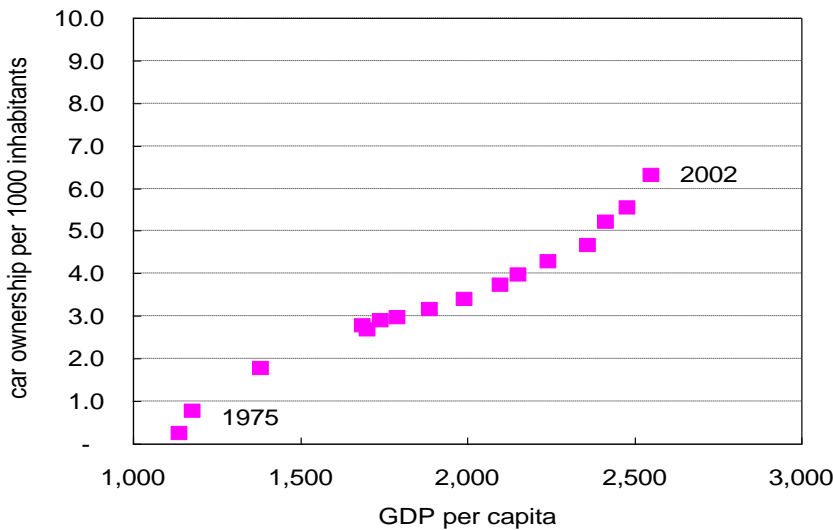

Figure 1. Car Ownership and GDP per Capita

2.1 Bottom-Up Approach

Energy consumed in the transport sector responds to the demand of mobility services. Statistics that describe transport energy consumption can be analyzed under two main approaches. The first approach typically consists of analyzing statistics on fuel consumption from national sources and constitutes in a top down approach. A second approach consists in gathering detailed statistics such as car ownership, vehicle registration and surveys that assess transport characteristics such as load factors, distance traveled and vehicles fuel economy. The second approach corresponds to a bottom up analysis of transport services. Our interest in this paper is to look at how the two approaches compare in India.

Demand for transportation is a matter of movement of people and freight over certain distances and technology. Two main breakdowns are introduced to deepen the analysis. We separate passenger from freight transport and distinguish between each transport modes. We measure passenger-kilometers and tonne-kilometers by looking at vehicle registration, the quantity of tonnes carried in the case of freight and persons transported in the case of passenger travel, kilometers traveled and vehicle efficiency. This task requires an extensive data investigation, since load factors and efficiencies of cars and other forms of passenger transport are difficult to monitor. Equation 1 describes the relationship between drivers of transport energy consumption.

Equation 1: $$E = \sum_{k}^{OPTION} \sum_{t}^{OPTION} \sum_{r}^{OPTION} V_{t,r} \times Km_{t,r} \times LF_{t,r} \times EI_{k,t,r}$$

where:

E	=	final energy demand in the transport sector,
k	=	fuel type
t	=	transport type (passenger, freight)
r	=	mode type (road, rail, water, air, pipeline)
$V_{t,r,i}$	=	number of vehicles of transport service of type t in mode r
$Km_{t,r}$	=	distance traveled of transport service of type t in mode r
$LF_{t,r}$	=	load factor of vehicles of transport service of type t in mode r
$EI_{k,t,r,}$	=	average energy intensity of energy type k for transport service of type t in mode r in MJ/(passenger-km-year) and MJ/(tonne-km-year).

Passenger-km and tonne-km are available from statistics for rail and air, and vehicle stock, average traveled distance and load factor are used to scale up the activities for road passenger-km, while ton-km for truck were obtained from multiple sources. We further disaggregated it to truck stock, travelled distance and average tonnage.

2.2 Existing research

Many studies to date have addressed the major modes in passenger road transport, namely cars, two-wheelers, auto-rickshaws, and buses. Singh (2006) estimated the passenger mobility on road and the major drivers from1950 to 2000. An earlier research done by Bose (1998) has formulated a simulation model to analyze the drivers also in road transport in four Indian metropolises. Many other studies have also been focused on the same sector, and some detailed analysis has been conducted for few major cities in India, for example Reddy (2000) has analyzed the trend in passenger transport in Mumbai and Maharashtra, and estimated the energy consumption from 1987 to 1996. Das (2004) looked at the different growth scenario in vehicles and travel demand up to 2020 in Mumbai and Delhi, and estimated energy needs and environmental implication. However no comprehensive data collection or analysis has yet been done and current studies have lacked detail on energy demand and fuel mix for each mode. Additionally, different data sources often show large inconsistencies, and the calibration with existing statistics in energy use has not been seen.

This paper attempts to fill a gap in current efforts by developing a database on all transport modes including passenger air and water, and freight in order to facilitate the development of energy demand scenarios and assess the significance of transport technology potential in a global greenhouse gas (GHG) emissions model. An extensive literature review and data collection has been done to establish the database with breakdown of mobility, intensity, distance, and fuel mix of all transportation modes. In addition to being as comprehensive as possible, an emphasis is placed on consistency between bottom up and top-down sources. Therefore, energy consumption was compared with aggregated transport energy consumption from the International Energy Agency (IEA). In some cases, the aggregate data was used for calibration, while in others, the bottom-up suggests instances where the official statistics may under- or overestimate actual consumption.

From a theoretical standpoint, the establishment of an analytical framework for bottom-up energy accounting will facilitate accurate and detailed forecasting models from which GHG emissions mitigation policies can be evaluated. The underlying (macroeconomic) drivers of transport activity and projections of energy demand that follow will be the subject of a forthcoming report.

3. India Transportation Energy Use from the bottom-up analysis

3.1 Passenger

3.1.1 Vehicle Stocks and Car Ownership

The passenger vehicle stock data in India are most available in the Statistical Abstract (MOS, 2004). It is growing fastest in two wheelers and auto-rickshaws (Figure 2). They have increased at a AGR of 11% and 12% respectively. The growth in auto

population is also significant, which is 11% for taxis and 10% for personal cars and jeeps. The growth rate for buses is only

7%. Car ownership (cars and jeeps) increased from 0.33% to 0.67% cars per capita in 1991-2001[1].
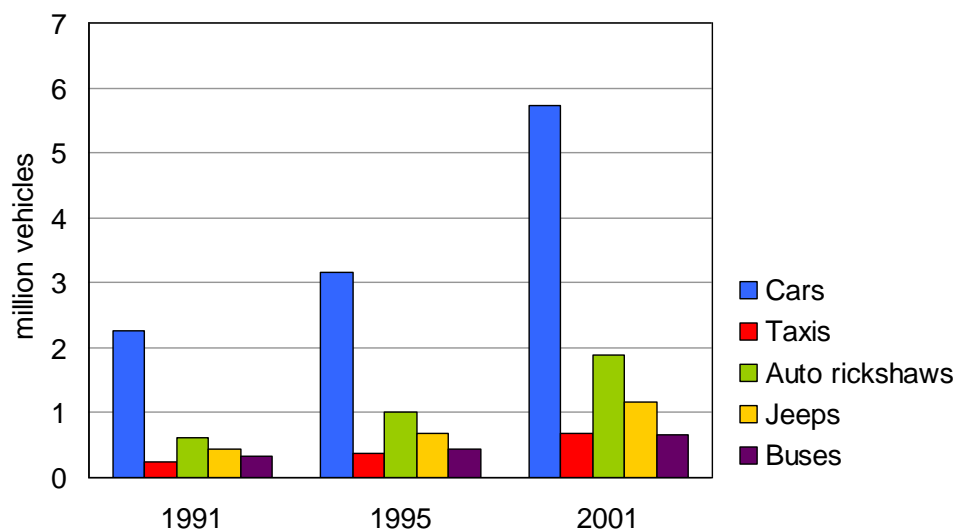
Figure 2. Change in Vehicle Stock

3.1.2 Travelled Distance and Average Load Factor

Travel distance and average load factor (occupancy) and source are shown in Table 1. Singh (2006) suggests that the

increase in passenger-km is due to a 12 fold increase in annual distance travelled per person, from 285 km in 1950 to 3470 km

in 2000. Historic trends in IEA-11 countries show that the average use of vehicles has not risen as passenger travel and car

ownership level. Vehicles in those countries are driven between 10,000 and 20,000 km per year, and car travel (passenger-km)

has grown at about the same rate as car ownership. We assume, therefore, the per vehicle travel distance did not change in

India between 1991 and 2000. The travel distance in 2000 was derived from Singh (2006)

We took a similar approach for average passenger load, assuming a constant factor of 3.18 persons for cars, 1.76 for auto-

rickshaws and 1.5 for two-wheelers (Singh, 2006).[2]

Table 1. Vehicle Utilization in Road Passenger

	Travel distance (km)	Occupancy (person)
Car, Taxi and Jeep	12,600. 6, 9919 for car, 35,000 for taxi	3.18
Bus	88,342	41.6

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[1] This is registered vehicles. There is a possibility that the registration overestimates actural in use vehicles, since some non-operational vehicles may still be registered

[2] Bose (1998) suggests the number for car and jeep is 2.5 person

Auto rickshaw		33,500			1.76		
Two-wheeler		6,300			1.5		

3.1.3 Intensity by Mode

Table 2 lists the energy intensities for all modes. Energy intensity on road and rail are derived from Singh (2006), together with the data from the Ministry of Railways (MOR, various issues). Water and air intensity (MJ/passenger-km) are estimated from the authors' previous research in China (Jiang Lin, Nan Zhou, et.al.2006). No data are available for historic trends in energy intensity for most of the modes. However experience in the developed world has shown that energy intensity has not declined as much except for air (IEA, 2004). Car energy intensity only declined by about 10% across the IEA-11 countries from 1974 to 1998, while almost no change can be observed for that of rail and for bus; an actual increase in energy intensity can in fact be seen. In many cases, energy efficiency improvements have been largely offset by the use of more powerful cars. We assume that energy intensity remains constant for all modes in the period 1991-2000.

Among the modes, bus and rail (particularly electric) appears to be the most efficient, and air travel energy intensity is just slightly higher than that of cars. These are all attributable to their higher load factor or occupancy, and travel distance.

Table 2. Derived Energy Intensities in Passenger Transport (MJ/Passenger-km)

Road		Rail		Water		Air	
Car, Taxi and Jeep	0.94	Steam	1.28	Inland	0.4	Jet Kerosene	2.5
Bus	0.19	Diesel	0.24	Coastal	0.49	Aviation gasoline	1.5
Auto rickshaw	0.58	Electricity	0.12				
Two-wheeler	0.53						

3.1.4 Fuel Share

Previous studies have shown that the share of diesel use for cars has increased from 40% to 80% in 1991-2000 in four Indian metropolises, while the gasoline share fell correspondingly (Bose, 1998 and Das, 2004). Government policies call for the introduction of CNG and electricity-driven vehicles in big cities; it will take time, however for these to have a significant impact in fuel shares.

In the rail mode, steam-driven train use declined from 22% in 1991 to almost 0% by 1994, with a corresponding increase in both diesel and electric trains. Diesel use increased from 50% to 64%, and electric train from 28% to 36%, an approximately 7.1% and 7.4% of annual growth respectively. Diesel is predominately used in bus and water transport, while air uses mostly jet kerosene, and possibly some aviation gasoline[3].

3.1.5 Passenger-Km by Mode trend

Using the vehicle stocks and travelled distance described above, it allows the calculation of passenger-kms. Passenger-km in India has increased from 1847 billion passenger-kilometers (BPkm) to 3700 BPkm between 1991 and 2001, at an annual growth rate (AGR) of 7.6% (Figure 3), while the AGR is 1.8% and 6% for population and GDP, respectively. The growth in each passenger transport mode varies from 1.7% (water) to 8.3% (road). Road transport rose the fastest at 8.3%, followed by air at 5.8% and rail by 4.2%, while demand for water has grown at a slower pace with an AGR of only 1.7%. Among the four modes, road dominated overall passenger transport with a share of 82% in 1991 and 86% in 2000. Although rail has also increased, the share for railway has decreased from 17% to 13% during the ten years, which is not surprising. All over the world, rail transport shares are stagnating as a result of intense competition from road transport. Operational inefficiencies and capacity constraints on key routes have also played a role in the slow growth of India's rail traffic (WB,2002).Although a large proportion of passenger mobility (in terms of passenger-km) is still catered to by buses, the share of bus use in road transport has decreased from 81% to 76% (Figure 4 and Table 3). The use of cars and jeeps has increased from 7.9% to 9.2%, motorcycles (two wheelers) from 8.9% to 11.8%, and auto-rickshaws from 2.4% to 3.4%. In per capita terms, the passenger-km by cars(including taxis), two wheelers and auto-rickshaws has increased by 136%, 145% and 156% respectively, in contrast with the increase of 70% in buses and a mere 31% for railways (Figure 5).
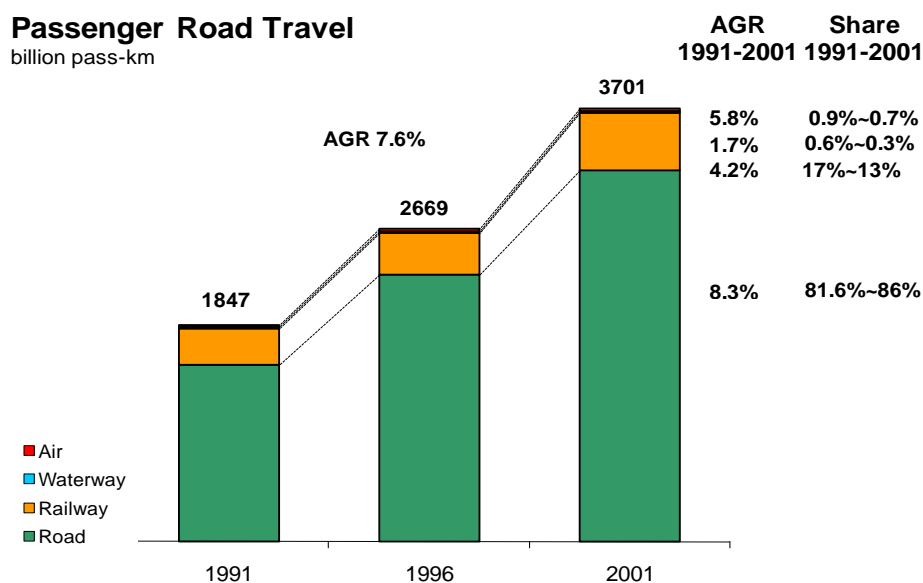
India has about 5,560 km of main coastline serviced by 12 major ports and about 184 minor ports. The capacity of Indian ports increased from 20 million tonnes of cargo handling in 1951 to 281 MT on March 2001, and 390 MT as of March 2004 (Planning Commission of India, 2002, and India Factfile). The main passenger movement by inland waterways is via ferry operations across rivers, on short stretches along rivers and tourism-based passenger traffic. Although data exist for the total length and ports of waterways, data on mobility from published sources leave much to be desired. Given limited published data on vessel numbers, survey results on inland water passengers carried in a few major ports (Rangaraj and Raghuram, 2006) are used. The extent of traffic has been estimated in 2003-2004, for the government run services only as about 24 million passengers and 0.733 million tonnes of freight on the ferry services across rivers and about 0.6 million passengers and 57 thousand tonnes on long distance. By applying average travelled distance of inland waterways in China (Fridley, 2006), we

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[3] In China, about 2% of the fuel used in air transport is aviation gas.

estimated water mobility year by year, and Figure 6 shows the result. Water transportation accounts for only a very small proportion, 0.6% of Indian transport in 1991 and 0.3% in 2001. Inland water transport in India is dominated by country boats which cater to passenger traffic. Although inland water transport plays a small supplementary role in freight, it dominants the water mobility in the passenger sector with a share of 60% in 1991 and 79% in 2001.

Statistical data are available for both passenger and passenger-km for air transport in India (MOS,2004), indicating that domestic air grew at 6.4% per year, slightly faster than that of international air which is 4.2% (Figure 7).

Passenger Road Travel
billion pass-km

	AGR 1991-2001	Share 1991-2001
	5.8%	0.9%~0.7%
	1.7%	0.6%~0.3%
	4.2%	17%~13%
	8.3%	81.6%~86%

3701

AGR 7.6%

2669

1847

Legend:
- Air
- Waterway
- Railway
- Road

1991 1996 2001

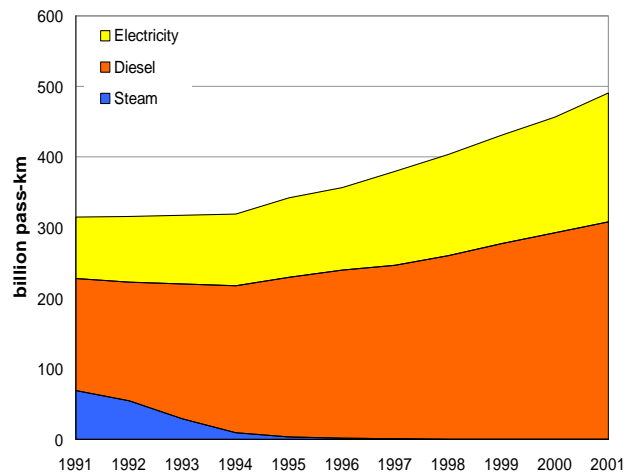*Figure 3. Estimated Passenger Transportation Mobility by Mode*
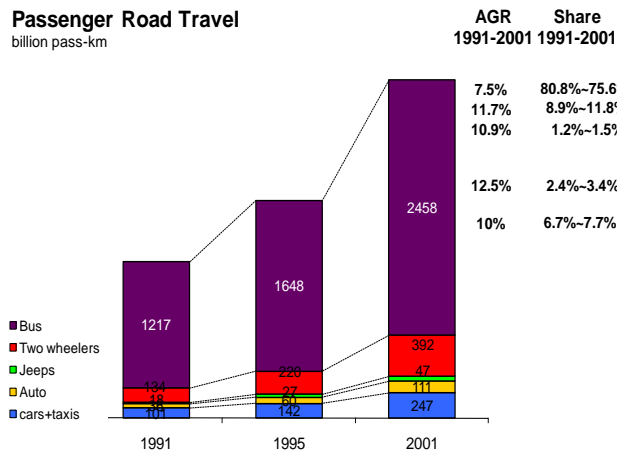
Figure 4. Road Passenger Transportation Mobility by Vehicle Type

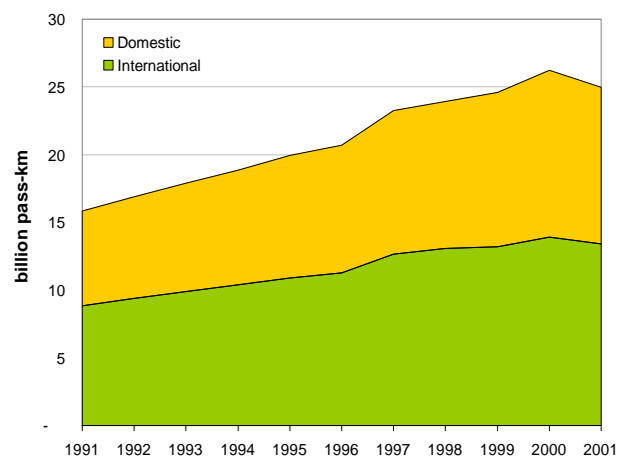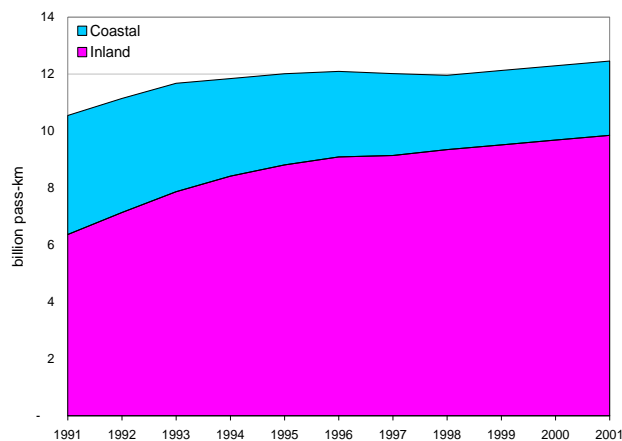*Figure 5. Passenger Rail Mobility by Energy Type*

Figure 6. Passenger Water Mobility

Figure 7. Passenger Air Mobility

Table 3. The Growth Rate of the Passenger-km in Transportation Road Sector

	Passenger-km			Share	
	1991	2001	growth rate	Share in 1991	Share in 2000
Road	1505.76	3172.71	8.3%	81.5%	86.1%
Cars	87.19	245.39	9.8%	5.8%	6.6%
Taxis	13.39	37.61	11.2%	0.9%	1.1%
Auto	36.40	110.91	12.5%	2.4%	3.4%
Jeeps	17.78	46.84	10.9%	1.2%	1.5%
Two wheelers	134.19	391.97	11.7%	8.9%	11.8%
Bus	1216.80	2457.95	7.5%	80.8%	75.6%

3.2 Freight

While passenger travel patterns are more closely related to personal wealth and lifestyle changes, freight transport activities are closely connected to overall economic activity.

3.2.1 Ton-Km by Mode

Historical statistics in freight transport activity, measured in tonne-km, does not exist for freight road mobility, nor has it been discussed in existing studies. Estimates could be found from different departments in India and international organizations, however. Estimates from different sources vary significantly. For instance, the tenth five year plan shows 520 billion tonne-km in 1999. Similarly, a report from National Maritime Development Programme[4] indicated it is 600 billion tonne-km in 2005. Most of the sources (WB, 2002 and FICCI, 2005) (Figure 8), however, suggest higher figures. The World Bank report suggests that it had already reached 586 billion tonne-km by 1998[5]; the report of the Transport Corporation of India (TCI) shows 800 billion tonne-km[6] in 1999, whereas another analysis indicates 1,390 billion tonne-km in 2003[7]. The National Planning Commission estimated freight traffic by road would increase from 807 in 1997 to between 1,276 and 1,700 billion ton-km by 2002 (Bose,2001). Finally, the FICCI report (2005) indicates 1,500 billion ton-km in 2005. As listed, the interpolated freight road mobility in 2000 ranges from 541.7 to 1,100 billion ton-km. One indication of the reliability of these estimates is consistency with total diesel fuel consumption statistics. As we discuss below, however, the diesel consumption statistic itself is in some doubt. To address this uncertainty, we created two scenarios(high-case and mid-case) which were constructed by interpolation between the 1997 data point to either the high and low estimates in 2001 (Figure 9), thus bounding the range of likely values .

Freight mobility increased between 1991 and 2001 at 11.4% in the high-case and 5.7% in the mid-case annually, which is most attributable to the increase in truck use. There has been a shift of freight ton-km from rail to trucks. Truck activity enjoyed an increase of share from 47% to 74% in the high-case. In the mid-case, the share remains almost constant, increasing to only 49%. In absolute terms, it increased 412% at the high-case and 203% at the low case from 1991 to 2000.

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[4] http://www.shipping.gov.in/writereaddata/linkimages/NMDP9895746561.doc

[5] It shows a annual growth rate of 11.9% from 1991 to 1998 and it is 267 billion ton-km in 1991

[6] http://www.tcil.com/rt.asp

[7] Phasing Out Overloading… How Truck Manufacturers Can Go on an Overdrive
http://www.way2wealth.com/research/content_details.php?section=Insights&section_desc=viewsonnews&sid=41&pubid=28575

As observed in passenger transport, the rail sector has experienced sharp reduction in share from 45.4% to 21% at the high-case and 34% at the mid-case. Due to the increase of truck activity, the share of water and air transportation has shrunk. Within water-borne freight, coastal water has accounted for 99% across the years, while for air, the international still dominates, but its' share has declined from 84% to 71%.The increase in the role of trucks reflects freight toward products for which trucks have inherent advantages over competing modes, and the trend observed in India is consistent with experience in other countries (Lee and Merer,1992).
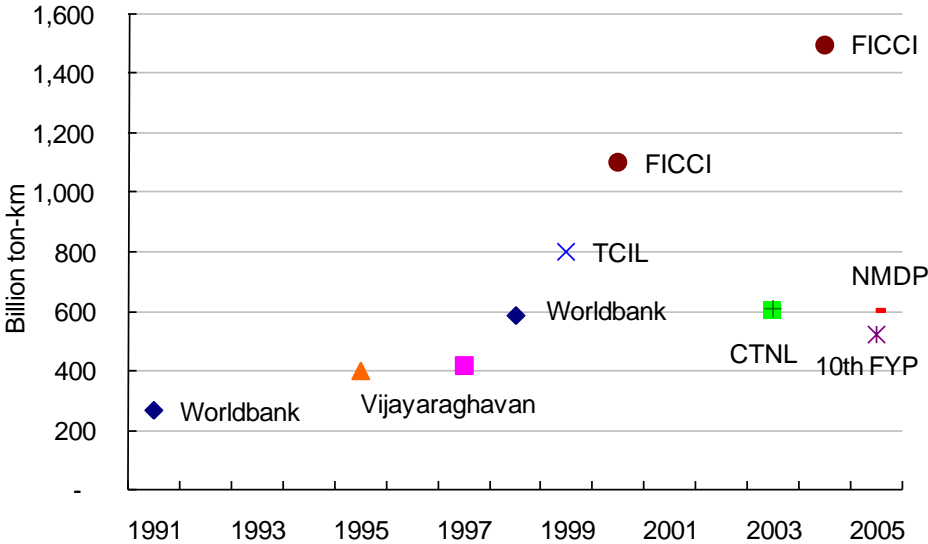
Note: FICCI (Federation of Indian Chambers of Commerce and Industry), TCIL(Telecommunications Consultants India Ltd)
CTNL(Consolidated Toll Network Ltd), NMDP(National maritime Development Programme)

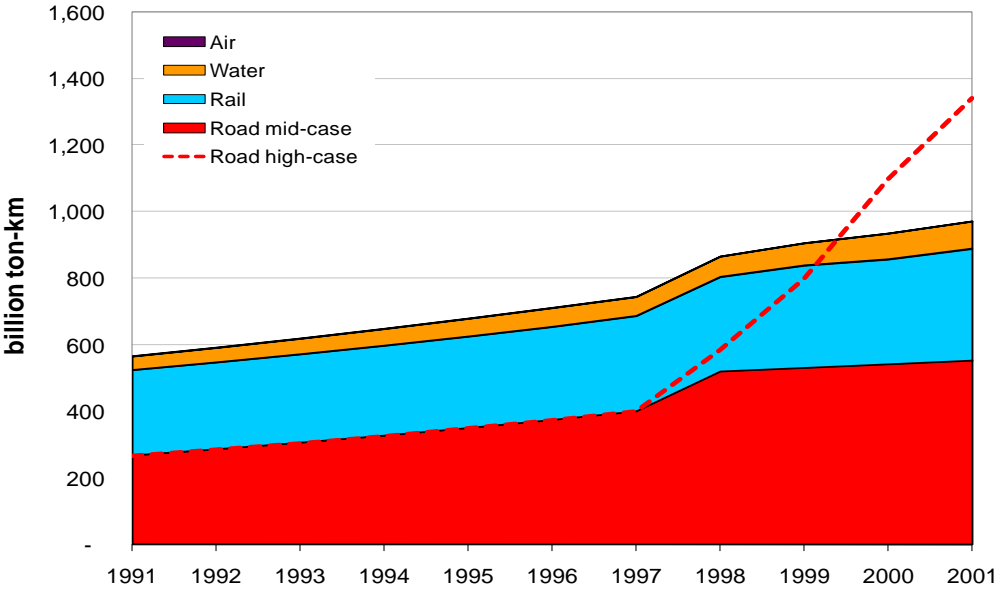*Figure 8. Available data for Freight Ton-km by different sources*

Figure 9. Freight Transportation Mobility by Mode

3.2.2 Intensity by Mode

The aggregate energy intensity for freight in the developed world has been remarkably stable, indicating that freight transport is not becoming less energy intensive across countries. We assume the trend to be the same in India. Energy intensity data are generally not available for Indian freight transport except for rail, which can be derived from the Ministry of Railways' statistics (MOR, multiple years). Intensities for the remaining modes are estimated based on our previous China study (Lin,2006), and calibrated based on fuel consumption reported in the public statistics such as (TERI,2001 and IEA,2004)

Table 4 shows the average energy intensity for all modes of freight transport in India. The intensity for trucks is 1.85MJ per tonne-km, compared with that of IEA countries at from 1,8 to 4.7 MJ in 2000 and China at 1.55 MJ. Intensity of steam trains in Rail sector has increased significantly; this is because of the decline of ton-km in steam.

Table 4. Energy Intensities in Freight Transport (MJ/ton-km)

Road		Rail		Air		Water
Truck	1.85	Steam	3.3 in 1991, 15.88 in 2000	Jet Kerosene	17.3	0.3 in 1991 0.28 in 2000
Tractor	2.64	Diesel	0.117	Aviation gasoline	16.6	
		Electricity	0.064			

3.2.3 Truck Stocks and distance travelled

The significant increase of freight road ton-km can be attributed to the dramatic growth of the truck stock and the average distance travelled. The stock of trucks includes both vehicles for goods transport and tractors, and is available in the statistics historically. The data show steady growth from year to year at an annual growth rate of 7% (Figure 10). The number of the trips or distance travelled increases with the industrial and agricultural output, which is linked to economic development. Although statistics are not available for the two variables driving tonne-km, some information was found through a search of the literature. They indicate that average distance travelled per truck per day in India is 280km and the number of annual days in operation were 250 days in 2003 [8], which can be translated to 70,000 km. The World Bank report indicates that the average travelled distance for trucks in India ranges from 60,000 to 100,000 km[9]. However, from the tonne-km data, we could back calculate the distance using

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[8] Phasing Out Overloading……… How Truck Manufacturers Can Go on an Overdrive
http://www.way2wealth.com/research/content_details.php?section=Insights&section_desc=viewsonnews&sid=41&pubid=28575
[9] available at http://web.worldbank.org/servlets/ECR?contentMDK=20747263&sitePK=579306

the stock and the average tonnage presented earlier. The results show 25,212 km in 1991, 53,299 km for high-case and 26,248 km for mid-case in 2000.
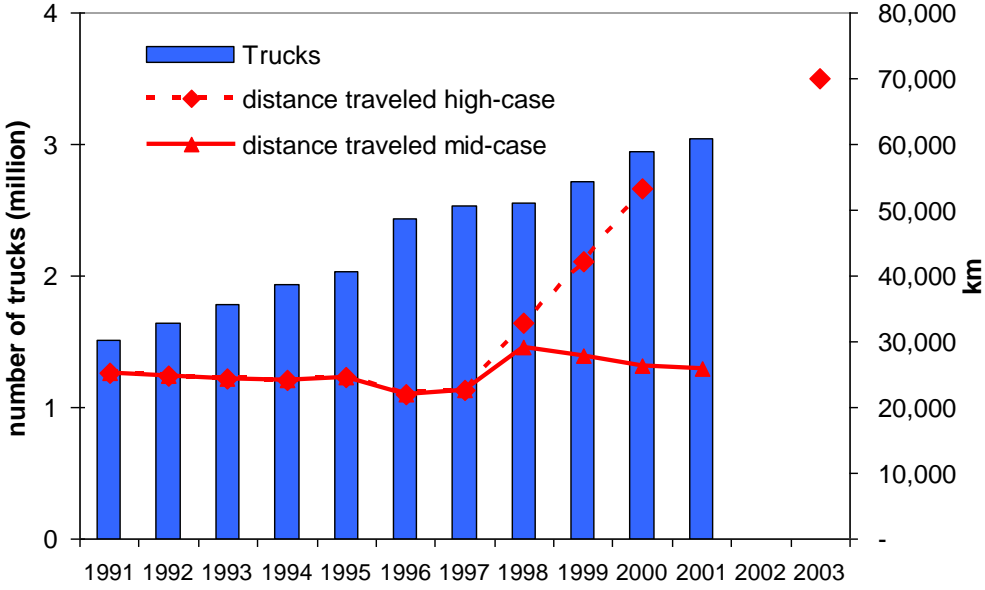

Figure 10. Change in Truck Stock and Utilization

3.2.4 Truck Average Load per Vehicle

As is the case for travel distance, the average load of trucks is generally not available in the statistics, nor could this quantity be easily found in technical papers. From the above mentioned article, the average tonnes carried per truck in India is 7 tonnes in 2003. Trucks are generally overloaded, it is estimated that a 16 tonne truck carries as much as 12 to 14 tonnes of load despite the stipulated carrying capacity of 9 tonnes.

Historical trends in IEA countries also suggest that the truck load has not changed over time, thus we assumed constant load in India across the years (IEA,2004a).

4. Transportation Energy Use and Discussion

4.1 Discussion on diesel use in transport sector

Energy use in India has grown rapidly over the years, and the transportation sector is a major energy-consuming sector, particularly of petroleum products. The transportation sector consumes more than 85% of the total High-speed-diesel consumed nationally (Singh,2006). However, the energy data released by the Ministry of Statistics

(MOS) shows the High-speed-diesel used in transportation sector only accounts for 59% of the total in 2000, at 22.2 million tones (950 PJ) out of 37.9 million tones (1,625 PJ)[10]. The same data also show a significant drop in diesel consumption in the transport sector after 1996. It is possible that the definition or reporting system has been changed, but why and how still remains mysterious. On the other hand, Pundir (2001) suggested that the automotive diesel consumption alone in 1999 is 42(1,798 PJ) million tons, more than the total diesel consumption in the country in 2000 that is reported in the MOSPI's statistic. Furthermore, another study done by the Department of Road Transport &Highways, India (Rewat, 2004)[11] indicates the high-speed-diesel consumption in Indian transport sector in 2000 should be about 40 million tons (1,712 PJ), using data from CMIE (Centre for Monitoring Indian Economy) monthly report. Our bottom-up analysis using the drivers presented in the previous sections, suggests that high-speed-diesel used in road transport sector is 1,705 PJ.

Before making judgment of whether these assumptions or the statistic is more accurate, an analysis on what the reasonable assumptions of driving pattern needs to be made. Given the significant inconsistency in the statistics, three scenarios were made to have a adjustment. The Post 96 adjusted transport diesel scenario (Post 96) is to assume the data after 1996 were right, and with a back calculation for the previous years; Pre 96 adjusted transport diesel (Pre 96) assumes the data before 1996 are more reliable; Siphoning off of kerosene from PDS (public distribution system) is estimated as 18.1 % of the total PDS sales, which is mostly sold in gas stations and could be allocated to transport diesel use (NCAER,2005). Transport Diesel +18% Kero scenario have added the kerosene use from PDS on top of Pre 96 scenario. Figure 11 illustrates the three scenarios and corresponding total diesel consumption scenarios. Assuming the vehicle stock statistic is accurate, and the intensity number is reasonable, traveled distance could be derived from the three scenarios. The estimated travel distance of a truck is 12,500 km in Post 96 scenario, 36,900 km in Pre 96 scenario, and 43,900 km in + 18% Kero scenario. Considering it is 25,212 km in 1991 in India, ad China is 50,000 km in 2000 (Fridley,2006), the Post 96 scenario implies an unrealistically low distance travelled. We therefore conclude that the more recent statistics on diesel consumption probably represent an underestimate.

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[10] available at http://mospi.nic.in:80/mospi_energy_stat.htm
[11] available at www.iea.org/Textbase/work/2004/shanghai/Rawat.PDF
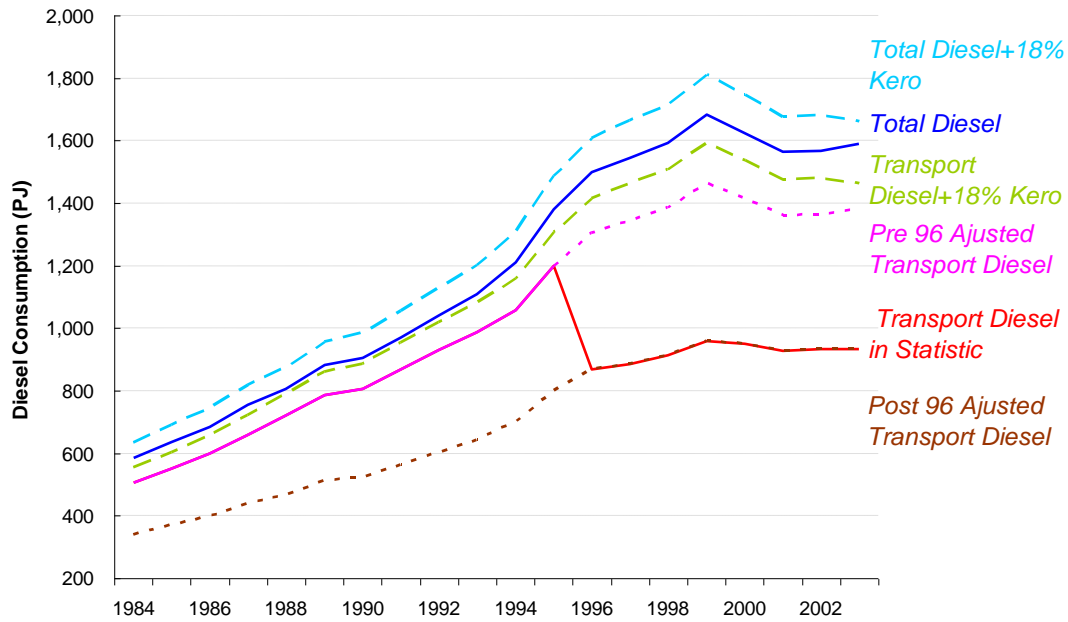
Figure 11. Top-down Estimates of Indian Transport Diesel Consumption Based on Statistics

4.2 Comparison with IEA data

The energy consumption estimates described above were compared with IEA India data. As the result our bottom-up analysis, we estimated that the energy consumption from 1991 to 2000 has increased at a growth rate of 14% for the high-case and 9% for mid-case ,which corresponds to considerable growth in mobility, and is much higher than IEA estimate of 1.7% annual growth, which is based on more aggregate data. Figure 12 shows the comparison by fuel type. For the rail and road sectors, most of the fuels are consistent except for diesel consumption. As in the statistic from India Ministry of Statistics, the IEA data indicates a sharp drop in diesel consumption from 1995 and a steady level thereafter through 2000, which does not seem to reflect the growth in mobility. The same trend could be observed in water energy consumption; furthermore, the IEA data also show significant use of coal in water transport, which could not be deduced from our bottom-up analysis. This paper intends to establish a database for India transport energy consumption in order to facilitate the development of energy demand scenarios and assess the significance of transport technology potential in a global climate change model. The discussion of the discrepancy and accuracy of the data will be addressed in the next step.
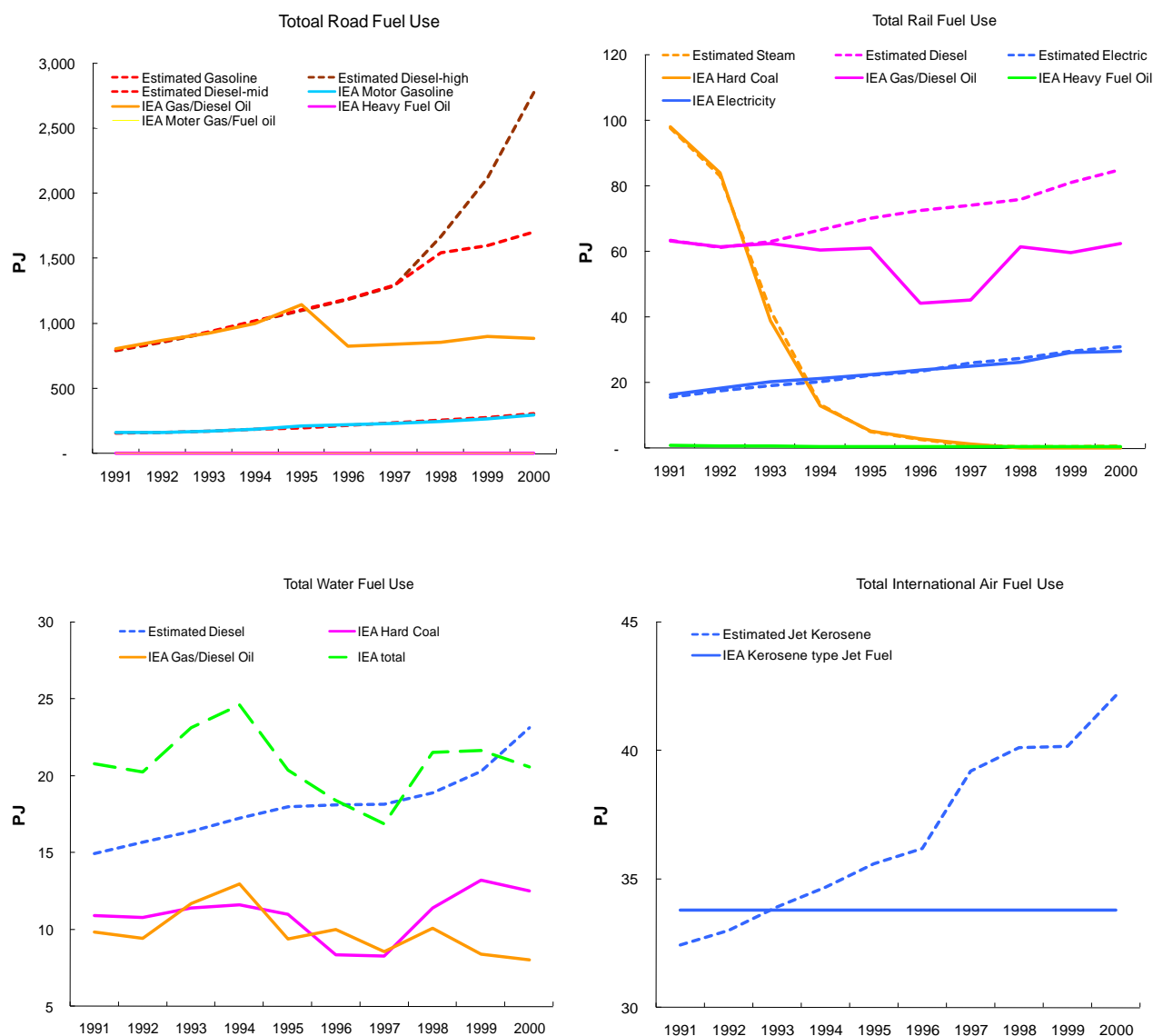
Figure 12. Comparison of the Estimated and IEA Transport Energy Use in India

4.3 Estimated Transportation Energy Use by mode

Singh (2006) also suggested that passenger transport accounts for a significant proportion of energy consumed in the transport sector. Our analysis, however, shows that passenger transport accounted for a about half of the total energy in 1991, and that this share decreased to 34% by 2000 in the high-case scenario and remained constant in the mid-case scenario (Figure 13).The total energy used in the transportation sector has increased from 1183 PJ to 3309 PJ in high-case and 2232 PJ in mid-case. Energy use in freight surged by 275% and 90%, at an AGR of 16% and 7% respectively, compared to 83% growth and AGR of 6% in passenger transport energy use. This growth has mostly been in the road mode, which grew by 121% in passenger and 312% (high-case) and 103% (Mid-case) in

freight; Energy use in the rail mode has declined by approximately one third in both passenger and freight; energy used in water accounts for only a very small proportion of the total, particularly in passenger which has also declined by 49% ,while it increased by 76% in water-borne freight; Air energy consumption has increased by 65% in passenger and 51% in freight, and the air in freight is insignificant compared that in passenger which accounts for more than 90% of the total air energy use.

For freight road, the increase is driven by truck ton-km, which is in turn driven by increase in both truck stock and travel distance.
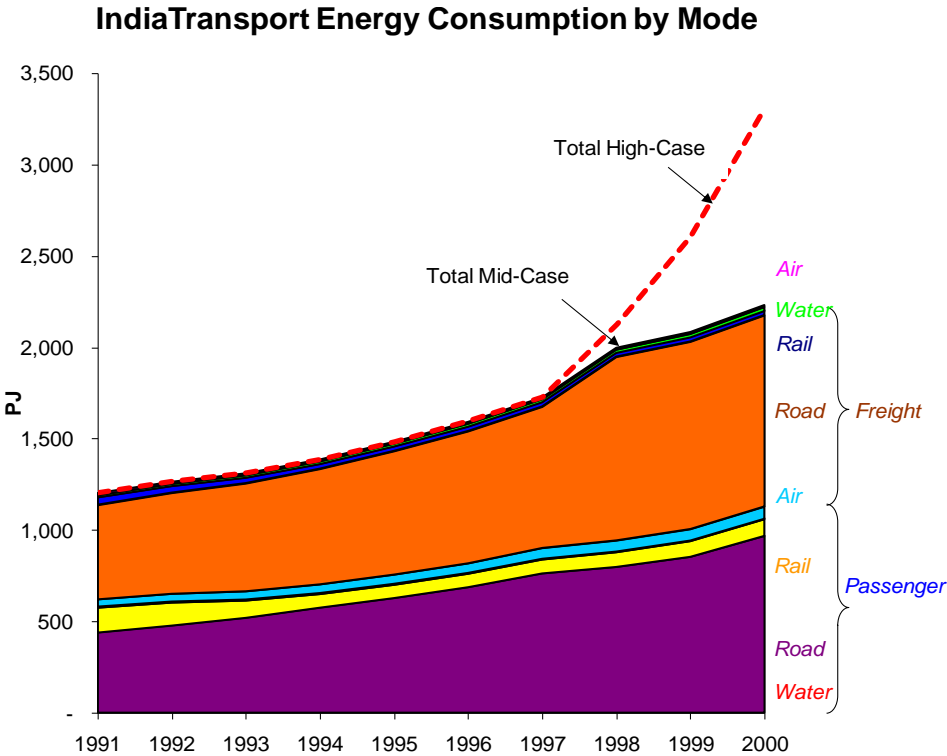

Figure 13. India Transportation Energy Consumption by Mode in 1991-2000

4.4 Transportation Energy Use by Fuel

Fuel use in transportation in India is dominated by diesel, which accounted for 73% of the total in 1991 and increased to 87%for the high-case and 81% for the mid-case in 2000, with 75% and 60% used in freight sector in 2000, respectively (Figure 14). There also has been a gradual shift from coal to diesel as the main fuel in rail transport. While the share of coal in the total transport energy demand in 1980/1981 was 27% (Tata, 1996), it declined to 8% in 1991 and almost zero in 2000. The share of electricity use in total transport, which is mostly used in rail, is insignificant and has been steady. Gasoline accounts for 27% in passenger transport and only 9% (high-

case) or 14% (mid-case) in total transport in 2000. While it is a major fuel in passenger road transport, its share has decreased from 78% in 1991 to 65% in 2000, during which time diesel increased from 22% to 35%. This could be because current tax policies are accelerating the trend towards diesel cars and bigger cars. As a consequence, more diesel powered vehicles have been adopted over the years. In Delhi, diesel cars have increased by 425% over the past decade[12]. Fuel use in air transport is jet kerosene, which accounted for 4% of total transport energy in 1991 and decreased to 2% in 2000. This fuel is mostly used for passenger air transport.
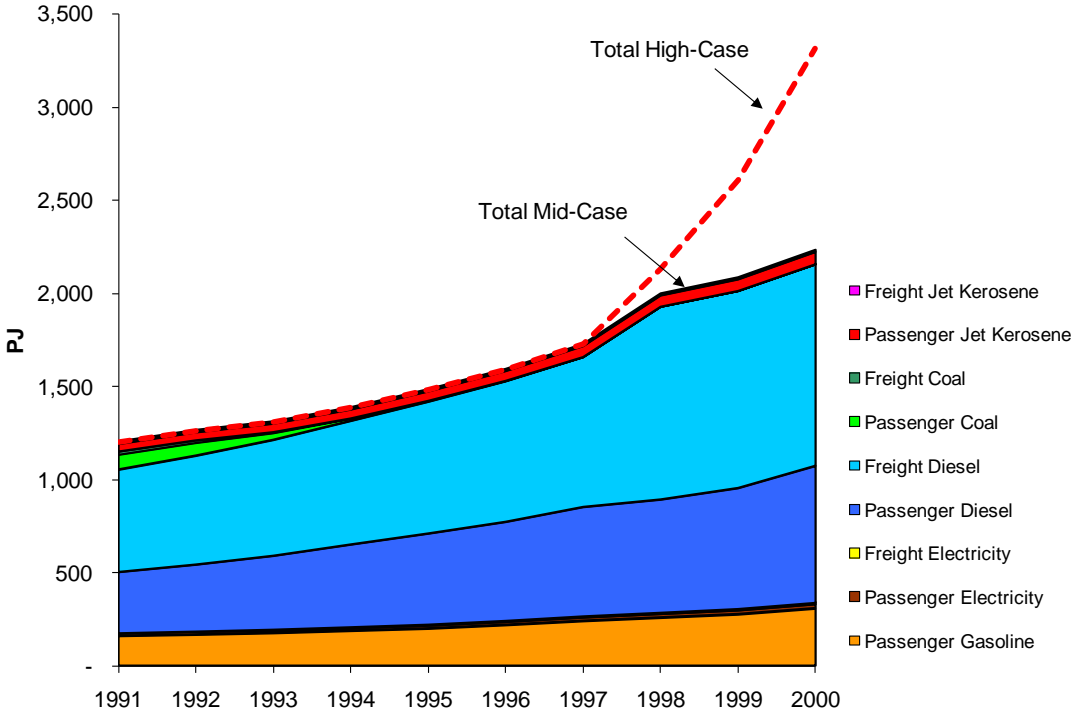
IndiaTransport Energy Consumption by Fuel

Figure 14. India Transportation Energy Consumption by Fuel in 1991-2000

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[12] according to Centre for Science and Environment's website, http://www.cseindia.org/campaign/apc/letter.htm

5. Conclusions

We hope that this paper fills an important gap by characterizing the trends and drivers in a major energy sector in India. The analysis gives a fairly detailed picture of the influence that economic growth has had in the recent past, and is likely to continue to have. The advantage of using a bottom-up analysis is that it provides this detail, but hopefully, it gives a more accurate picture as well. In the case of Indian transport, the bottom-up approach seems to point to possible inaccuracies in the top-down data, particularly in terms of diesel fuel consumption. Further research is required to determine if there are not also errors in our assumptions, but the decrease and flattening of diesel fuel consumption on roads– by far the largest component of the sector – seems difficult to explain with reasonable assumptions of driver behavior.

In presenting this analysis, we hope not only to say something about a particular sector in India, but to demonstrate an approach that we hope will provide insights into other sectors and countries as well. In terms of India, we hope to continue this effort towards building a more complete and detailed database which will be useful to policymakers there, as well as to the international community of researchers, for whom India is likely to continue to gain attention. Ultimately, however, energy-related environmental impacts, particularly climate change, are a global issue. We hope that continuing research applying the approach presented above contributes to the understanding of global energy-related emissions, and towards strategies of their reduction.

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