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Residential and Transport Energy Use in India: Past Trend and Future Outlook

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Disclaimer

Preface

The past decade has seen the development of many scenarios describing long-term patterns of future Greenhouse Gas (GHG) emissions. Each new approach adds additional insights to our understanding of overall future energy trends. In most of these models, however, a description of sectoral activity variables is missing. End-use sector-level results for buildings, industry or transportation or analysis of adoption of particular technologies and policies are not provided in global energy modeling efforts.

All major analyses of long-term impacts of greenhouse gas emissions to date rely on scenarios of energy supply and demand. The underlying drivers of all such major scenarios are macro socioeconomic variables (GDP, population) combined with storylines describing the context of economic and social development. Unfortunately, these scenarios do not provide more detail than the sector level (i.e., buildings, industry and transportation). This is to say that the scenarios are developed without reference to the saturation, efficiency, or usage of air conditioners, for example. For energy analysts and policymakers, this is a serious omission, calling into question the very meaning of the scenarios. Energy consumption is driven by the diffusion of various types of equipment; the performance, saturation, and utilization of the equipment has a profound effect on energy demand. Policy analysts wishing to assess the impacts of efficiency or other mitigation policies require more detailed description of drivers and end use breakdown.

Based on these considerations and EETD's extensive expertise in energy demand, the goal of this project is to build a new generation global energy and CO_2 emissions model that will be based on the level of diffusion of end use technologies. The model will address end-use energy demand characteristics including sectoral patterns of energy consumption, trends in saturation and usage of energy-using equipment, technological change including efficiency improvements, and links between urbanization and energy demand.

To this end, LBNL has initiated the Global Energy Demand Collaborative (GEDC) to develop of a new generation of models. The ultimate goal of the GEDC is a complete modeling system that covers the entire world (by region or country), and covers all economic sectors at the end use level. In the short and medium term, the core GEDC team has performed a series of studies such as: country studies, sector studies, or methodology reports. The first of these reports include:

- Sectoral Trends in Global Energy Use and Greenhouse Gas Emissions (Price et al., 2006; de la Rue du Can and Price, 2007)
- Forecasting Building End Use Consumption in Developing Countries (McNeil M. et al, 2008)
- Energy Use in China: Sectoral Trends and Future Outlook (Zhou et al., 2007)
- COBRA-Energy (Wagner and Sathaye, 2005)

The present report draws upon the expertise developed over many years in the Laboratory's International Energy Studies Group in order to present as complete and detailed picture as possible of the components and trends in energy consumption in India.

Executive Summary

The main contribution of this report is to characterize the underlying residential and transport sector end use energy consumption in India. Each sector was analyzed in detail. End-use sector-level information regarding adoption of particular technologies was used as a key input in a bottom-up modeling approach. The report looks at energy used over the period 1990 to 2005 and develops a baseline scenario to 2020. Moreover, the intent of this report is also to highlight available sources of data in India for the residential and transport sectors.

The analysis as performed in this way reveals several interesting features of energy use in India. In the residential sector, an analysis of patterns of energy use and particular end uses shows that biomass (wood), which has traditionally been the main source of primary energy used in households, will stabilize in absolute terms. Meanwhile, due to the forces of urbanization and increased use of commercial fuels, the relative significance of biomass will be greatly diminished by 2020. At the same time, per household residential electricity consumption will likely quadruple in the 20 years between 2000 and 2020. In fact, primary electricity use will increase more rapidly than any other major fuel – even more than oil, in spite of the fact that transport is the most rapidly growing sector. The growth in electricity demand implies that chronic outages are to be expected unless drastic improvements are made both to the efficiency of the power infrastructure and to electric end uses and industrial processes. In the transport sector, the rapid growth in personal vehicle sales indicates strong energy growth in that area. Energy use by cars is expected to grow at an annual growth rate of 11%, increasing demand for oil considerably. In addition, oil consumption used for freight transport will also continue to increase .

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List of Abbreviations and Acronyms

AAGR	Average Annual Growth Rate
ACMA	Automotive Component Manufacturers Association
BEE	Bureau of Energy Efficiency
CEA	Central Electricity Authority
CSO	Central Statistical Organization
GDP	Gross Domestic Product
IEA	International Energy Agency
LCV	Light Commercial Vehicles
LBNL	Lawrence Berkeley National Laboratory
M&HCV	Medium and Heavy Commercial Vehicles
MNES	Ministry of New and Renewable Energy
MOC	Ministry of Coal
MOCI	Ministry of Commerce & Industry
MOG	Ministry of Petroleum and Natural Gas
MOP	Ministry of Power
MOSPI	Ministry of Statistics and Programme Implementation
MOR	Ministry of Railways
MoRTH	Ministry of Road Transport and Motor Transport Statistics of India
MPV	Multipurpose Vehicle
MPCE	Monthly Per Capita Expenditure
MUV	Multi-Utility Vehicle
NSSO	National Sample Survey Organization
SIAM	Society of Indian Automobile Manufacturers
SRES	Special Report on Emissions Scenarios
T&D	Transmission and Distribution
UEC	Unit Energy Consumption

1. Introduction

This study of residential and transport sectoral energy use in India is part of a larger effort at LBNL to provide analysis of energy use patterns at the level of sub-sectors and end uses for all sectors. 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 (Zhou, 2007). India seems poised to be the next emerging giant, in both economic and energetic terms. This report focusing on two key sectors will constitute one of the first in a series of steps on the details of recent trends in order to inform the development of effective policies to address the negative impacts of energy demand growth.

This report looks at energy used at the end use level over the period 1990 to 2005 and develops a baseline scenario to 2020. End-use sector-level information regarding adoption of particular technologies was used as a key input in the bottom-up modeling approach.

2. Macro Activity and Structure Change

2.1 Activity

Population and GDP are two fundamental activity drivers that influence energy demand from all the sectors. Between 1990 and 2005, India's population increased at an annual average growth rate of 1.9% and GDP grew at an average rate of 6.0% (WB, 2005). Urbanization rate remained low at 29% (2004) but is expected to increase rapidly. Population and urbanization rate forecast were based on the United Nations projections for India (UN, 2007a) which estimate a population growth rate of 1.3% and an urbanization level of 35% by 2020 (UN, 2007b). We assume a 7% increase in GDP with continuous increase of service and industry share at the expense of the agriculture sector (Table 1).

Table 1. GDP Projection Assumptions

	1990	2005	2020	AAGR 1990-2005	AAGR 2005-2020
Total	**244**	**585**	**1618**	6.0%	**7.0%**
Agriculture, value added (constant 2000 US$)	78	112	151	2.5%	2.0%
Industry, value added (constant 2000 US$)	64	156	461	6.1%	7.5%
Services, etc., value added (constant 2000 US$)	101	317	1006	7.9%	8.0%
Share					
Agriculture		19%	9%		
Industry		27%	28%		
Services		54%	62%		

2.2 Primary Electricity Factor

National and international statistics generally show energy use in the end use sectors in final energy terms. However final energy does not account for the full energy consumption. One should keep in mind that electricity production requires on average three times its final energy content (de la Rue du Can and Price, 2008). Through out this report energy consumption is displayed using two different accounting methodologies: primary and final energy consumption. Final energy consumption represents the direct amount of energy consumed by end users while primary energy consumption includes final consumption plus the energy that was necessary to produce and deliver electricity. When primary energy consumption in the end use sector is shown, primary electricity is calculated to include all energy use from the electric sector.

In the case of India, the factor that converts final electricity consumption to primary energy is relatively high and was equal to 4.2 in 2005. Hence, consuming one unit of energy from electricity is equal to consuming more than four units of energy at the source of generation. Two reasons explain this large primary energy conversion factor: first electricity distribution and transmission (T&D) losses are substantial, representing 31% of electricity production in 2004 (CEA, 2006) and second electricity is generated for a large part (82%) with the use of fuel combustion with low efficiency (26% for coal, 28% for oil and 41% for gas). Indian T&D losses are among the highest in the world. Only about 50% of the electricity in India is billed on the basis of metered consumption. Balance between metered accounts and total net electricity is met by including the consumption from un-metered agricultural customers and transmission and distribution losses. T&D losses include technical loses and commercial loses that are theft of electricity. However, the primary electricity factor calculated in this report excludes commercial loses from the residential sector as it is based on residential survey data rather than metered consumption. Hence the T&D calculated for 2005 are in the order of 20% of the electricity generated, a lower rate than the 31% estimated by the Central Electricity Authority of India (CEA, 2006).

In this report, the ‘‘direct equivalent’’ accounting method is used similarly as the methodology used in the *Special Report on Emissions Scenarios* (SRES) (Nakicenovic et al., 2000; de la Rue du Can and Price, 2008). This method accounts for the primary energy of the non fossil- fuel energy at the level of secondary energy with an efficiency of a 100%. For example, the primary energy equivalence of electricity generated from hydro or nuclear power plants is set equal to their respective gross electricity output.

Reduction of 1% of T&D losses is estimated to generate savings of over Rs.700 to Rs.800 crores ($17, 5 to 20 Million[1]) and reduction of 10% will save energy equivalent to an additional capacity of 10,000-12,000 MW (MOP, 2007). Realizing the importance of the commercial loss for the country, the Indian government has made one of its priority to reduce them. In 2003, the Electricity Act was enacted, that set stringent penalties for power theft among other reforms directed to promote competition and protecting consumers' interests. Primary electricity factor was forecast to decline at an annual rate of 0.9% during the period 2005 to 2020 to account for the new policy in place and also in conjunction with recent trend that showed an annual rate of decline of -2.3% over the period 2000 to 2005.

Table 2. Primary Electricity Factor Forecast

	1990	**2005**	**2020**	**AAGR 00-05**	**AAGR 05-20**
Fuel input	**2,709**	**6,969**	**19,842**	**6.5%**	**7.2%**
coal	*2,191*	*5,919*	*15,947*	*6.8%*	*6.8%*
gas	*126*	*412*	*1,400*	*8.2%*	*8.5%*
oil	*112*	*210*	*703*	*4.3%*	*8.4%*
nuclear	*22*	*63*	*697*	*7.3%*	*17.4%*
Hydro	*258*	*365*	*1,094*	*2.3%*	*7.6%*
Energy output	**952**	**2,249**	**7,159**	**5.9%**	**8.0%**
Own Uses	81	157	501	4.5%	8.0%
Transmission and distribution loses	204	439	1,289	5.2%	7.4%
Electricity delivered	**682**	**1,652**	**5,369**	**6.1%**	**8.2%**
Primary factor	3.97	4.22	3.72	0.4%	-0.9%

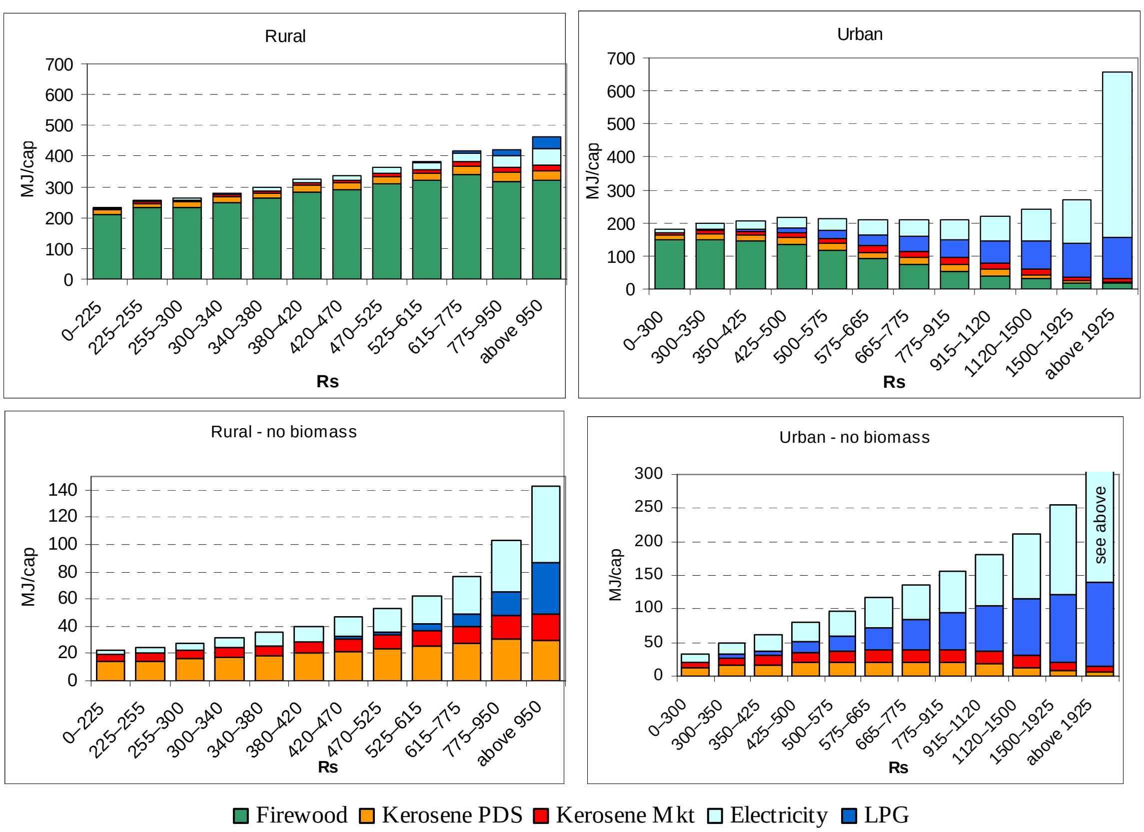
[1] Exchange rate of $1=40 INR, 1 July 4, 2007.

3. The Residential Sector

India is the second world's most populous country, after China, and the 10th largest economy. Residential energy consumption represents 39% of final energy consumed and slightly less (37%) in terms of primary energy consumption. However, energy consumption in the residential sector in India is still largely dominated by the use of firewood. When biomass energy use is excluded, residential energy use represents only 12% of total final energy use and 19% of total primary energy use.

A large quantity of incremental electricity demand will come from the residential sector in India. Energy services examined in the residential sector include cooking, water heating, lighting, and appliance usage. Urban and rural homes are distinguished due to their difference in energy requirement. The number of urban and rural households is used as drivers for residential energy consumption. Figure 1 shows the result of the National Sample Survey Organization's survey on *Consumption of Some Important Commodities in India* (NSSO, 2001a) conducted in 2000. It shows the average quantity of fuel consumed per capita by monthly per capita expenditure (MPCE) in rural and urban areas. In rural areas, firewood remains the predominant fuel used irrespective of expenditure.

Figure 1. Final Energy Consumption per Capita per MPCE per Month



Source: NSSO, 2001a

The two figures shown at the bottom exclude biomass in order to better represent trends in other fuel use. All fuel consumption tends to increase with income. However, the quantity of kerosene consumed remains fairly constant across income categories in urban areas and regardless of its price. Quantities bought through the PDS (public distribution system[2]) and quantities bought at market prices are similar. However, the demand for LPG and electricity are income elastic and increase considerably with higher expenditure level. These observations are even more pronounced in urban areas, where consumption of firewood phases out almost completely, while LPG consumption increases progressively and electricity use escalates with households that have the highest level of expenditure.

Household energy consumption patterns are often associated with the concept of an energy "ladder" to explain the transition in fuels consumed. Solid fuels such as biomass and coal are at the lowest level of the ladder while kerosene, LPG, electricity, and natural gas are on successively higher rungs. This transition to more efficient fuels occurs with economic growth. However, other factors also influence the choice of energy carriers in India. Access to modern cooking fuels is severely limited in rural areas (Bhattacharyya, 2006) which explains to some extent why the quantity of fuelwood remains large in the higher range of income level in rural areas. Analysis at the end use level allows a better understanding of a household's energy consumption and leads to more accurate projections (Price, 2006). The next section includes a description of the different data sources used in this report, followed by a decomposition of energy consumption at the end use level for rural and urban households.

3.1 Methodology

Residential energy provides numerous services associated with household living, including space cooling, water heating, cooking, refrigeration, lighting, and the powering of a wide variety of other appliances. Energy demand is shaped by a variety of factors, including location (in both geographic location and urban vs. rural) and climate. In developing countries such as India, it is important to divide households into rural and urban locales due to the different energy consumption patterns found in these locations. Within the locales, end uses were broken out into air conditioning, appliances, cooking and water heating, lighting, and a residual category.

The end uses were further broken out by technologies. Each end use was assigned appropriate devices and fuel types, with diffusion rates and energy efficiencies based on survey data and literature research. Changes in energy demand in the model are in part a function of driver variables, e.g., GDP, population, household size and urbanization rate, which were determined exogenously and included in the model and in part a function of energy intensities. Equation 1 shows the decomposition of energy use in the residential sector that serves for modeling its growth:

Annual average appliance Unit Energy Consumption (UEC) are calculated based on a stock turnover modeling, which includes information on initial stocks by vintage, energy efficiencies by vintage (allowing explicit modeling of the impacts of standards), efficiency degradation profiles, and lifetime or survival profiles.

[2] Kerosene available at a subsided price

Equation 1.

$$E_{RB} = \sum_{m}^{OPTION} \left[\frac{P_m}{F_m} \times \left(\sum_j S_{j,m} \times UEC_{j,m} + E_m \sum_{i}^{OPTION} L_{i,m} \times Ca_{i,m} \times H_{i,m} \right) + P_m \times \sum_{k}^{OPTION} \left(CW_{m,k} + LK_{m,k} \right) \right]$$

where:

m	=	locale type *(urban, rural),*
P_m		population in locale *m,*
F_m	=	number of persons per household *(family)* in locale *m,*
E_m	=	electrification rate in locale *m,*
j	=	type of appliance or end-use device,
$S_{j,m}$	=	penetration of appliance or device j in percent appliance owned by household *(values in excess of 100% would indicate more than one device per household on average),*
UEC_j	=	energy intensity of appliance *j* in MJ or kWh/year,
i	=	type of lighting bulb *(incandescent, fluorescent),*
$L_{i,m}$	=	number of lighting bulb of type *i* per household in locale *m,*
$Ca_{i,m}$	=	power of bulb of ty*pe i* in locale *m,*
$H_{i,m}$	=	hours of use of bulb of type *i* in locale *m,*
k	=	fuel type
$CW_{m,k}$	=	cooking and water heating energy use of fuel *k* per capita per month in locale *m* in MJ /ca/month, *and*
$LK_{m,k}$	=	Lighting energy use of fuel *k* per capita per month in locale *m* in MJ /ca/month

3.2 Data Source and Adjustment

The NSSO surveys provide a wealth of information regarding energy consumption in the Indian residential sector, based on micro level household data collected across the country. The data collected allow detailed estimations of energy consumption by households in urban and rural areas. In this report, a bottom up approach was used to estimate total residential energy consumption. Two surveys were used in particular, NSSO (2001a) and National Council of Applied Economic Research (NCAER, 2005). The NSSO survey provides detailed data on quantity of fuels used per capita and per MPCE class, used as a proxy to income. The NCAER survey provides thorough details on kerosene use and was employed to break down the quantity of kerosene used for cooking from the quantity used for lighting.

Furthermore, total energy consumption by fuel type from the Internaional Energy Agency (IEA, 2007a and 2007b) was used to compare with results from the bottom up computation.

Table 3 compares data for 2005.

Table 3. Fuel Consumption in the Residential Sector in 2005 in PJ

	IEA	Bottom Up Model
Biomass	5,176	3,300
Coal	103	0
Kerosene	410	506
LPG	466	488
Electricity	372	557

IEA reports some coal consumption for the domestic sector that the NSSO survey showed to be very marginal. Our estimation for biomass is much lower than IEA estimates. The official data doesn't report the total biomass consumption. Data from the MOSPI "Energy Statistics" (MOSPI, 2006) do not include data on biomass consumption, LPG or kerosene consumption. The CEA reports electricity consumption for the domestic sector, which are close to the data reported from the IEA. Estimates from our model are considerably higher (32%). One reason that may partly explain this difference is our model includes consumption from theft either circumventing or tampering with meters to avoid registration. This consumption is accounted in commercial losses (T&D losses) in the official CEA statistics.

3.3 End Use Analysis

Residential energy is typically used for cooking, water heating, space conditioning, lighting and appliances. Cooking and lighting are the most essential activities requiring energy, while the importance of other functions varies. Although efforts have been made to assign energy consumption to each category, in many situations they overlap. In this report, water heating is considered as a single category with cooking unless an electric appliance is used, in which case we included this use in the appliance section.

Figure 2. Final Energy Consumption by End Uses in 2005

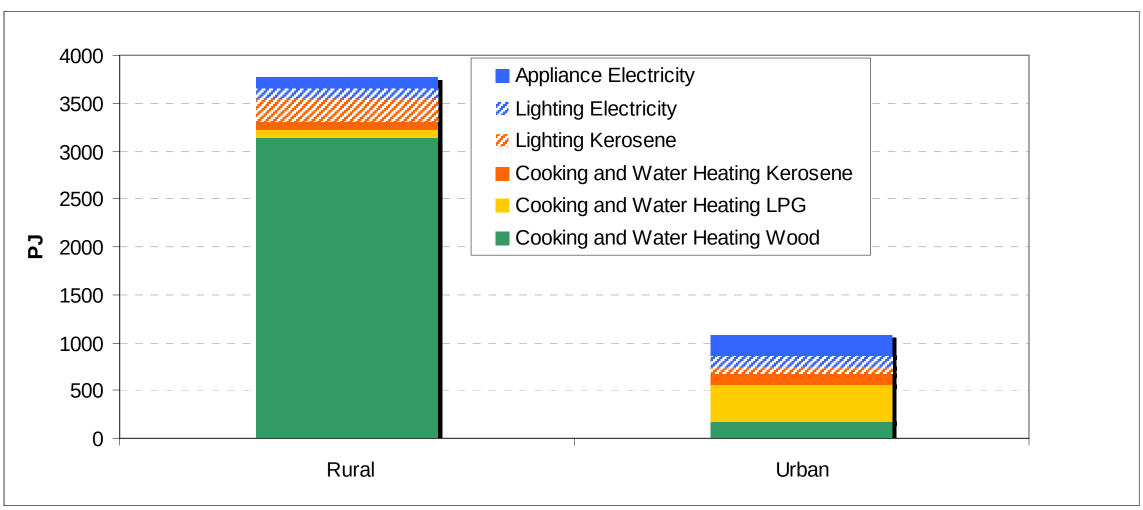


Figure 2 shows the decomposition of energy consumption in the residential sector by end uses. The predominant energy requirement serves the basic need of cooking and water heating. In rural areas, cooking and water heating represent up to 90% of household energy needs. The vast majority of energy use relies on traditional wood fuel. Lighting and services from basic appliances such as TVs, fans and refrigerators constitute the major remaining energy use. The substantial difference of final energy use between urban and rural areas arises from the fact that rural households use much more inefficient fuels, such as fuelwood for cooking and kerosene for lighting. Hence, their requirement to provide equivalent energy services than urban households is much higher.

3.3.1 Cooking and Water heating

Data from NSSO (2001a) as shown in Figure 1 were used to estimate the energy use for cooking and water heating[3]. The quantities reported in the NSSO survey for LPG and wood were entirely assigned to cooking and water heating energy use. Electricity use for cooking is very small and was entirely allocated to the appliance energy use. Kerosene was the most challenging fuel to disaggregate as it is used both for cooking and lighting. A survey from NCAER (2005) shows that in rural areas, 34% of kerosene consumption is used for cooking and water heating while the remaining quantity is used for lighting. In urban areas, the share of kerosene used for cooking and water heating is much larger, representing 61.2% and 3.9% respectively, while 34% is used for lighting.

Average useful energy[4] was calculated to assess how much energy households require according to their living area (urban/rural) and income level. Useful energy consumption was derived by multiplying each quantity of fuel with its efficiency rate (Table 4).

Table 4. Efficiency of Fuel Use

Wood	LPG	Kerosene (heat)
13%	60%	40%

Source: TERI, 2006

The data show that useful energy consumption is correlated with income as well as with fuel choice. For instance, households using wood, use it more when their income rises but less than households with similar income that use commercial fuels. The main reason is that commercial fuels are more convenient to use and therefore people tend to use them more. Cooking and water heating useful energy for urban households is about 4,500 MJ/year whereas rural households use only 3,000 MJ/year. However, due to the preponderance of wood in rural areas, the final energy consumed by a household living in rural areas represents more than twice the energy consumed by an urban household (22,500 MJ vs 13,000 MJ).

The undeveloped distribution system of commercial fuels in rural areas is a barrier to fuel switching. Nevertheless, over the period 1993 to 2000, there was a decreasing trend in the percentage of households using biomass of about 5% offset almost entirely by the use of LPG. The percentage of urban households using firewood decreased over 1993-

[3] Water heating from stove only

[4] Useful energy is the energy available to the consumer after equipment conversion losses.

2000 by about 8 percentage points and the use of LPG increased by 14 percentage points. Use of kerosene decreased marginally over 1993-2000 by 1 percentage point.

3.3.2 Lighting

Source of energy used for lighting by India households includes kerosene, gas, candle, electricity, other oil, etc. Among these, only kerosene and electricity are commonly used. In urban areas, households using electricity represent almost 90% while 10% are still using kerosene (NSSO, 2001b). In rural areas, kerosene and electricity as a primary source of energy for lighting are split evenly. The share of households in rural areas using electricity has increased from 37% to 50% in approximately 10 years (1993-2000), due to the increase in electrification over the period.

The usage of electric lighting was estimated based on a survey carried out in 1989 in the cities of Pune, Ahmednagar and Talegaon (Kulkarni and Sant, 1994). Data were reported with income level, which allowed estimating the level and the type of bulb possessed by households in 2000 using a regression on income. Hence, on average we estimated that in 2000 electrified households possessed 3.2 incandescent bulbs of 60W and 2.1 fluorescent tubes of 40W in urban areas versus only 2.1 incandescent bulbs of 60W and 1.5 Fluorescent Tubes of 40W in rural areas. We estimated that households used four hours of lighting per day. Kerosene lighting was estimated as the remaining of total kerosene consumption after subtracting cooking and water heating consumption. Figure 3 shows the final energy consumption for lighting in urban and rural areas.

Figure 3. Use of Lighting

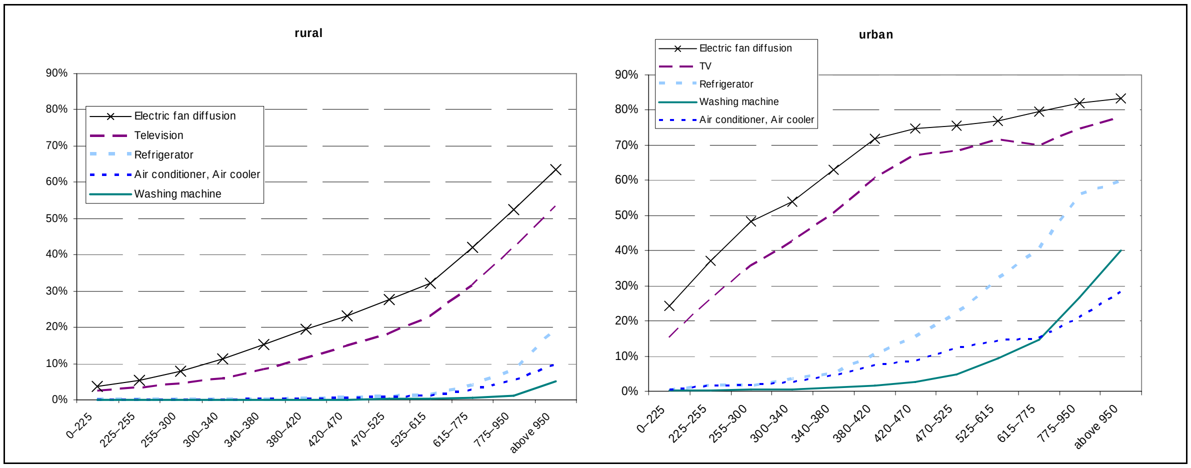
	Urban	Rural	Hours of Use
Kerosene Consumption (MJ/hh)	2,151	1,562	
Number of Incandescent Bulb 60W	3.2	2.1	4h
Number of Fluorescent Tube 40W	2.1	1.5	4h
Electricity Consumption (kWh/hh)	402	271	

Several reports including the NCAER survey (2005) report that electrified households still use kerosene for lighting, with a quantity of only 27% less than non electrified households. One reason is the frequent power shortages affecting electricity distribution and to some extent the low price of subsidized kerosene. Also, statistics of electrification level have an extensive coverage, including households that have only one electric fixture for one room. These households will then use kerosene to provide light in other rooms.

3.3.3 Appliances

Most of the electricity consumed in the residential sector is used to power appliances. The diffusion of appliances ownership is particularly elastic to income. With increasing electricity access and raising income level, the number of households owning appliances is increasing very rapidly in India. NSSO surveys (1997, 2001a, 2005b) provide appliance saturation by MPCE for rural and urban areas. The number of households owning a TV doubled from 13% in 1993 to 26% in 2002 in rural areas and increased from 49% to 66% in urban areas (NSSO, 2005b). In the case of refrigerators, the upward trend was even more impressive; saturation went from 12% in 1993 to 28% in 2001 in urban areas and from 1% to 4% in rural areas (NSSO, 1997 and 2005b). Some hierarchical level of preference among appliances can be observed. Basic appliances such as fans and TVs are more evenly distributed among households with different levels of income (Figure 4), while other appliances are owned only by households with the highest level of income. This is the case of water heaters, washing machines and air conditioners, which can be considered as more luxurious goods. In between, air coolers and refrigerators are increasing more steadily throughout the different level of income.

Figure 4. Average Saturation of Energy Consuming Appliances per MPCE class (Rs)[5]



Source: NSSO, 2001a

Appliance energy consumption can be broken down into two factors, the penetration of appliances or diffusion and the annual Unit Energy Consumption (UEC) per appliance. UECs are a function of the efficiency and the capacity of the appliance used as well as the level of use. It rises with increased size of equipment or hours of usage and decreases with energy efficiency through technological improvements. UECs by appliances were estimated based on different surveys (Table 5) and are assumed to be the same for urban and rural areas. Air conditioner UEC in 2000 is based on estimates made by India's Refrigeration and Air conditioning Manufacturers Association (RAMA) provided to the Indian Bureau of Energy Efficiency (BEE) in 2006.

Table 5. Unit Energy Consumption in 2000

	UEC (kWh)	Reference/Assumption
Refrigerators	494	LBNL Estimates
Air Conditioners	2160	based on RAMA
Air Coolers	298	Narasimha Murthy et al, 2001
Washing Machines	190	Euromonitor, 2003 and Sanchez, 2006
Fans	145	Narasimha Murthy et al, 2001
TV	150	Narasimha Murthy et al, 2001
Water Heaters	617	Reddy, 1994

[5] Monthly per Capita Expenditure expressed in Rupees (Rs)

3.3.4 Renewable energy

India is the only country in the world to have a Ministry dealing exclusively with new and renewable energy sources. The Ministry of New and Renewable Energy (MNRE, 2008) develops and deploys new and renewable energy for supplementing the energy requirements of the country. Programs relating to rural and urban household energy use have been developed across the country.

According to MNRE (2008), about 3 million family biogas units have been installed, resulting in an estimated biogas consumption of 8PJ in 2005[6]. The ministry has also provided basic lighting/electricity facilities to about 4,000 un-electrified villages. Rural applications of solar have increased to 340,000 home lighting systems, 540,000 solar lanterns, and 600,000 solar cookers. In urban areas, the ministry is subsidizing households and, industrial & commercial applications for solar water heating systems. A total of about 2.15 million square meters of collector area has been installed. No account of this energy use was estimated in our modeling approach as no breakdown was available between domestic and commercial use.

3.4 Drivers of Energy Use in the Residential Sector

Energy consumption in the residential sector is closely linked to the urbanization rate. Urban households tend to have higher levels of energy needs and hence, the migration of rural population towards urban centers increases the level of energy use. In addition, other factors, such as the diminution in household size and increase in housing floorspace represent major drivers of energy demand (Schipper, 1997, 2001). Table 6 shows some activity variables for the residential sector and their trends over the period 1990 to 2005.

Table 6. Residential Activity Variables

Population		1990	2005	AAGR 90-05
Population	Million	850	1,095	1.70%
Share of urban	Percent	26%	29%	0.79%
Urban Population	Million	217	314	2.51%
Rural Population	Million	633	780	1.41%
Number of Households	Million	154	232	2.76%
Number of Households (Urban)	Million	41	73	3.98%
Number of Households (Rural)	Million	114	159	2.26%
Household size urban	persons	5.34	4.31	-1.42%
Household size rural	persons	5.57	4.91	-0.84%

Source: WB, 2008; NSSO, 2001a; NSSO, 2008.

The number of persons per household in India is on average equal to 4.5 persons in urban areas and 5.2 persons in rural areas and has declined over time, particularly in urban areas (Table 6). Household size in developed countries is generally much smaller, between 2.5

[6] Based on average fuel wood useful energy use of 21.6 MJ/ca/month converted in biogas with an estimated efficiency of 50%.

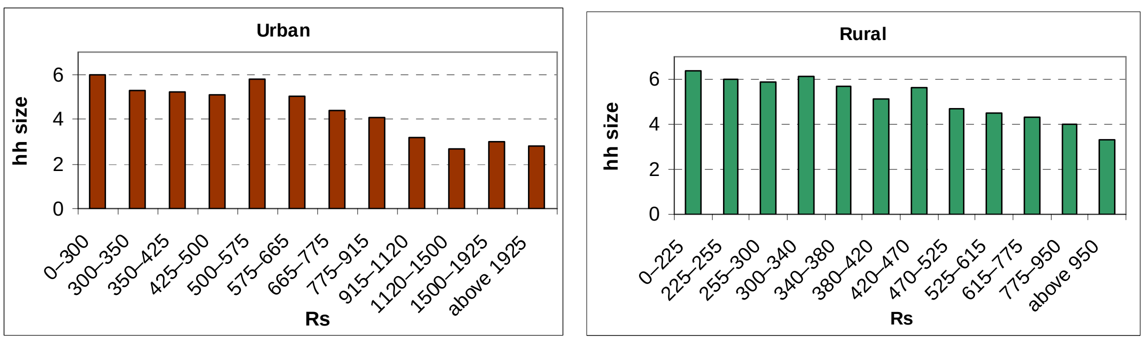
to 3 members per household. A shift toward smaller household size increases the total number of households and hence the number of appliances sales and energy services demanded. Other drivers also influence the level or the type of energy consumed. Electrification level and access to cleaner fuels have a direct impact on rural energy consumption.

3.5 Residential Future Outlook

3.5.1 Driver Forecast

The main drivers of energy consumption in the residential sector are the number of households and the penetration of appliance ownership by household.

Figure 5. Household Size per MPCE Class

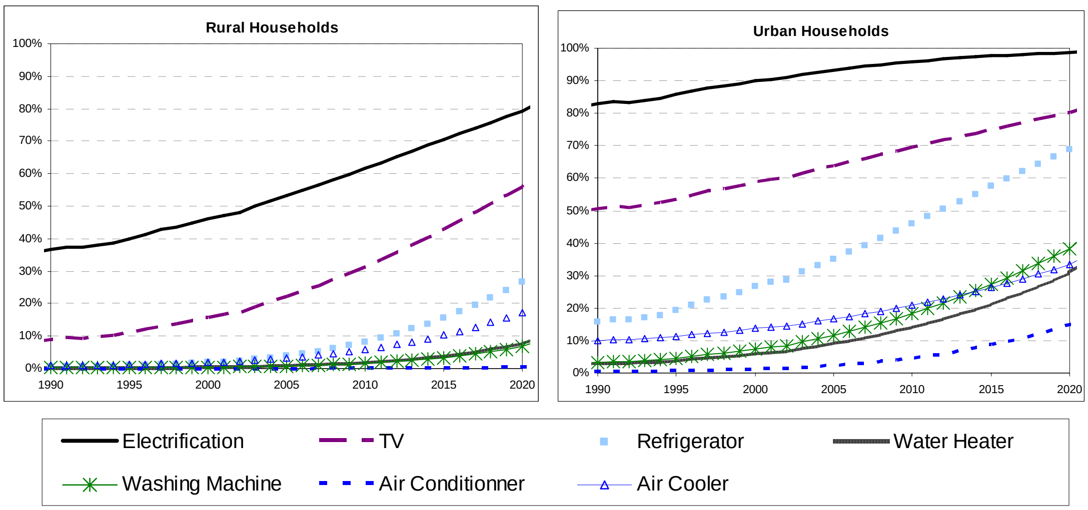


Source: NSSO survey (2004)

In 2005, average household size in India was estimated at 4.91 persons in rural areas and 4.31 in urban areas (NSSO, 2008). The average size in rural areas has decreased slightly from 5.57 to 4.91, while it has declined in urban areas from 5.34 to 4.31 (MOSPI, 2006; NSSO, 2008). Size of household is a key driver as it determines the number of household units that require energy. NSSO survey (2008) shows that household size varies greatly between MPCE's classes (Figure 5). In the lower classes, average household size is equal to 4.57 in rural areas and 5.97 in urban areas and in the higher class, it is equal to 3.68 and 2.80 in rural and urban areas respectively. We assumed that household size will decrease slightly less rapidly than historically with increasing income to reach 4.75 in 2020 and that urban household average size will reach 3.70. These values are quite conservative and are for example higher, compared to China's current level (4 in rural areas and 3 in urban areas).

Ownership of the major electric appliances such as refrigerators, air conditioners, clothes washers and TVs increased significantly from 1981 to 2000 as explained in Section 3.3.3. For example, refrigerator ownership started at 12.3% in 1993 and increased to 31.9% in 2004 in urban India. Increased income levels and decreasing appliance prices drive the growth of the ownership of appliances. In urban areas, color TVs are already very common (66%); refrigerator is becoming a necessary appliance (32%); and air conditioning penetration is also growing rapidly (18.2%). Appliance ownership was forecast using a regression on income on electrified households. NSSO (2001a) provides appliance saturation by MPCE for rural and urban areas while the diffusion level is available only by urban and rural areas[7] but not per MPCE class. When the diffusion was a lot more important than the average saturation (in the case of fans), the saturation levels by MPCE class were converted in diffusion level assuming a linear relation with income. Appliance diffusion[8] was then projected using Gompertz[9] equations as shown in Annex 1. Figure 6 shows the projection's results from 1990 and 2020, assuming a 7% economic growth from 2005 and historical growth rate in earlier years.

Figure 6. Projections of Rate of Appliance Diffusion



3.5.2 Residential End Use Intensities

3.5.2.1 Cooking and Water heating

Cooking and water heating energy consumption per household was projected using an income regression. The relation between each individual fuel consumption and MPCE was analyzed with data provided by the NSSO Survey (2001a). Equations used for the projections are described in Annex 2.

[7] Diffusion of appliances refers to the number of appliances per household as opposed to the saturation level that expressed the number of household owning an appliance. When modeling electricity consumption the diffusion level (which can be greater than 1) is used instead of the appliance saturation.
[8] Fans are not represented here because they are out of scale compared to other appliances
[9] After using different equation type, we choose a Gompertz equation due to its relatively good fit to the model (Annex 1).

Figure 7. Average Energy Consumption per Capita per Month

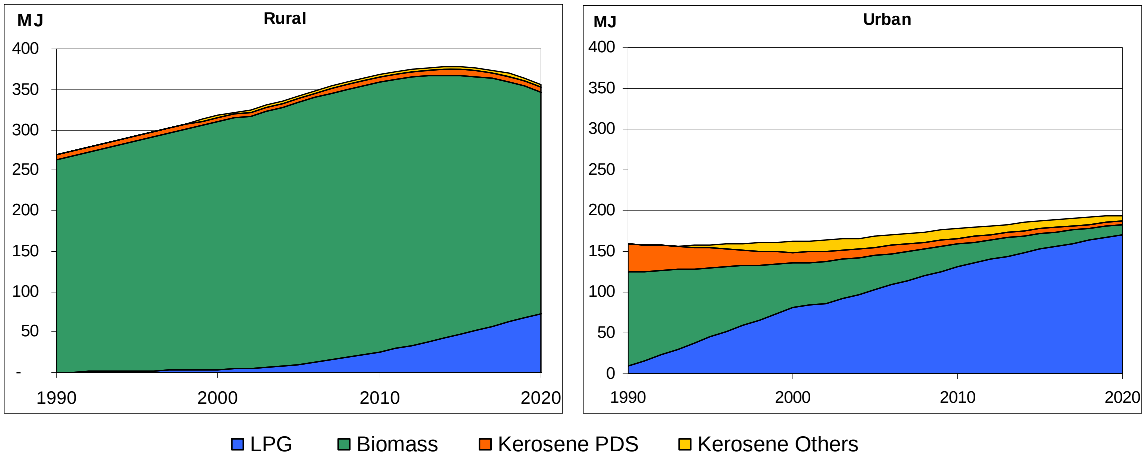


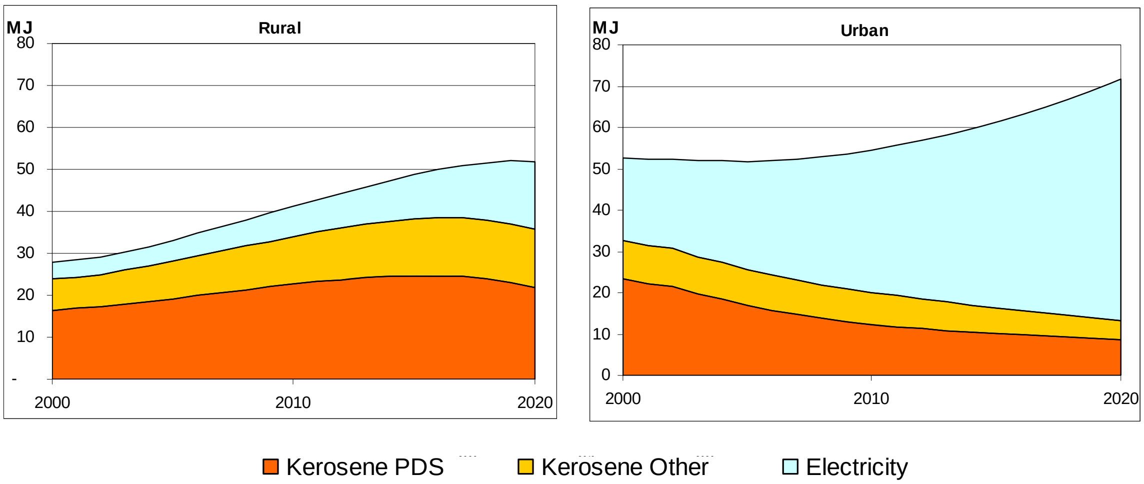
Figure 7 shows projections of final energy consumption for cooking and water heating per capita per month living in urban and rural areas. With increasing level of income, households augment their demand for energy. In urban and rural areas, this additional demand will be mostly met with LPG. Additional to the income effect, LPG growth is furthermore underpinned by a substitution effect in urban areas where wood is gradually replaced by LPG. In the case of rural areas, projections show that biomass continues to meet about 40% of the energy requirement by households in 2020. However, from 2010 fuel wood consumption starts to decline to be gradually replaced by LPG. Kerosene use stays somewhat constant over time.

3.5.2.2 Lighting

In order to forecast electric lighting, we first projected the level of electrification with income level and then projected the number of bulbs per household (usage per bulb is supposed to be constant). Kerosene lighting was projected based on an income regression as was done for cooking and water heating kerosene (see Annex 2).

Lighting energy intensity increases rapidly in both urban and rural areas. However, the level of consumption per household in rural areas remains much lower compared to urban households. Electricity use in urban areas increases due to the dual effect of income and substitution. In rural areas, the substitution effect takes place only toward the end of the period studied, when kerosene starts declining. Figure 8 shows the resulting energy consumption of kerosene and electricity for lighting.

Figure 8. Lighting Energy Consumption per Capita and per Month



3.5.2.3 Appliances

Appliance Unit Energy Consumption (UEC) is assumed to stay constant over time with three exceptions: refrigerators, air conditioners and water heaters. Refrigerator consumption is expected to grow due to the growing market share for larger models, two-door refrigerator freezers, and frost-free units. Air conditioner UEC growth includes the use of multiple units, increase in unit cooling capacity, and increase in hours of use. Air conditioner UEC in 2000 is based on estimates made by India's Refrigeration and Air conditioning Manufacturers Association (RAMA) provided to the Indian Bureau of Energy Efficiency (BEE) in 2006. Air conditioning use in 2020 is based on current use patterns in Hong Kong as the same type of climate apply. Water heater UEC is expected to decrease slightly during the forecast period due to the projected decrease of the number of persons per household. Table 7 shows a summary of our assumptions and references used to determine the average UEC of Indian appliances. The table also shows equivalent data for Europe and North America (IEA, 2003) for comparison.

Table 7. UEC Assumptions

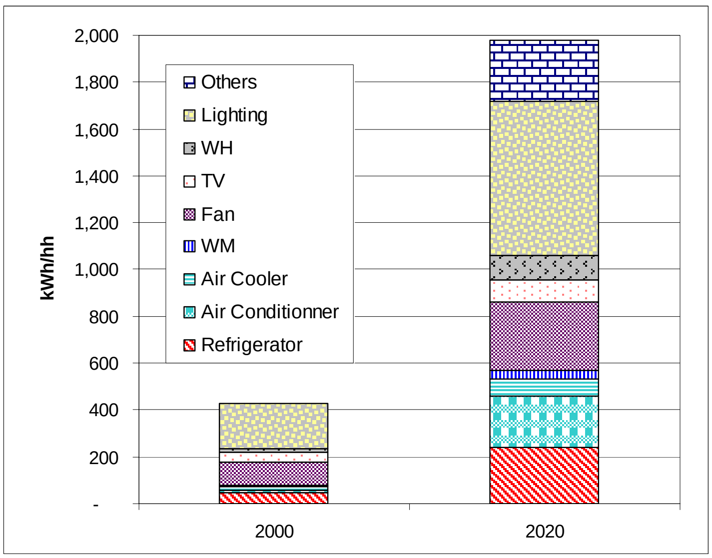
	UEC (kWh)	Reference/Assumption	Europe	North America
	2020	**2020**	**2000**	**2000**
Refrigerators	589	LBNL Estimates	432	850
Air Conditioners	3800	Hong Kong in 1996 (Lam,2000)[10]	1,714	714
Air Cooler	298	Same as 2000	-	-
Washing Machines	190	Same as 2000	221	955
Fans	145	Same as 2000	-	-
TV	150	Same as 2000	124	136
Water Heaters (geysers)	598	Reddy, 1995	2,492	3,823

[10] Assumed to be 4620 kWh in 2030, the data was interpolated to 2020

3.5.3 Baseline Energy Projection in the Residential Sector

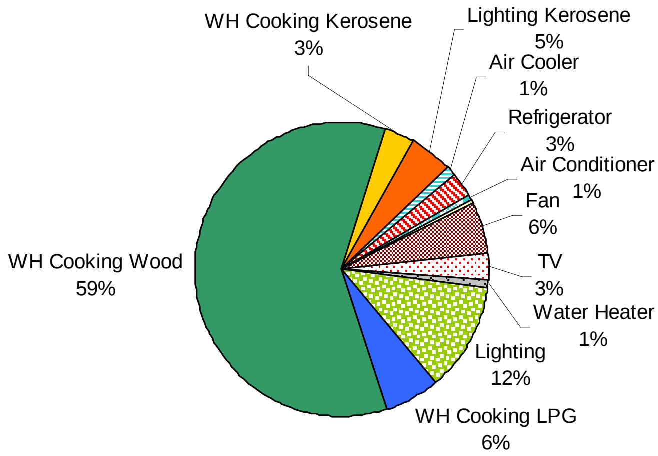
Figure 9 shows the evolution of the electricity consumption for all households in the residential sector. According to the projections, the average household will consume five times more electricity in 2020 than in 2000. Urban household consumption rises from 908 kWh in 2000 to 2972 kWh in 2020, while rural rises from 224 to 1311 kWh. Per household rural consumption grows twice as fast as urban. Rural households see a higher growth because they transition from low access to electricity (48% in 2000), and very low appliance ownership to a situation where almost all households are electrified, and a significant portion can afford at least the main appliances.

Figure 9. Electricity Consumption per Household per year, 2000-2020

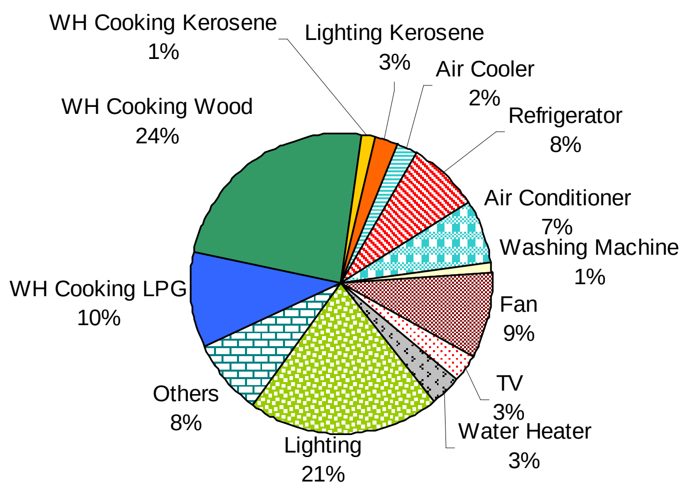


Residential final energy consumption increases from 4,030 PJ in 2000 to 7,864 PJ in 2020. In 2000, most of the energy is used to satisfy the basic needs of cooking, water heating and lighting whereas in 2020, appliance energy use represents 31% of the final share of energy use. In terms of primary energy use, appliance energy use represents the largest share of energy use (62%) in 2020. Figure 10 shows the primary energy consumption of all households, combining all the end use projections for 2000 and 2020.

Figure 10. Residential Primary Energy Use in 2000 and 2020



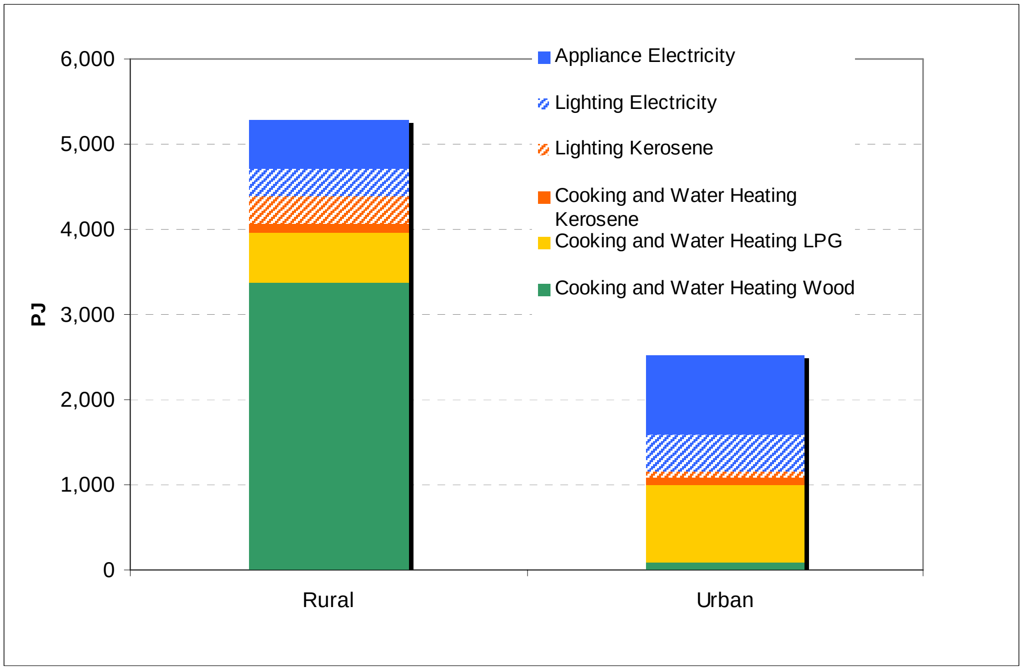
2000



2020

Energy consumption projections for urban and rural households are shown on.Figure 11. Rural households remain the major consumer of energy, with biomass still constituting the bulk of it (55%). Energy consumption from urban households is projected to increase rapidly due to a rapid urbanization. In 2020, the urbanization rate is projected to be 35%. Energy used for appliances in urban areas surpasses the energy use in rural areas.

Figure 11. 2020 Rural and Urban Energy Consumption Projections



4. The Transport Sector

Energy consumption in the transport sector currently represents a small share of the total energy consumption in India (15%). However, motorized vehicle ownership is increasing very rapidly as well as the need to transport goods across the country. Car ownership in India remains very low compared to developed countries indicating that the rate of growth will continue to accelerate. Nearly all motorized vehicles necessitate the combustion of petroleum-based fuels. Indian transport accounted for nearly half of petroleum products considered in 2005. The growth in transport demands directly weigh on the country needs for oil imports. Growth in vehicle ownership has contributed to energy and environmental issues, and an energy strategy incorporating efficiency improvement and other measures needs to be designed. Unfortunately, existing energy data do not provide all the information on driving forces behind energy use and sometimes show large inconsistencies.

Existing research has addressed the major modes in road transport, namely cars, two-wheelers, auto-rickshaws, and buses. Singh (2006) estimated the passenger mobility on road and the major drivers from 1950 to 2000. Earlier research done by Bose (1998) has formulated a simulation model to analyze the drivers in road transport in four Indian metropolises. Many other studies have also been focused on passenger transport, and some detailed analysis has been conducted for few major cities in India. For example Reddy (2000) 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 scenarios in vehicles and travel demand up to 2020 in Mumbai and Delhi, and estimated energy needs and environmental implications. 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.

4.1 Methodology

In a fashion peculiar to the transport sector, final energy is employed in a large variety of modes and technologies to provide a small range of end-use services, i.e., the transport of passengers and goods, ultimately representing a single service: *mobility*.

While for the other sectors the combination of fuel and technology is nearly always sufficient to determine the end-use service provided, this is not necessarily true for transport. Neither does the combination of the end-use and technology alone provide a level of detail adequate to accurately estimate end-use energy demand. For example trucks and locomotives used to haul freight can share the same engine technology and fuel and provide the same end-use service, but the associated energy intensity will be significantly different.

Transport can be broken out by *mode*:

- water (inland and coastal waterways)
- air (national and international air transport),
- rail (intracity and intercity mass transit)
- road transport is further divided into cars, taxis, motorcycles and buses

The physical energy intensities used are in terms of energy use per km, per passenger-km, or per tonne-km. This can be summarized as follows:

Equation 2.

$$E_{TR} = \sum_{t}^{OPTION} \sum_{r}^{OPTION} \sum_{j}^{OPTION} \sum_{k}^{OPTION} (V_{t,j,k} \times K_{t,j} \times EI_{TR,t,r,j,k} + Q_{t,r} \times S_{t,r,k} \times EI_{TR,t,r,j,k})$$

where:

t	=	transport type (passenger, freight),
r	=	mode type (road, rail, water or air),
j	=	vehicle technology class (passenger car, multi purpose vehicle, two wheeler, three wheeler, bus, heavy truck, and light truck),
k	=	fuel type (motor gasoline, diesel, kerosene, coal, and electricity)
$V_{t,j,k}$	=	number of vehicles of type *j* of transport service of type *t* using *k* fuel type in millions of unit, and
$K_{t,j}$	=	distance driven from vehicle of type *j* of type *t* in km per year, and
$Q_{t,r}$	=	quantity of transport service of type *t* in mode *r* in passenger-km and tonne-km, and
$S_{t,r,k}$	=	share of transport services *t*, delivered through the mode *r* employing the fuel *k*, and

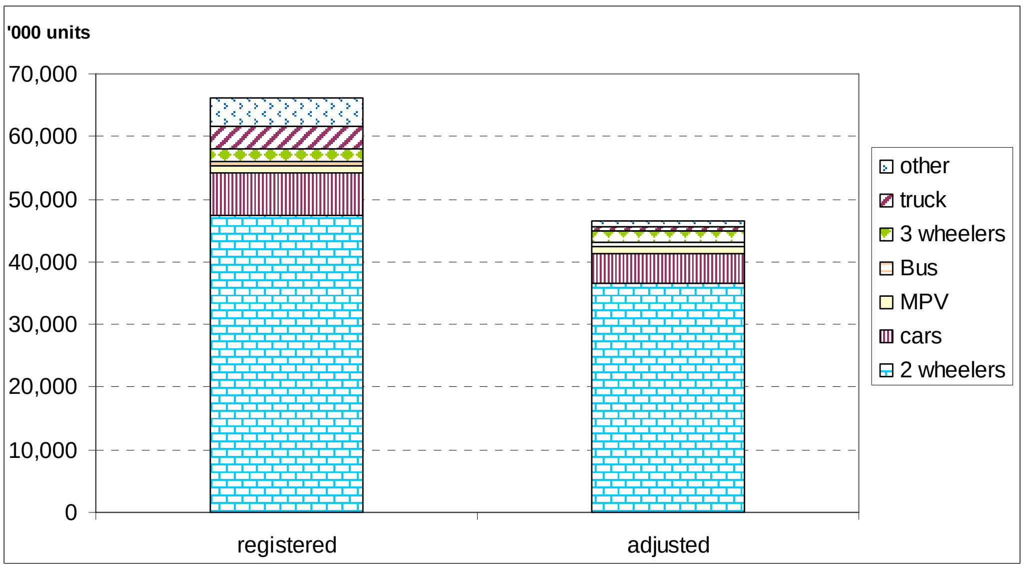
$EI_{TR\ t,r,j,k}$	=	average energy intensity of energy type *k* for transport service of type *t* and in mode *r* in km per liter of fuel used or in MJ/(passenger-km-year) and MJ/(tonne-km-year).

4.2 Data Adjustments

4.2.1 Vehicle Stocks

Passenger and freight transport are distinguished and mobility is analyzed for each transport mode. We measure passenger-kilometers and tonne-kilometers by looking at vehicle sales, the quantity of tonnes carried in the case of freight and persons transported in the case of passenger travel, kilometers traveled and vehicle efficiency. Since load factors and km driven are difficult to monitor, they have been estimated.

Figure 12. Vehicle Stock built from Sales data



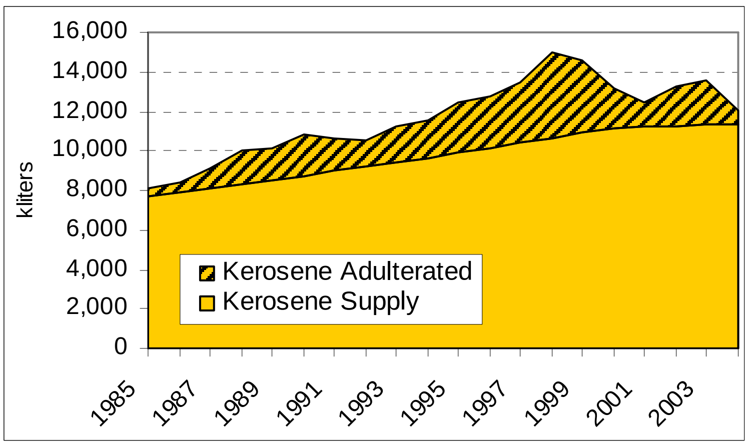
The Ministry of Road Transport and Highways (MoRTH, 2002) publishes vehicle registration statistics; however, theses data do not include a retirement rate and have been questioned. Several agencies have published estimates on road and freight traffic but results vary widely (Zhou, 2007b). Therefore, vehicle stocks have been built from data on domestic sales provided by the Society of Indian Automobile Manufacturers (SIAM, 2007) as well as data on domestic vehicle production reported by the Automotive Component Manufacturers Association of India (ACMA, 2007). The "Statistical Profile" data report published by SIAM (2007) provided very detail information on annual sales by vehicles types (size, weight, passenger capacity and model types). However, no detail on the fuel type consumed (motor gasoline or diesel) is provided. Figure 12 shows the vehicle stock taken from MoRTH and the stock based on sales iteration. An average life of 12 years was estimated for 2-wheelers and 3-wheelers, and an average of 15 years for cars, multi-utility vehicle (MUV), for Light Commercial Vehicles (LCV), Medium and Heavy Commercial Vehicle (M&HCV) and Buses.

Stock calculated based on sales data results in about a 30% downward adjustment of total vehicles registered (Figure 12). In absolute values, the largest difference concerns 2 wheelers, with a reduction of 11 million vehicles and in relative terms, the stock of trucks bears the largest downward adjustment of 80%, going from 3.5 million vehicles to 0.7.

4.2.2 Adulteration of Kerosene

Pricing of petroleum products varies greatly between the different types of petroleum products sold in India. Kerosene is highly subsidized while motor gasoline and diesel prices incur governmental taxes. The price of a liter of kerosene is about a third of the price of a liter of diesel in 2005. The price difference is such that it has encouraged the use of kerosene for other purposes than cooking and lighting. Different studies have shown that part of the kerosene is siphoned off and used for adulteration of diesel in the transport sector (NACER, 2005; Misra et al., 2005). In order to account for this consumption in the transport sector, we calculated the difference between estimation of kerosene consumed in the residential sector based on the bottom up model developed in Section 2 and data on total kerosene supplied in India from the Ministry of Oil and Gas (MOG, 2006).

Figure 13. Quantity of Kerosene adulterated



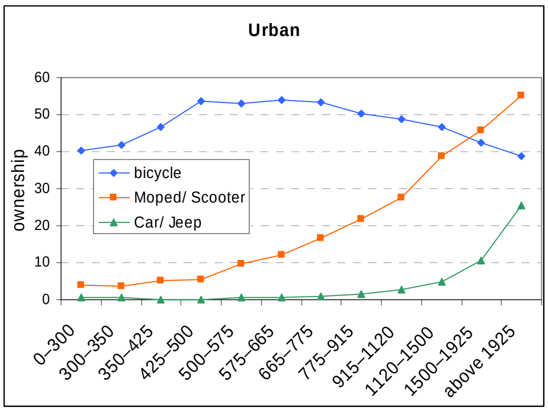
Adulteration of kerosene is mostly directed to the transport sector where the difference in price is the greater. However, some resale to the commercial and industrial sectors also occurs. Depending on the years, we accounted that approximately 80% of the kerosene diverted was use in the transport sector. Figure 13 shows the total quantity of kerosene supplied in India and the estimated quantity of kerosene diverted from its typical use in the residential sector. Kerosene supplied reaches a peak in 1998 and then start to decline. In 2003, the government conscious of the problem of kerosene adulteration, has banned kerosene imports from private companies.

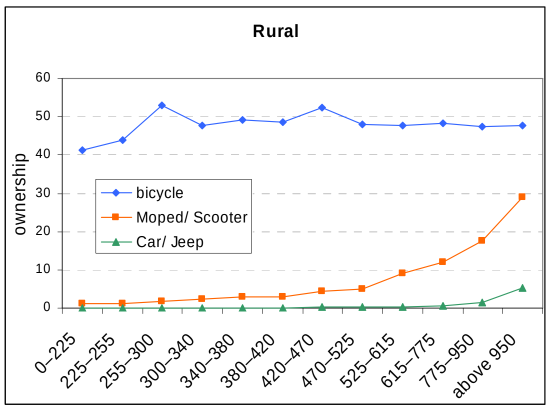
4.3 Transport by Mode

4.3.1 Passenger Modes

Walking to work remains the prevalent mode of transport for Indian households today. An NSSO survey was conducted in 1997 (NSSO, 1998) reporting that about 46% of urban commuters walk to their place of work, while 17% take the bus and another 16% bicycle. The remaining urban commuter used a moped for 7%, rail for 5%, an owned animal for 4%, and a car only for 2%. In rural area, the share of commuters walking to their place of work is higher (59%), while bus represents 18% and bicycle 15%. Among motorized transport, buses are widely used. However, ownership of moped and scooters has increased rapidly over the last 20 years. Car ownership is still very low in India but sales of cars are starting to increase rapidly.

Figure 14. Vehicle Ownership in India by MPCE class



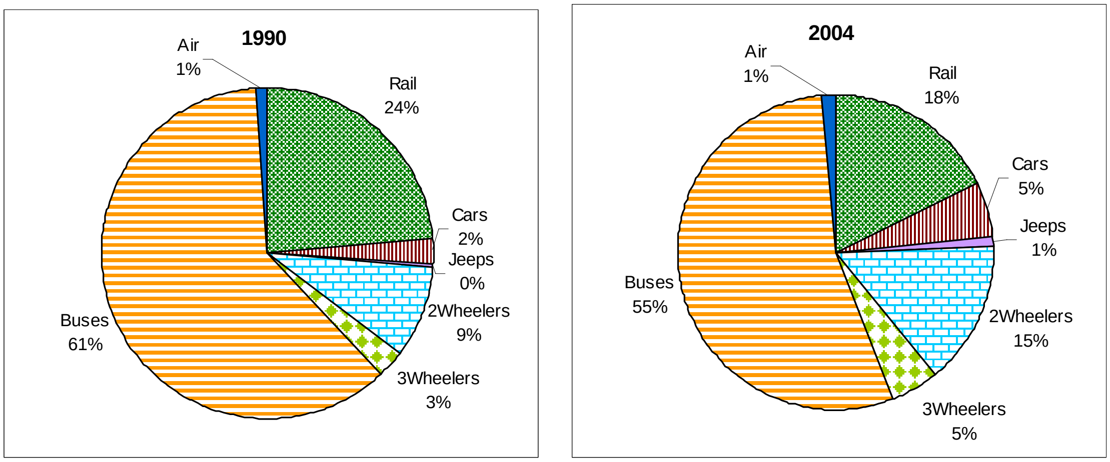


Source: NSSO, 2005b

A NSSO survey (2005b) has surveyed ownership of vehicles in Indian population. Not surprisingly, bicycles are the most widely used vehicle type owned by households. Bicycles are owned by about 50% of households in both rural and urban areas and little variation exists over different income classes, suggesting that affordability was not a constraint for this means of transportation. Conversely, only 7% of rural and 24% urban households own a moped or scooter and about 4% urban and less than 1% rural households owned a 4 wheeler - car or jeep. Figure 14 shows the ownership distributed by monthly per capita expenditure (MPCE). The percentage of households owning a 2 wheeler vehicle rises steadily with increase in MPCE, reaching 29% for the top MPCE class in rural areas and 55% in urban areas. Car ownership is very low for all MPCE classes, except the very high MPCE class where ownership increases rapidly.

In terms of motor transportation, traveling by bus is by far the most used means of transport in India, accounting for 56% of total passenger km. This results from a high passenger load factor in bus transport. Using the vehicle stock described in Section 4.2.1 and estimated load factors and distance travelled as described in Annex 3, average passenger-km per mode and vehicle type were calculated for 1990 and 2004 in Figure 15.

Figure 15. Passenger-km



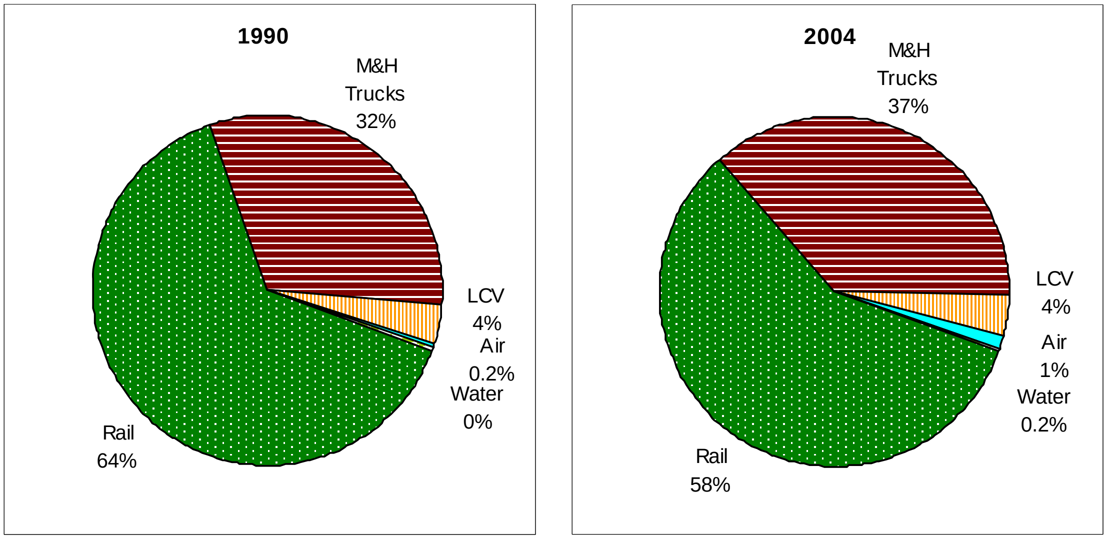
Passenger-km in India has increased from 1,327 billion passenger-kilometers (BPkm) to 2,933 BPkm between 1990 and 2004, at an average annual growth rate of 5.9%, while the AAGR for population and GDP were respectively is 1.8% and 6%. The growth in each passenger transport mode varies, from 3.6% (rail) to 16.3% (Jeep) from 1990 to 2004. Overall road transport is the fastest growing mode of transportation with an average annual growth rate of 6.4%, followed by air at 6.2% and rail by 3.6%. Road dominated overall passenger transport with a share of 75% in 1990 and 81% in 2004. Although transport by rail has also increased, its share has decreased from 24% to 18% during the last 14 years, due to 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 has decreased from 61% to 55%. The use of cars and jeeps has increased from 2% to 6%, two wheelers from 9% to 15%, and auto-rickshaws from 3% to 5%. The share of transport by waterways is small compared to other modes; it represents less than one percent of passenger kilometres and of freight tonne kilometres.

4.3.2 Freight Modes

While passenger travel patterns are more closely related to personal wealth and lifestyle changes, freight transport activities are closely connected to overall economic activity. Official historical statistics on freight transport activities, measured in tonne-km, do not exist and estimates that could be found from different departments in India and international organizations vary significantly. Estimates range from 600 billion tonne-km to 1,156 for the year 2000 as pointed by Karpoor (2002).

Based on the domestic sales data collected through SIAM (2007) and estimations of average tonne load per type of trucks and km driven per year (see Annex 3), tonne-km was estimated to be equal to 610 billion in 2004 (Figure 16), with an increase of 3.1% annually over the period 1990-2004. Rail transport represented 58% of tonne-km in 2004, down from 64% in 1990, medium and heavy trucks represent 37%, while light commercial vehicles represent a constant share of 4%.

Figure 16. Freight Tonne-km per Mode

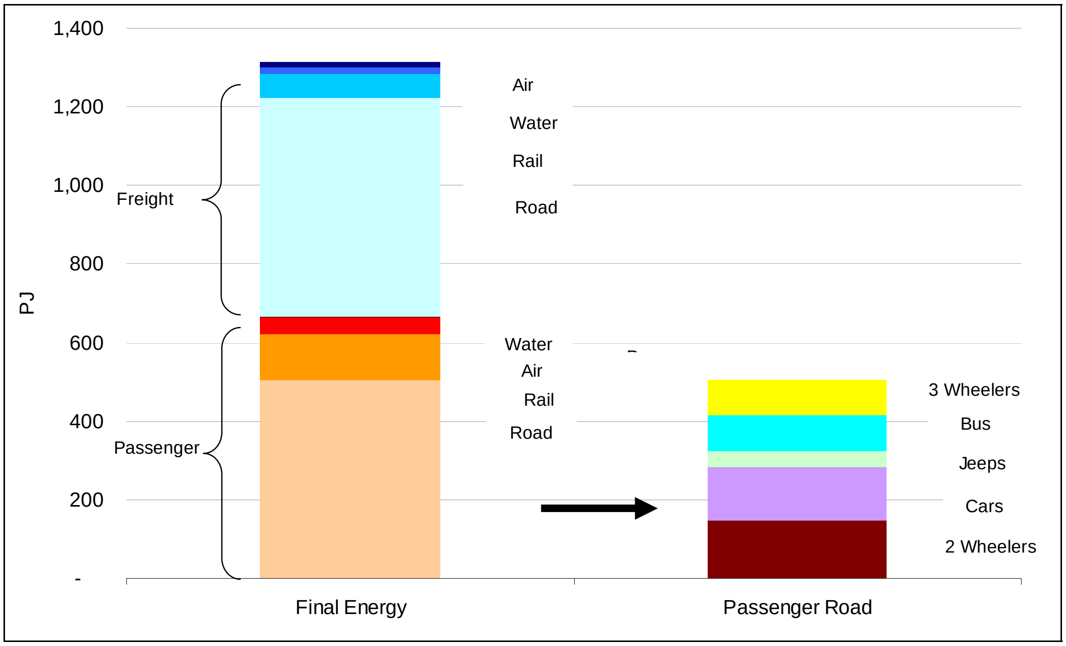


4.4 Fuel Consumption

Nearly all motorized vehicles necessitate the combustion of petroleum-based fuels. In India, transport accounted for nearly half of petroleum products consumption in 2004/05. The growth in transport demands directly weigh on the country's needs for oil. India's oil dependency has increased over time and stood at 76% of total crude oil refinery requirements in 2005 (MOSPI, 2006). In 1990, crude oil dependency was only 39%. This reflects the increasing need for petroleum products to feed the growing Indian vehicle market. Refinery capacity covers all of the needs of the domestic market and exports a very small quantity.

Energy consumption in the transport sector is evenly distributed between freight and passenger transportation as shown in Figure 17. Road transport is the most used mean of transport, followed by air, then rail. Finally a very small quantity of energy is used for waterways transport.

Figure 17. Transport Energy Consumption per Mode in 2004

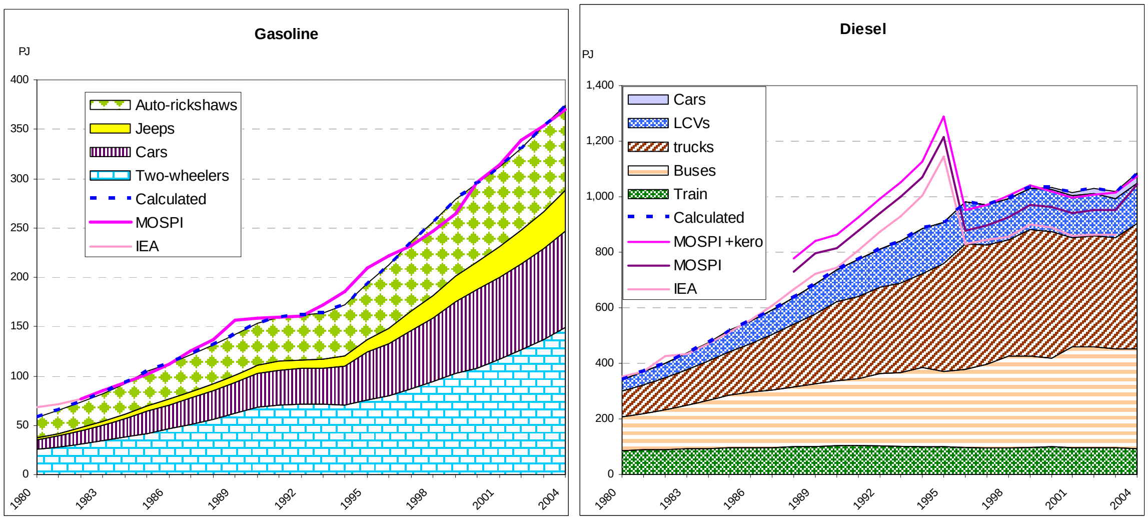


4.4.1 Motor Gasoline and Diesel Consumption

In 2004, diesel and motor gasoline represented 90% of final energy consumed in the transport sector, while jet kerosene represented 8% and electricity 2%. Diesel is the most used form of energy, with a share of 66% and motor gasoline representing 24%. Statistics of energy consumption over time from the Ministry of Oil and Gas show a steady increase of motor gasoline, however statistics for diesel consumption show uneven trends. In 1996, a serious break in the series occurs where diesel consumption in the transport sector plunged by 26%. 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, weback calculated with the vehicle stock the historical diesel consumption.

Figure 18 shows data for motor gasoline and diesel consumption based on the bottom up model. The figure also shows trends from data collected from the national statistics from MOSPI and the IEA. As explained in Section 4.2.2, a quantity of kerosene is adulterated from residential use to use for transport. To reflect this use, the assumed kerosene adulterated for transport are shown as added to total official data for diesel in Figure 18.

Figure 18. Gasoline and Diesel Transport Consumption



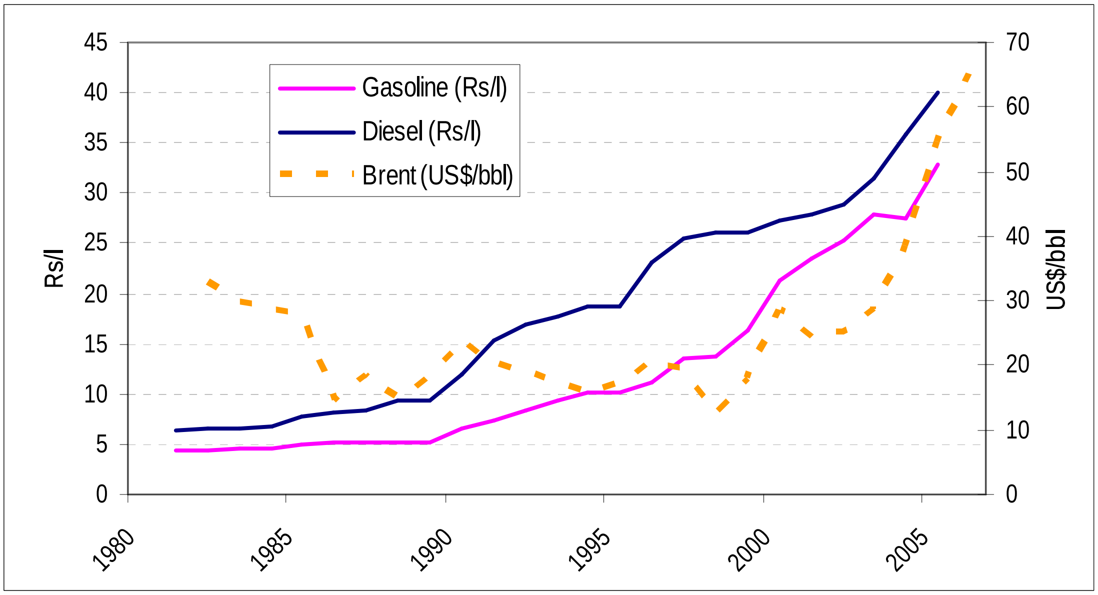
Diesel consumption shows a different trend compared to motor gasoline. From 1999, instead of continuing its escalating trend, diesel consumption decreases during a couple of years and starts increasing again after 2003. This contrasts significantly with sales data on truck and diesel cars.

4.4.2 The Effect of Price

Energy consumption in the transport sector is particularly sensitive to prices for two main reasons. First, immediate substitution to other fuels is impossible and requires waiting until the end of life of the vehicle owned. Second, transport mobility is necessary but not vital and people tend to restrain their need and/or switch to more economical mode of transport.

The price of petrol and especially diesel has increased sharply over the last 10 years. This was primarily due the dismantlement of the price system reinforced during this trend and to the increase in international oil prices. Petroleum pricing in India has been regulated until recently. In the 1970's, India put in place the Administered Pricing Mechanism (APM) to ensure more stable price of oil and insulate the domestic market from the volatility of international crude oil prices. This system was accompanied by the Oil Pool Account fund that allowed balancing surplus and deficit to ensure regulated returns to oil companies. The dismantlement of the APM in 2002 is part of a broader policy to put in place economic reforms that started in the early 90's. It is been conducted to allow parity with import prices. Figure 19 shows the evolution of motor gasoline and diesel price in India. Major increases since the 90's have been affecting motor gasoline and diesel in India.

Figure 19. Wholesale Price Indices of Diesel and Motor Gasoline



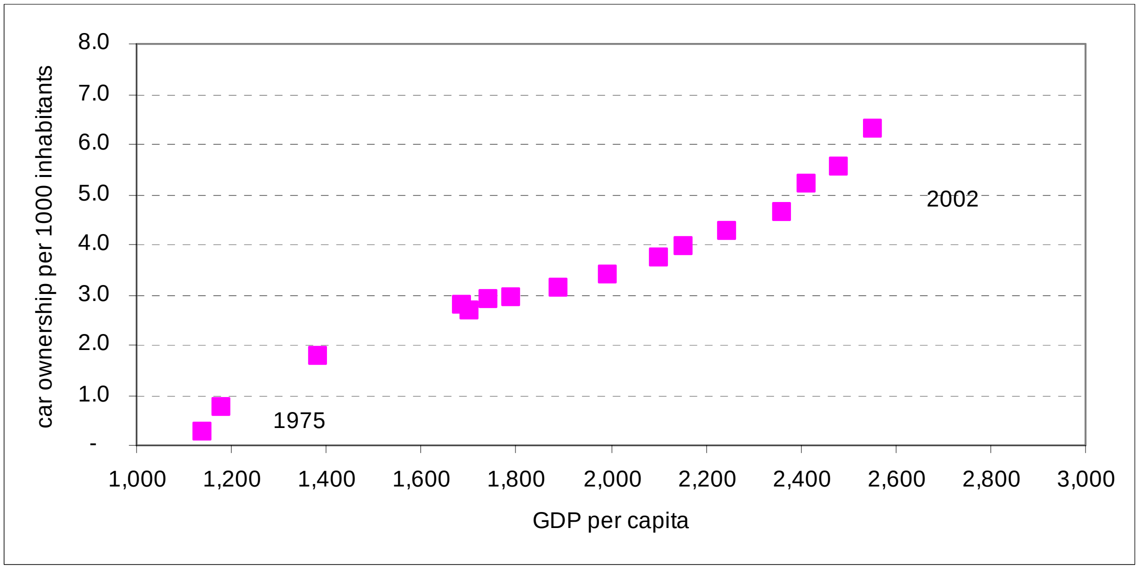
Source: MOG, 2006

Since 1999, diesel consumption has leveled off. In order to assess the impact of price on diesel consumption, we carried out a regression of diesel use on GDP and diesel prices. GDP is considered as the main driver and is used as a surrogate for other economic variables influencing the growth of fuel consumption, such as urbanization, increases in stock, etc. The correlation of GDP and diesel consumption was found to be statically significant with a R^2 of 71%. When the independent variable price was added, the R^2 adjusted was greater with 87%. It was found that over the period 1996-2005, price had an inverse impact on fuel consumption (see: Annex 4). On the other hand, gasoline price increased more slowly but started from a higher level. Moreover, the absolute motor gasoline consumption is lower than diesel consumption and is mostly used by the population that can afford a car who are in the highest income class. In order to take into account the effect of price in our bottom up model to reflect the slowdown of diesel use since 1999, we reduced by 5% the average km driven by vehicle using diesel between 2000 and 2004.

4.5 Drivers of Energy Use in the Transport Sector

Population and GDP are two fundamental drivers that influence person and freight mobility demand. In India, motorization is still low but car ownership is increasing fast as GDP increases. Figure 20 shows the evolution of car ownership per inhabitant as income increases. Car ownership per capita increased at annual average rate of 25% between 1975 and 1980, at 13% between 1980 and 1990 and at 7.4% between 1990 and 2002. Increase of car ownership represents the main driver of increasing energy use in the transport sector due to its high level of energy demand per passenger-km.

Figure 20. Car Ownership and GDP per Capita

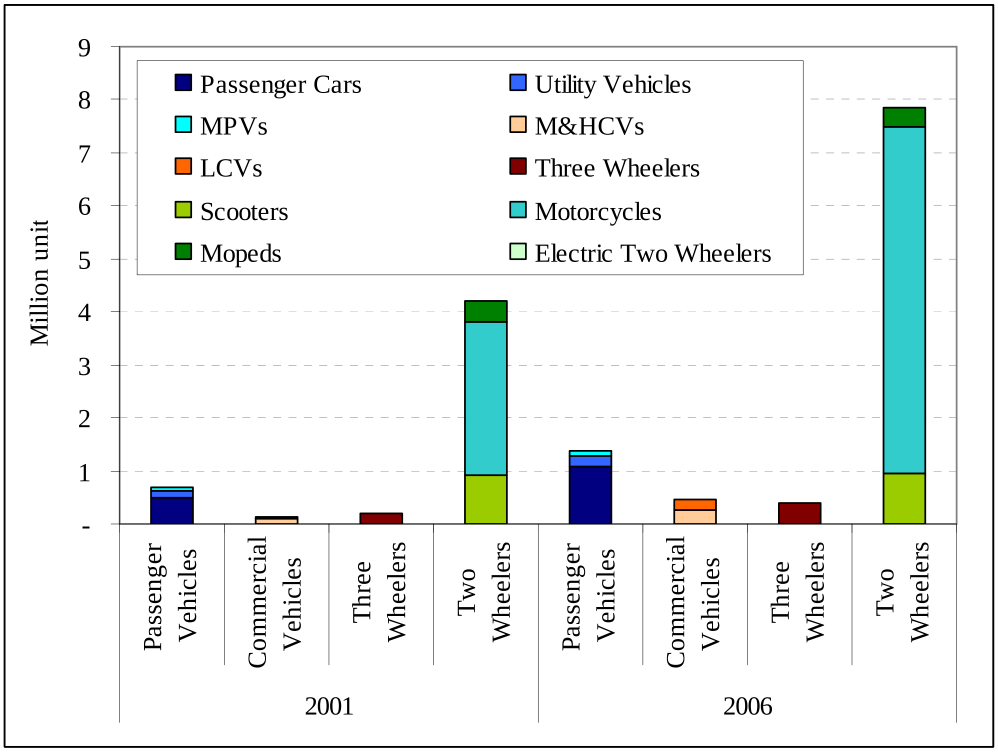


4.6 Transport Future outlook

4.6.1 Drivers of Transport Energy Consumption

Future mobility in India will increasingly be met with private cars. The introduction of small and cheap cars, such as the new Nano car from Tata Group priced at $2,500, is rising rapidly in the Indian market. Multinationals see India as a manufacturing hub for small cars. Sales of vehicles in India have increased very rapidly over the last 15-20 years. Sales data from the Society of Indian Automobile Manufacturers (SIAM, 2007) show that total vehicle sales increased by an annual average rate of 15% over the last 5 years (Figure 21). The highest increase is the light to heavy commercial vehicles that grew at an average annual rate of 26%. Growth in commercial vehicles contrasts with trends of diesel consumption that has leveled off between 1998 and 2005.

Figure 21. Domestic Annual Sales of Vehicles in 2001 and 2006



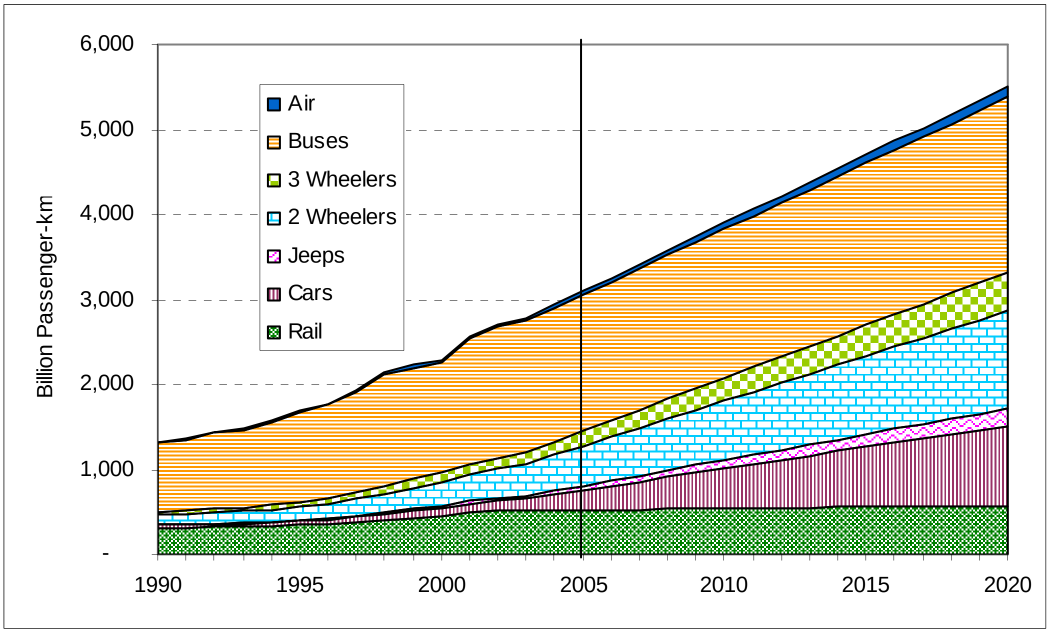
Source: SIAM, 2007

Note: M&HCVs: Medium and Heavy Commercial Vehicles, LCVs : Light Commercial Vehicles; MPV: Multipurpose Vehicle (van type of vehicle)

Passenger

Experience in other countries shows that car ownership versus GDP per capita tends to follow an S-shaped curve as described by Bouchara and Mazarati (2007). Car ownership increases gradually at first, and after a certain level of economic development, growth takes off and increases rapidly to finally leveling off at a maximum saturation level. Trends in two wheeler ownership tend to reach a peak and decline slowly, reflecting a decrease in two wheeler ownership after a certain level of economic development and when car ownership takes off (see Annex 5). In fact, a substitution effect can be observed in some countries, where cars are becoming more affordable. Projection of cars and two wheeler diffusion levels are projected using an income regression based on the NSSO survey (NNSO, 2005b). The NSSO survey provides the percentage of households possessing motorcycles and cars by MPCE class. The type of curve chosen was a logistic curve in the case of urban car ownership due to the very rapid increase of diffusion level across class of MPCE. In the case of rural car ownership, a Gompertz curve was used for its better fit. In both cases, the maximum saturation level of car ownership was estimated to be 1.3 per household which represents the level of OECD countries today. Even with projected car ownership increasing fast, saturation is not reached in the time frame of this study. For two wheelers in urban and rural areas, a polynomial function was chosen due to the slower slope of the curve. The maximum saturation for two wheelers was chosen to be 60% which is the highest level of two wheelers saturation in the world, reached in Malaysia (WB, 2005). Annex 6 provides detail the modeling of car and two wheelers ownership. Three wheelers and buses were projected according to their historic growth rate of 8.5% and 2% respectively. The resulting projections of passenger km are shown in Figure 22. Even if the stock of cars and 2 wheelers augment rapidly, bus remains the mean of transport used by the largest share of the population. Rail is the only mode of transport that will not increase over the next 15 years if no investments are made to renovate its infrastructure.

Figure 22. Passenger-km Projections



Freight

Sales of medium and heavy commercial vehicles (M&HCVs) and light commercial vehicles (LCVs) have increased very rapidly in India over the last 5 years as shown in Figure 21. We observe the growth of the stock of these vehicles with the growth of industrial value added and found a very close correlation of 98% in the case of M&HCVs, and 99% in the case of LCVs, see Annex 7. We then used the equation developed to forecast the stock of vehicles over growth of the industrial value added. Figure 23 shows the resulting projection of tonne-km per mode of transport and class of vehicle. Freight transport from medium and heavy trucks is projected to increase very rapidly, at an annual rate of 9.4%.

Figure 23. Freight-Tonne Projections

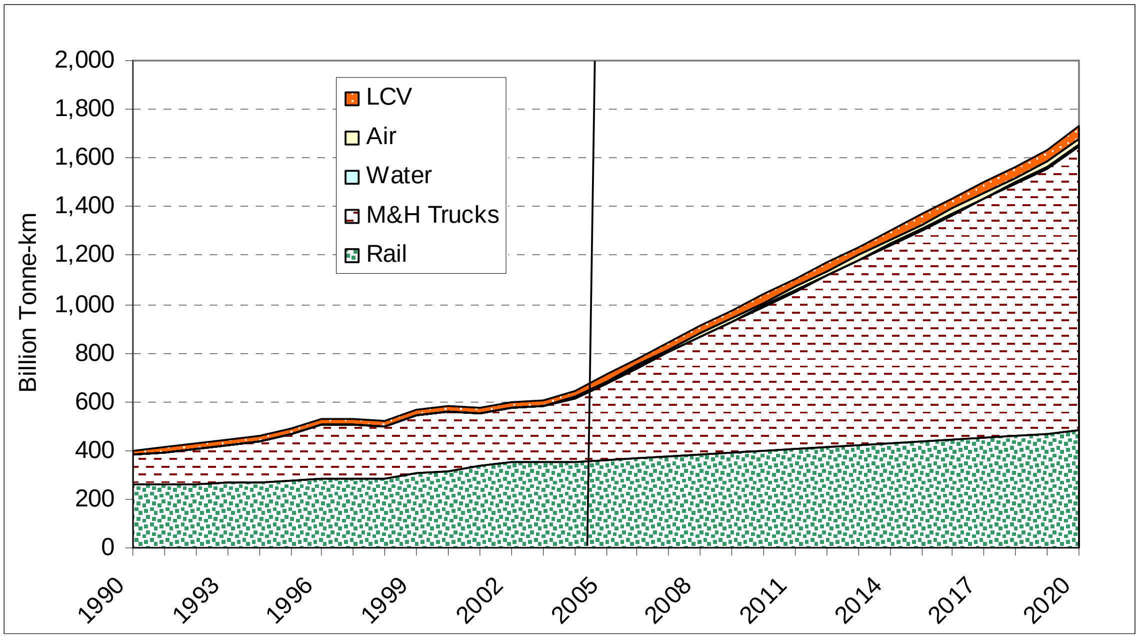
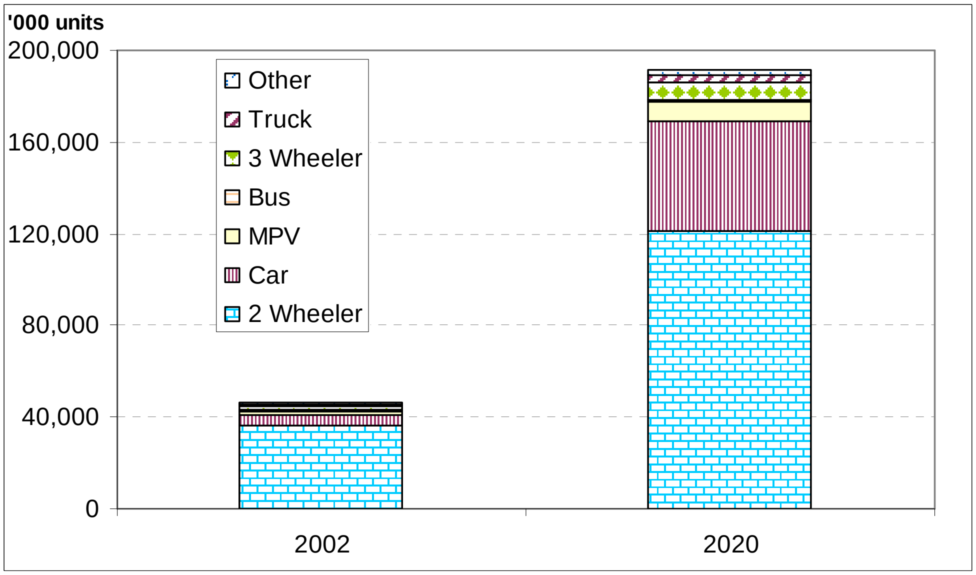


Figure 24 shows the projection to 2020 of vehicle stock in India. Two wheelers are expected to continue to represent the highest share of vehicles, growing at a rate of 6.9%. However, the highest growth is expected to be in car ownership, with an annual rate of 13.5%.

Figure 24. Stock Vehicle Projections



4.6.2 Transport Fuel Intensities

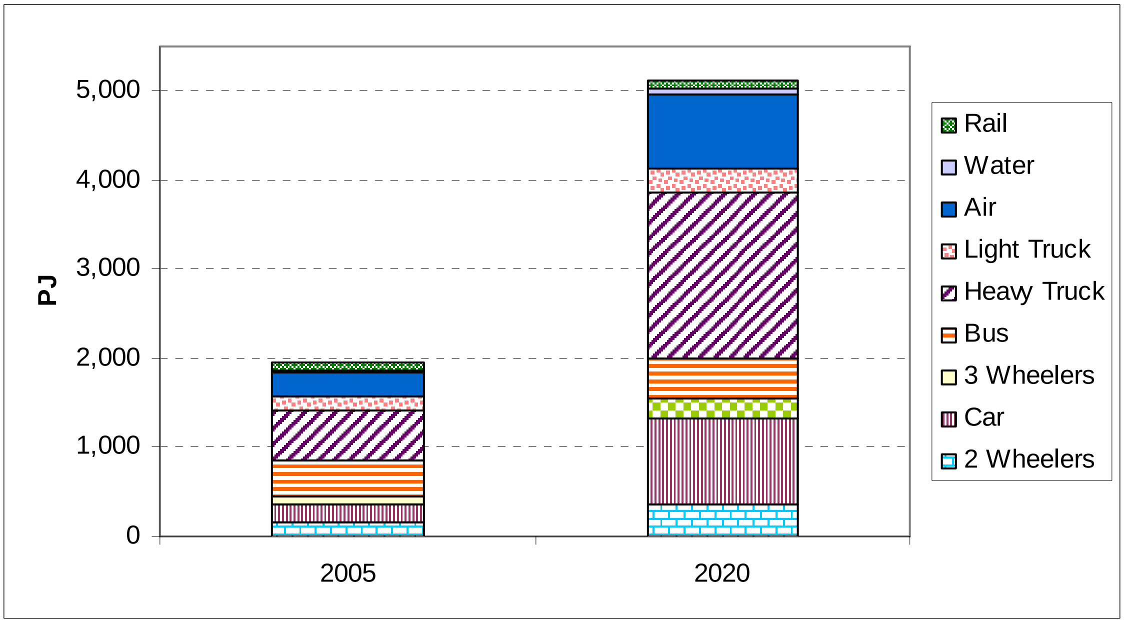
Estimates of fuel intensities are shown in Annex 3 and are derived from expert jugements (Annex 3 and Annex 9). The highest improvement pertains to the 2 wheeled vehicles. Two wheeler engines can be broadly classified as two and four stroke based on number of strokes used to produce a single power stoke. Two-stroke engines consume more energy per km driven than the four stroke engines. Recently, a shift toward 4-stroke has allowed more efficient use of energy and reduced air pollution. However, the population of two-stroke engines remains large. The introduction of electric two wheelers is increasing but represents only 1% of the sale in 2005 (SIAM, 2007).

Industry estimates show that the market share of diesel cars has already increased to over 30% in the last 18 months and the share is expected to be 50% of the total car sales by 2010. The implementation of Euro III emission norms in major cities since 2005 and nationwide in 2010 is helping to reduce particulate emissions and is accelerating improvement in energy efficiency. Moreover, India's 11th Five-year plan (2007-2012) strongly advocates policies for improving the efficiency of new vehicles. Petroleum Conservation Research Association (PCRA) is working on developing fuel efficiency standards for all classes and types of vehicles, including cars, scooters, bikes, trucks, buses and three-wheelers in association with BEE (2007) under the Energy Conservation Act. However, this has not been included in our estimates as the endorsement of the fuel standards is still to come.

4.6.3 Energy Projection in the Transport Sector

In 2020, the transportation sector is projected to account for 21% of total final energy use and 14% of primary energy use, versus 16% of total final energy use and 12% of primary energy use in 2005. This sector is expected to grow rapidly, with a projected annual growth rate of 6.8% for the period 2005 to 2020. The main source of future growth of energy is the increasing use of cars. Energy use by cars is expected to grow at an annual growth rate of 11%. Figure 25 shows how energy consumption is projected to grow by mode and type of vehicle. Energy consumption from trucks is also expected to increase rapidly at 8.8% AAGR, followed by air transportation at 7.9%. In terms of share, energy used by buses decreased from a share of 20% to 8% while energy used by trucks, still representing the largest consumption, grows from 28% to 38%, and energy used by cars increase from 10% to 18%.

Figure 25. Energy Use Projection by Mode and Vehicle Types, PJ.



Two-wheelers make up about 63% of the projected vehicle stock, and yet they consume around 7% of transport fuels.

Concerning the type of fuel used, motor gasoline is expected to represent a slightly larger share of 23% compared to 21% in 2005. Penetration of CNG is not visible here, because sufficient data were not available to estimate the energy use of this type of fuel. However, it is worth noting that in 1998, The Indian Supreme Court mandated CNG as the fuel for public transport in Delhi to control pollution. In 2002 a further ruling directed the Union government to give priority to the transport sector for CNG and a further 5 cities have implemented programs for urban transport. These are Ahmedabad, Lucknow, Kanpur, Mumbai and Hyderabad.

5. Summary

The analysis presented in this report significantly advances, we believe, the understanding of sources of energy demand in the residential and the transport sectors in India, and the accuracy in predicting their trajectory over the next decade. In doing so, we have presented a consistent and robust framework for national and sector level demand forecasting, which relies on separating the drivers of energy demand, and the intensity of its use in meeting that demand. We believe this to be a critical step in developing a comprehensive strategy of national energy demand management – the need for which is becoming ever more urgent for large developing countries like India.

The analysis as performed in this way reveals several interesting features of energy use in India. In the residential sector, an analysis of patterns of energy use and particular end uses shows that biomass (wood), which has traditionally been the main source of primary energy used in households, will stabilize in absolute terms. Meanwhile, due to the forces of urbanization and increased use of commercial fuels, the relative significance of biomass will be greatly diminished by 2020. At the same time, per household residential electricity consumption will likely quadruple in the 20 years between 2000 and 2020. In fact, primary electricity use will increase more rapidly than any other major fuel – even more than oil, in spite of the fact that transport is the most rapidly growing sector. The growth in electricity demand implies that chronic outages are to be expected unless drastic improvements are made both to the efficiency of the power infrastructure and to electric end uses and industrial processes. In the transport sector, the rapid growth in personal vehicle sales indicates strong energy growth in that area. Energy use by cars is expected to grow at an annual growth rate of 11%, increasing demand for oil considerably. In addition, oil consumption used for freight transport will also continue to increase .

The intent of this report was to use as wide an array of available data at the highest level of detail possible. Undoubtedly, some already available sources were overlooked. In general, however, the authors feel that the greatest gaps in data availability arise from a lack of accurate statistics in some cases, such as in the transport sector. In this way, we hope to highlight areas where the greatest gains could be made through more thorough unearthing of data sources or, if necessary, completing the surveys and statistical analysis necessary to generate new data sources. We found that the transport sector lacks consistent data reporting from national source, specifically on the stock of vehicle in use and fuel economy of vehicles. Finally, only a few data points were found to describe the unit energy consumption per appliances types and little is known on their typical life time and hour of use. Future data collection on these issues will allow refining the first energy use breakdown matrix developed in this report for India.

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Annexes

Annex 1. Model of Electricity Consumption by MPCE Class

Model Urban/Rural

Differences in development between rural and urban areas are large in India. The data show us that even if the diffusion is corrected for electrification, there is still a big difference between urban and rural areas for the same level of income. Therefore, these two sub-populations were modeled separately.

- **Electrification and Lighting**

Modelling electrification serves two purposes. First, diffusion is modeled on the subset of electrified households only and it acts as a scaling parameter in the forecast. Second, electrification is used to forecast lighting use, with the assumption that all electrified households use electric lighting.

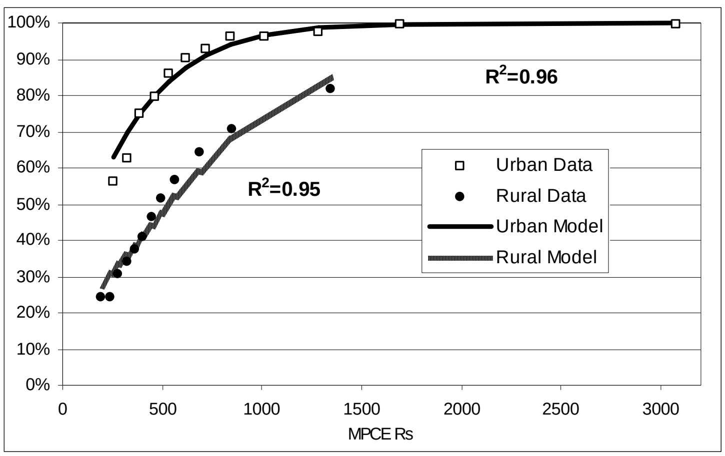
The NSSO provides data on use of electric lighting for each category of MPCE in urban and rural areas. We parameterize the relation between electricity use and income according to a Gompertz function:

$$\text{Elec} = \exp(\gamma \times (\exp(\beta \times Inc)))$$

The Gompertz function can be linearized and the parameters γ and β determined through a linear regression:

$$\ln(\ln(\frac{1}{\text{Elec}})) = \ln(-\gamma) + \beta \times Inc$$

Figure A 1. Electrification Regression Results for Urban and Rural Areas



Error! Reference source not found. shows the results of the regression. The correlation between the model and the data is very good, as indicated by the high values of R^2.

Using the data from Pune, Ahmednagar and Talegaon, (Kulkarni, 1994) the number of bulbs is modeled as a linear function of income.

It was found that: *IL=0.00037 x Income + 0.2011* (R^2*=0.85)*, and

$$FL = 0.0019 \times Income + 0.5333 \; (R^2 = 0.97)$$

Where *IL* and *FL* are the number of incandescent bulbs and fluorescent tubes per household, respectively , and *Income* is the monthly per capita income in 2000 Rs.

- **Appliance Saturation Model**

Diffusion data were parameterized in two steps, by first considering electrified households only for rural and urban areas, and then applying electrification rates. As in the case of electrification, the Gompertz functional form was used for all of the appliances.

$$Diff = Elec \times \alpha \times \exp(\gamma \times \exp(\beta \times Inc))$$

This equation can be transformed to a form that allows linear regression to find γ and β for each appliance for urban and rural sub-populations:

$$\ln\left(\ln\left(\frac{\alpha}{Diff} \times Elec\right)\right) = \ln(-\gamma) + (\beta \times Inc)$$

α is set to 1 except for fans (where we assumed 3.5). The parameters resulting from the regression are given in the following paragraph in Table 1. The table shows the generally good agreement between the data and the model with very high R2 and low P-values for all the parameters.

Figure A 2. Urban and Rural Appliances Ownership, Data and Model

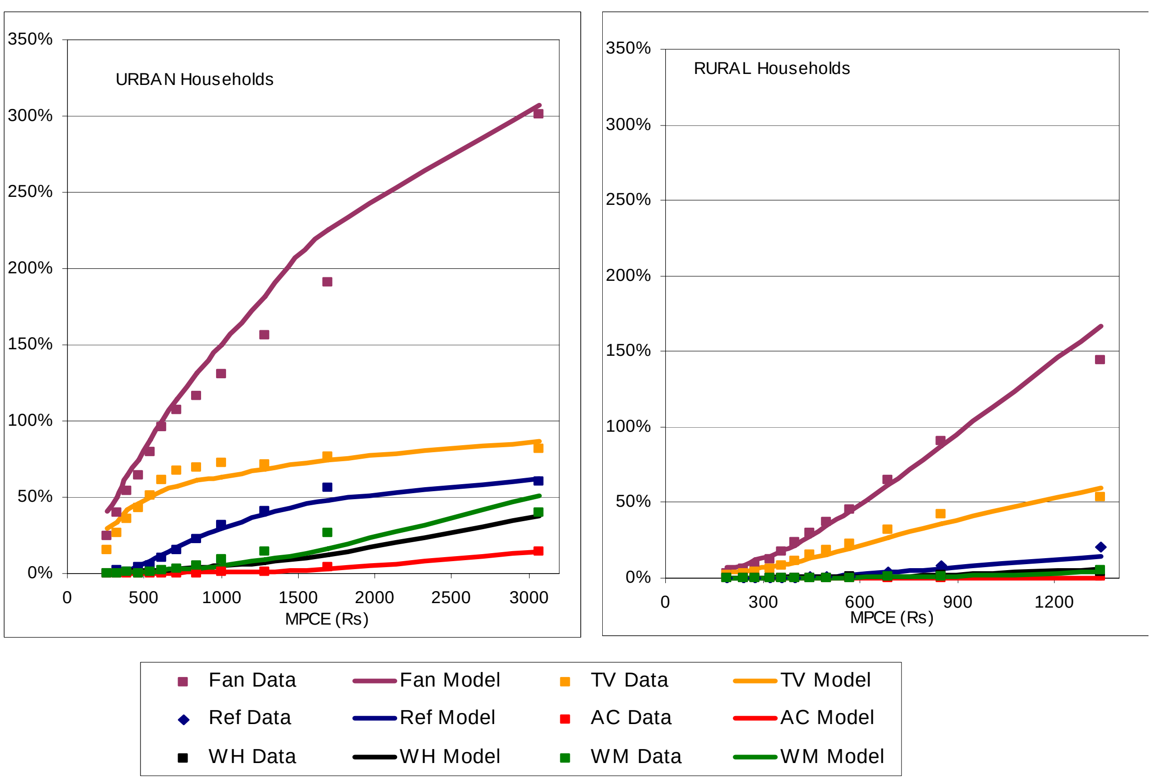


Table A 1. Results of the regression

Urban		*Coefficients*	*Standard Error*	*P-value*	*Rural*		*Coefficients*	*Standard Error*	*P-value*
Refrigerator	ln -γ	1.426	0.177	1.1E-05	**Refrigerator**	ln -γ	2.079	0.062	1.4E-11
R Square = 0.86 α = 1.00	β	-1.2E-03	1.5E-04	1.3E-05	R Square = 0.95 α= = 1.00	β	-1.4E-03	1.0E-04	1.2E-07
Air Condionner	ln -γ	1.990	0.046	1.1E-12	**Air Condionner**	ln -γ	1.953	0.035	8.2E-14
R square =0.93 α= = 1.00	β	-4.3E-04	3.9E-05	5.8E-07	R square =0.59 α = 1.00	β	-2.2E-04	5.8E-05	3.7E-03
Air Cooler	ln -γ	1.001	0.059	1.1E-08	**Air Cooler**	ln -γ	1.658	0.045	5.5E-12
R square =0.82 α= = 1.00	β	-3.4E-04	4.9E-05	4.7E-05	R square =0.92 α = 1.00	β	-8.1E-04	7.5E-05	8.6E-07
Washing Machine	ln -γ	1.787	0.088	1.8E-09	**Washing Machine**	ln -γ	1.959	0.050	2.9E-12
R Square = 0.90 α = 1.00	β	-7.1E-04	7.3E-05	2.0E-06	R Square = 0.85 α= = 1.00	β	-6.4E-04	8.4E-05	1.8E-05
Fan	ln -γ	0.688	0.054	1.7E-07	**Fan**	ln -γ	1.152	0.084	8.7E-08
R Square = 0.98 α = 3.50	β	-8.9E-04	4.5E-05	2.2E-09	R Square = 0.90 α= = 3.50	β	-1.3E-03	1.4E-04	2.9E-06
TV	ln -γ	-0.322	0.177	9.9E-02	**TV**	ln -γ	0.940	0.106	4.9E-06
R Square = 0.58 α = 1.00	β	-5.5E-04	1.5E-04	3.9E-03	R Square = 0.89 α= = 1.00	β	-1.6E-03	1.8E-04	4.8E-06
Water heater	ln -γ	1.651	0.053	3.0E-11	**Water Heater**	ln -γ	1.890	0.038	2.9E-13
R square =0.94 α= = 1.00	β	-5.4E-04	4.4E-05	2.5E-07	R square =0.91 α = 1.00	β	-6.4E-04	6.4E-05	1.7E-06

Annex 2. Model of Fuel Consumption by MPCE Class in the Residential Sector

Cooking and water heating energy consumption was forecast using an income regression based on the relation between consumption of each fuel as a function of MPCE provided in the 55th NSSO Survey (NSSO, 2001a). The quantities reported in kg were converted to MJ using the following heat rate.

Table A 2. Fuel Heat Contents

	LPG	Kerosene[11]	Wood
Heat Rate (MJ/kg)	47.3	43.75	16

Source: Ministry of petroleum (http://petroleum.nic.in/petstat.pdf)

The pattern of each fuel consumption was different from one fuel to another, hence different equation were used to model the relation.

LPG consumption for rural and urban household was modeled with a Gompertz function and rural kerosene with a quadratic function. For wood, we separated the part of wood users that is going down and the level of useful energy used that is going up. We used the product of two functions describing the data disaggregated between share of users and energy use by users. For urban kerosene, we modeled the household behavior starting at the 2000 income level with a modified exponential function. Figure A 3 shows the data and the model.

Figure A 3. Useful fuel Consumption in Urban and Rural Areas

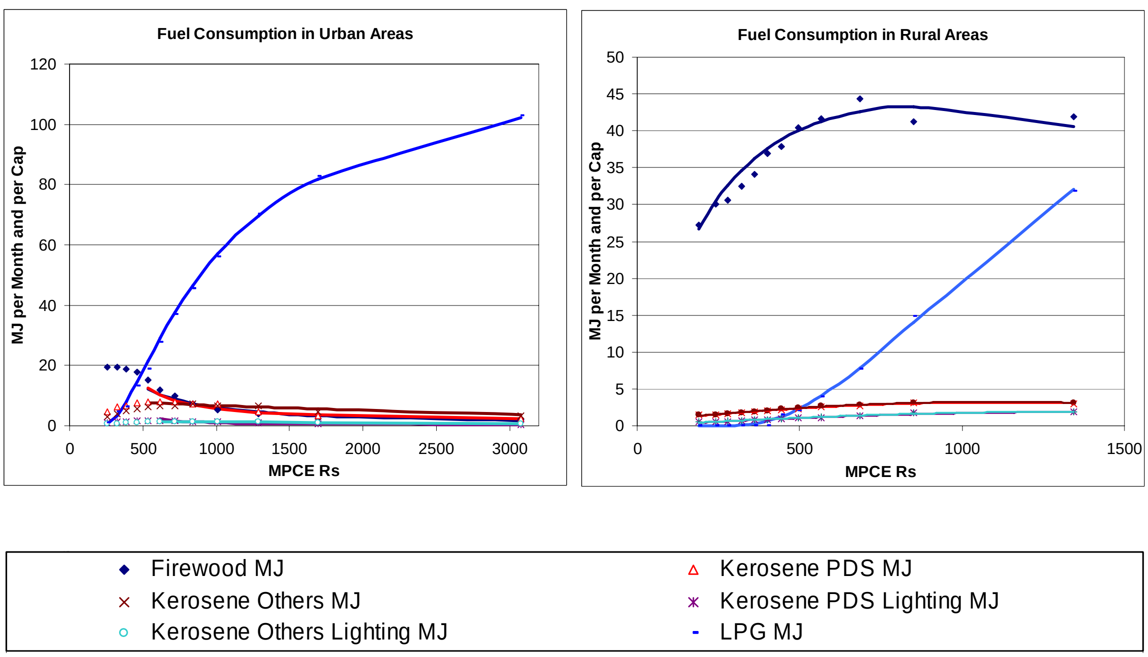


Table A3 gives the detailed equations, the parameters and error of each regression.

[11] Density of kerosene 0.81 kg/L

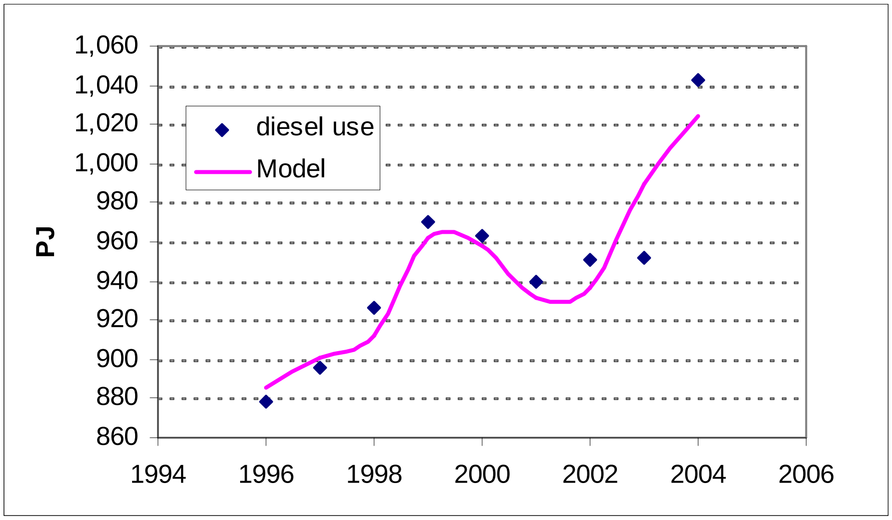
Table A3. Regression results

	Fuel	zone	equation	parameters a	b	c	d	e	r2
Water Heating and Cooking	LPG	urban	y=a/exp(exp(exp(b).Inc^c))	1.5E+02	3.4E+00	-3.3E-01			0.997
		rural	y=a/exp(exp(exp(b).Inc^c))	1.5E+02	3.1E+00	-2.6E-01			0.998
	Wood	urban	y=(a.ln(Inc)-b).c.Inc^d	8.3E+00	2.7E+01	2.5E+03	-1.4E+00		
		rural	y=(a.ln(Inc)-b).c.exp(-d.Inc^2-e.Inc)	1.4E+01	5.3E+01	1.0E+00	1.0E-07	2.0E-04	
	Kerosene PDS	urban	y =exp(a.Inc^b)	6.6E+01	-5.0E-01				0.943
		rural	y =a.Inc^2 + b.Inc + c	-3.0E-06	6.6E-03	5.8E-01			0.987
	Kerosene Others	urban	y=a.exp(-b.Inc^2-c.Inc)	1.1E+01	3.0E-08	2.0E-04			0.915
		rural	y =a.Inc^2 + b.Inc + c	-1.0E-06	3.6E-03	-8.8E-02			0.977
Lighting	Kerosene PDS	urban	y =exp(a.Inc^b)	2.0E+03	-1.1E+00				0.931
		rural	y =a.Inc^2 + b.Inc + c	-2.0E-06	5.4E-03	4.8E-01			0.987
	Kerosene Others	urban	y=a.exp(-b.Inc^2-c.Inc)	1.8E+00	3.0E-08	2.0E-04			0.915
		rural	y =a.Inc^2 + b.Inc + c	-1.0E-06	3.0E-03	-7.3E-02			0.977

Annex 3. Average Distance Traveled, Load Factors and Fuel Economy Estimations

Average Distance		**1990**	**2005**	**2020**
Two-wheelers	km/vehicle	9,000	6,300	6,300
Cars	km/vehicle	9,000	8,000	7,500
Jeeps	km/vehicle	10,000	7,800	7,500
Auto-rickshaws	km/vehicle	35,500	35,500	35,500
Buses	km/vehicle	65,000	55,000	52,000
trucks	km/vehicle	60,000	55,000	55,000
LCVs	km/vehicle	25,000	20,000	15,000
Occupancy		**1990**	**2005**	**2020**
Two-wheelers	passenger	1.50	1.50	1.50
Cars	passenger	3.18	3.18	3.18
Jeeps	passenger	3.18	3.18	3.18
Auto-rickshaws	passenger	1.76	1.76	1.76
Buses	passenger	41.60	41.60	38.00
Average Tons		**1990**	**2005**	**2020**
trucks	tons	6.00	6.00	6.00
LCVs	tons	1.40	1.40	1.40
Fuel Economy		**1990**	**2005**	**2020**
Two-wheelers	km/l	40.00	67.50	75.00
Cars Gasoline	km/l	8.86	12.83	14.00
Cars Diesel	km/l	-	14.00	14.50
Jeeps	km/l	6.20	8.98	9.80
Auto-rickshaws	km/l	16.93	32.26	37.00
Buses	km/l	3.00	3.93	4.50
trucks	Mj/km-ton	2.70	3.51	3.58
LCVs	Mj/km-ton	3.26	4.42	4.66

Annex 4. Correlation Diesel Price and GDP per Capita to Diesel Consumption

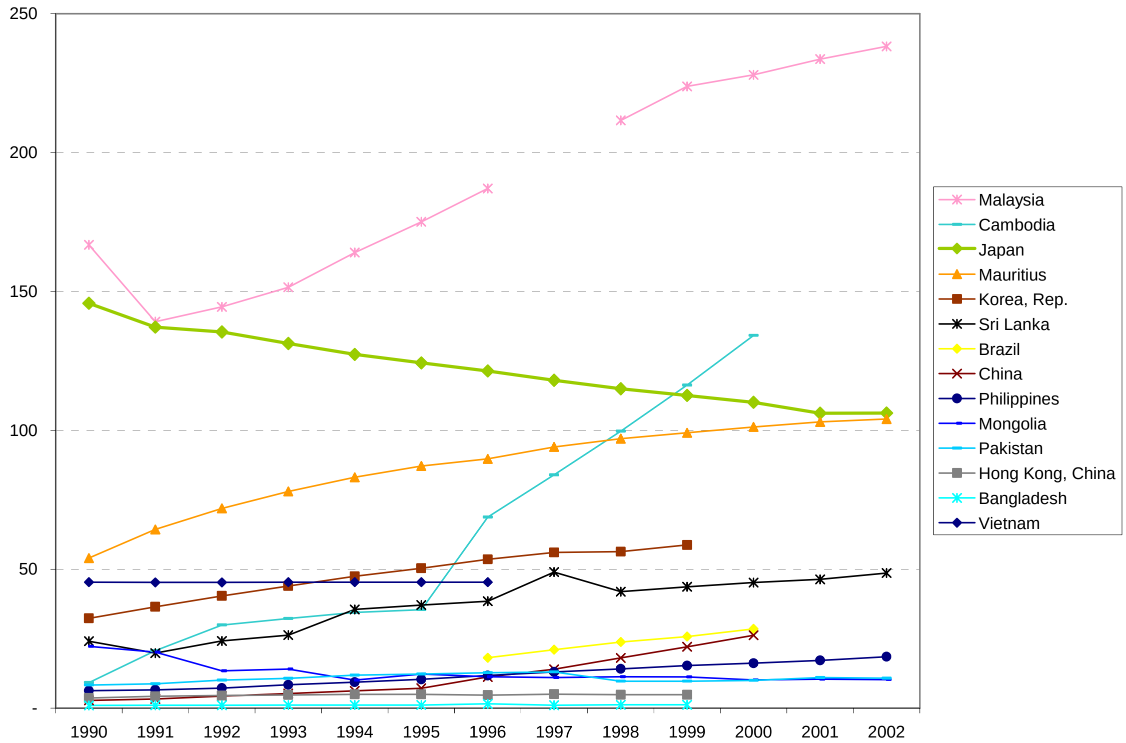


Y=333.1725+1.3556Income-17.15591Price

Stata, regression on Income and Price

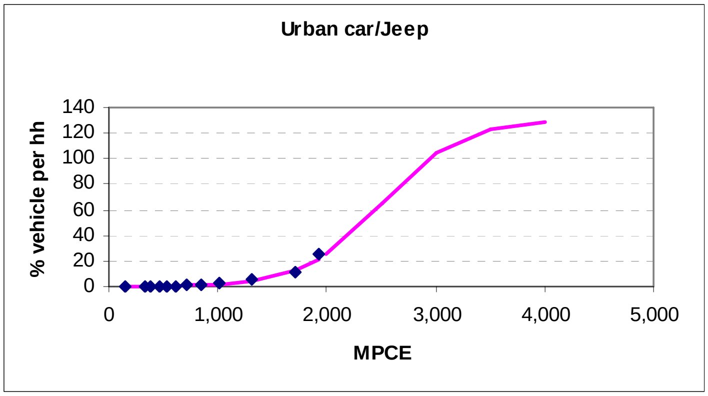
```
     Source |       SS       df       MS              Number of obs =       9
-------------+------------------------------           F(  2,     6) =   20.03
      Model |  15554.3644     2  7777.18219           Prob > F      =  0.0022
   Residual |  2329.73741     6  388.289568           R-squared     =  0.8697
-------------+------------------------------           Adj R-squared =  0.8263
      Total |  17884.1018     8  2235.51272           Root MSE      =  19.705

------------------------------------------------------------------------------
----
  diesel_use |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
       price |  -17.15591   6.346003    -2.70   0.035    -32.68402   -1.627798
      income |   1.355635   .3583452     3.78   0.009     .4787957    2.232474
       _cons |   335.1725   137.2314     2.44   0.050    -.6205132    670.9655
------------------------------------------------------------------------------
----
```

Annex 5. Asia Two Wheelers Ownership



Source: World Bank, 2005.

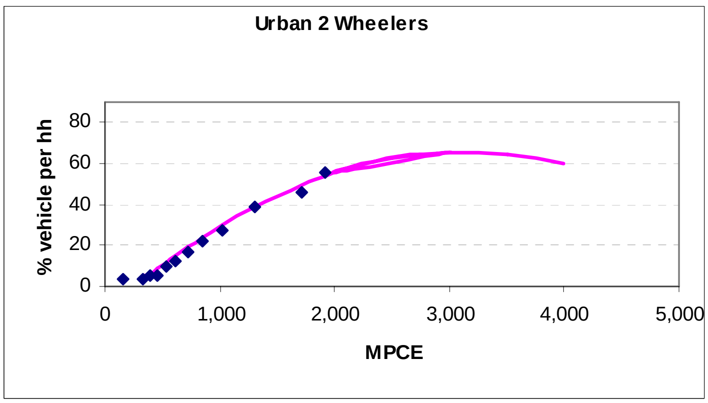
Annex 6. Passenger Vehicle Penetration Projection



Logistic curve with a maximum saturation of 130 cars per 1000 households.

$$Y = \frac{130}{1+1147\exp^{-0.0028\times \mathrm{Inc}}}$$

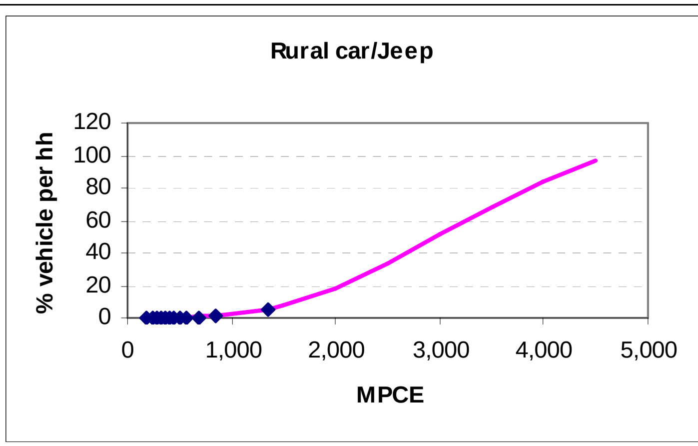
R^2: 91%



Polynomial curve with a maximum saturation of 60% of 2 wheelers owned per 100 households.

$$Y = 9*10^{-7} \times Inc^2 + 0.0297 Inc - 5.1436$$

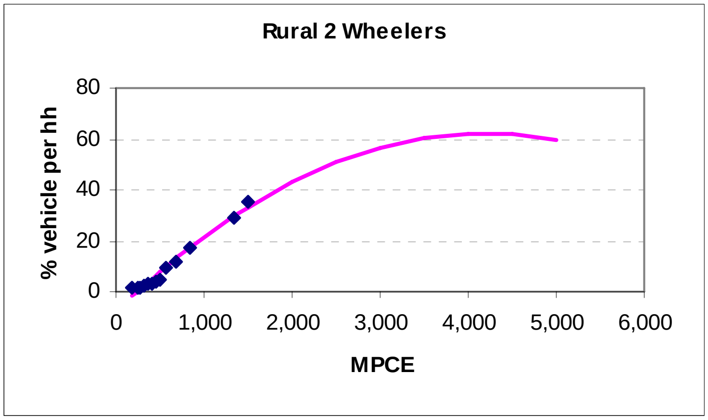
R^2: 98%



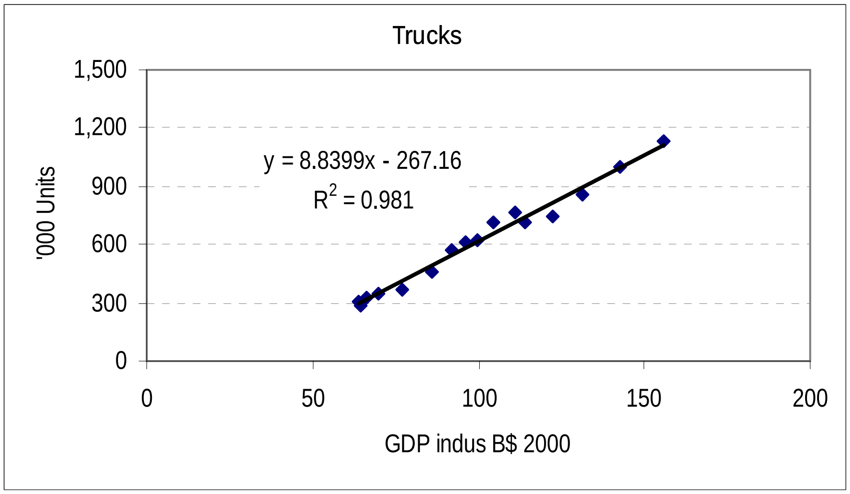
Gompertz curve with a maximum saturation of 130 cars per 100 households

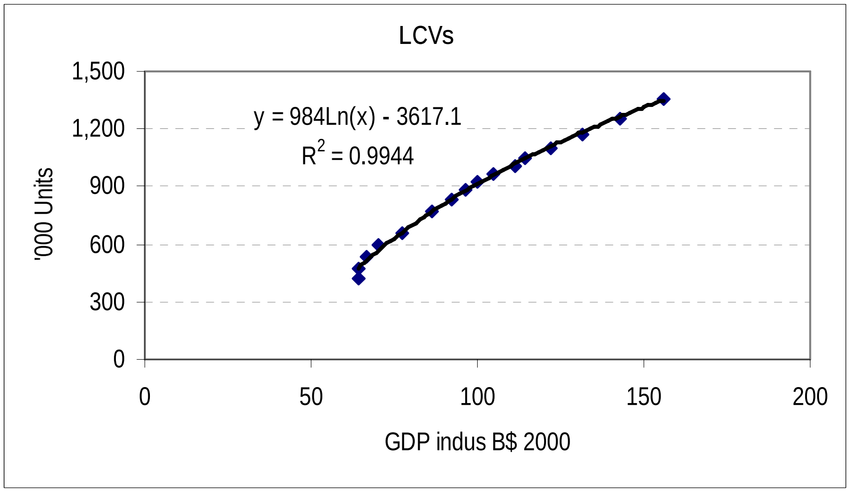
$$Y = 130 \times \exp(-8.9 \times \exp(-0.0008 \times Inc))$$

R^2: 98%

	Polynomial curve with a maximum saturation of 60 of 2 wheelers per 100 households. $Y = -4*10^{-6} Inc^2 + 0.0336 Inc - 8.126$ R^2: 99%

Annex 7. Model of Commercial Vehicles Growth





Annex 8. The Residential Sector Energy Use and Projections

Sector		Variable Type	Name	Unit	1990	1995	2000	2005	2010	2015	2020	AAGR 90-05	AAGR 05-20
RESIDENTIAL				PJ	2,897	3,288	4,030	4,854	5,825	6,861	7,864		
Residential	driver		population	k pers	860,195	954,282	1,046,235	1,134,403	1,220,182	1,302,535	1,379,198	1.9%	1.3%
Residential	driver		urbanization rate	%	25.5%	26.6%	27.7%	28.7%	30.1%	31.9%	34.3%	0.8%	1.2%
Residential	driver	*Pm*	m=rural	k pers	640,845	700,443	756,428	808,829	852,907	887,026	906,133	1.7%	0.8%
Residential	driver	*Pm*	m=urban	k pers	219,350	253,839	289,807	325,574	367,275	415,509	473,065	2.7%	2.5%
Residential	driver	*Fm*	m=rural	pers/hh	5.57	5.38	5.19	4.91	4.80	4.77	4.75	-0.8%	-0.2%
Residential	driver	*Fm*	m=urban	pers/hh	5.30	4.94	4.60	4.31	4.05	3.85	3.70	-1.4%	-1.0%
Residential	driver	*Em*	m=rural	%	36.7%	39.9%	46.2%	53.7%	65.0%	76.3%	86.0%	2.6%	3.2%
Residential	driver	*Em*	m=urban	%	82.8%	85.8%	90.0%	93.4%	96.6%	98.4%	99.3%	0.8%	0.4%
Residential	driver	*Sm,j*	m=rural, j=refrigerator	%	1%	1%	2%	4%	8%	16%	27%	14.6%	13.6%
Residential	driver	*Sm,j*	m=rural, j=Air Conditioner	%	0%	0%	0%	0%	0%	0%	1%	6.0%	10.4%
Residential	driver	*Sm,j*	m=rural, j=Air Cooler	%	1%	1%	2%	3%	6%	10%	17%	9.3%	11.8%
Residential	driver	*Sm,j*	m=rural, j=washing Machine	%	0%	0%	0%	1%	2%	3%	7%	11.0%	15.5%
Residential	driver	*Sm,j*	m=rural, j=fan	%	20%	25%	37%	54%	81%	117%	161%	7.0%	7.6%
Residential	driver	*Sm,j*	m=rural, j=television	%	9%	11%	16%	22%	32%	43%	56%	6.2%	6.3%
Residential	driver	*Sm,j*	m=rural, j=water heating	%	0%	0%	1%	1%	2%	4%	8%	10.3%	14.5%
Residential	driver	*Sm,j*	m=rural, j=other	%	37%	40%	46%	54%	65%	76%	86%	2.6%	3.2%
Residential	driver	*Sm,j*	m=urban, j=refrigerator	%	16%	19%	27%	35%	46%	57%	69%	5.6%	4.6%
Residential	driver	*Sm,j*	m=urban, j=Air Conditioner	%	1%	1%	1%	3%	5%	9%	15%	10.5%	12.6%
Residential	driver	*Sm,j*	m=urban, j=Air Cooler	%	10%	11%	14%	17%	21%	26%	33%	3.4%	4.8%
Residential	driver	*Sm,j*	m=urban, j=wash. Machine	%	3%	5%	7%	12%	18%	27%	38%	8.7%	8.2%
Residential	driver	*Sm,j*	m=urban, j=fan	%	103%	116%	140%	166%	196%	228%	259%	3.2%	3.0%
Residential	driver	*Sm,j*	m=urban, j=television	%	51%	54%	59%	64%	70%	75%	80%	1.6%	1.5%
Residential	driver	*Sm,j*	m=urban, j=water heating	%	3%	4%	6%	9%	14%	21%	31%	7.6%	8.4%
Residential	driver	*Sm,j*	m=urban, j=other	%	83%	86%	90%	93%	97%	98%	99%	0.8%	0.4%
Residential	intensity	*UECj*	m=rural, j=refrigerator	kWh/unit	459	477	483	497	512	528	550	0.5%	0.7%
Residential	intensity	*UECj*	m=rural, j=Air Conditioner	kWh/unit	2,160	2,160	2,160	2,329	2,657	3,038	3,426	0.5%	2.6%
Residential	intensity	*UECj*	m=rural, j=Air Cooler	kWh/unit	298	298	298	298	298	298	298	0.0%	0.0%
Residential	intensity	*UECj*	m=rural, j=wash. Machine	kWh/unit	190	190	190	190	190	190	190	0.0%	0.0%
Residential	intensity	*UECj*	m=rural, j=fan	kWh/unit	145	145	145	145	145	145	145	0.0%	0.0%

Sector		Variable Type	Name	Unit	1990	1995	2000	2005	2010	2015	2020	AAGR 90-05	AAGR 05-20
Residential	intensity	*UECj*	m=rural, j=television	kWh/unit	150	150	150	150	150	150	150	0.0%	0.0%
Residential	intensity	*UECj*	m=rural, j=water heating	kWh/unit	624	623	620	400	612	607	603	-2.9%	2.8%
Residential	intensity	*UECj*	m=rural, j=other	kWh/unit	-	-	-	89	164	238	298		8.4%
Residential	intensity	*UECj*	m=urban, j=refrigerator	kWh/unit	484	478	469	502	517	531	554	0.2%	0.7%
Residential	intensity	*UECj*	m=urban, j=Air Conditionner	kWh/unit	2,160	2,160	2,160	2,298	2,596	2,973	3,385	0.4%	2.6%
Residential	intensity	*UECj*	m=urban, j=Air Cooler	kWh/unit	298	298	298	298	298	298	298	0.0%	0.0%
Residential	intensity	*UECj*	m=urban, j=wash.Machine	kWh/unit	190	190	190	190	190	190	190	0.0%	0.0%
Residential	intensity	*UECj*	m=urban, j=fan	kWh/unit	145	145	145	145	145	145	145	0.0%	0.0%
Residential	intensity	*UECj*	m=urban, j=television	kWh/unit	150	150	150	150	150	150	150	0.0%	0.0%
Residential	intensity	*UECj*	m=urban, j=water heating	kWh/unit	620	623	624	400	612	607	602	-2.9%	2.8%
Residential	intensity	*UECj*	m=urban, j=other	kWh/unit	-	-	-	74	149	223	298		9.7%
Residential	driver	*Li,m*	i=fluorescent, m=rural	bulb/hh	1.2	1.3	1.5	1.8	2.1	2.5	3.0	2.6%	3.6%
Residential	driver	*Li,m*	i=fluorescent, m=urban	bulb/hh	1.6	1.8	2.1	2.5	3.0	3.6	4.4	3.0%	3.9%
Residential	driver	*Li,m*	i=incandescent, m=rural	bulb/hh	1.5	1.7	2.1	2.6	3.2	4.0	4.9	3.7%	4.4%
Residential	driver	*Li,m*	i=incandescent, m=urban	bulb/hh	2.3	2.6	3.2	4.0	5.0	6.2	7.8	3.9%	4.5%
Residential	power	*Cai,m*	i=fluorescent, m=rural	Watt	40	40	40	40	40	40	40	0.0%	0.0%
Residential	power	*Cai,m*	i=fluorescent, m=urban	Watt	40	40	40	40	40	40	40	0.0%	0.0%
Residential	power	*Cai,m*	i=incandescent, m=rural	Watt	60	60	60	60	60	60	60	0.0%	0.0%
Residential	power	*Cai,m*	i=incandescent, m=urban	Watt	60	60	60	60	60	60	60	0.0%	0.0%
Residential	usage	*Hi,m*	i=fluorescent, m=rural	hours	4	4	4	4	4	4	4	0.0%	0.0%
Residential	usage	*Hi,m*	i=fluorescent, m=urban	hours	4	4	4	4	4	4	4	0.0%	0.0%
Residential	usage	*Hi,m*	i=incandescent, m=rural	hours	4	4	4	4	4	4	4	0.0%	0.0%
Residential	usage	*Hi,m*	i=incandescent, m=urban	Hours	4	4	4	4	4	4	4	0.0%	0.0%
Residential	useful	*LKi,m*	i=kerosene, m=rural	MJ/ca/mth	8.3	10.2	19.6	24.7	29.0	31.7	28.5	7.5%	1.0%
Residential	useful	*LKi,m*	i=kerosene, m=urban	MJ/ca/mth	14.4	17.0	16.7	16.5	15.9	14.4	12.6	0.9%	-1.8%
Residential	final	*CWm,k*	m=rural, k=LPG	MJ/ca/mth	2.1	2.4	3.6	9.3	20.2	35.6	54.3	10.3%	12.4%
Residential	final	*CWm,k*	m=rural, k=wood	MJ/ca/mth	280.7	285.2	307.3	323.0	332.5	330.1	310.9	0.9%	-0.3%
Residential	final	*CWm,k*	m=rural, k=Kerosene	MJ/ca/mth	6.5	6.6	7.1	8.8	10.3	11.0	9.7	2.0%	0.6%
Residential	final	*CWm,k*	m=rural, k=biogas	MJ/ca/mth	0.3	0.6	0.7	0.8	0.9	0.9	0.9		
Residential	final	*CWm,k*	m=urban, k=LPG	MJ/ca/mth	30.27	44.63	80.52	101.77	123.12	141.83	157.72	8.4%	3.0%
Residential	final	*CWm,k*	m=urban, k=wood	MJ/ca/mth	97.44	85.29	54.92	42.38	31.60	23.32	17.05	-5.4%	-5.9%
Residential	final	*CWm,k*	m=urban, k=Kerosene	MJ/ca/mth	34.31	32.60	30.91	29.93	26.51	21.60	16.38	-0.9%	-3.9%

Sector	Variable Type	Name	Unit	1990	1995	2000	2005	2010	2015	2020	AAGR 90-05	AAGR 05-20
Residential	rural appliance	k=electricity	PJ	20	27	52	117	224	381	585	12.4%	11.3%
Residential	rural lighting	k=electricity	PJ	30	38	66	104	166	250	357	8.7%	8.5%
Residential	rural lighting	k=kerosene	PJ	64	86	178	239	297	338	310	9.2%	1.7%
Residential	rural cooking	k=LPG	PJ	17	20	33	91	207	379	590	12.0%	13.3%
Residential	rural cooking	k=wood	PJ	2,159	2,397	2,790	3,135	3,403	3,514	3,380	2.5%	0.5%
Residential	rural cooking	k=kerosene	PJ	50	56	64	86	105	118	105	3.6%	1.4%
Residential	rural cooking	k=biogas	PJ	2	5	6	8	9	10	10		1.5%
Residential	urban appliance	k=electricity	PJ	55	68	123	204	352	579	941	9.2%	10.7%
Residential	urban lighting	k=electricity	PJ	36	45	83	126	192	289	429	8.8%	8.5%
Residential	urban lighting	k=kerosene	PJ	38	52	58	64	70	72	72	3.6%	0.7%
Residential	urban cooking	k=LPG	PJ	80	136	280	398	543	707	895	11.3%	5.6%
Residential	urban cooking	k=wood	PJ	256	260	191	166	139	116	97	-2.9%	-3.5%
Residential	urban cooking	k=kerosene	PJ	90	99	107	117	117	108	93	1.7%	-1.5%
Residential	Energy	Eres	PJ	2,897	3,288	4,030	4,854	5,825	6,861	7,864	3.5%	3.3%

Mth: month
Wash. Machine: Washing Machine

Annex 9. The transport Sector Energy Use and Projections

Sector	Variable Type	Name		Unit	1990	1995	2000	2005	2010	2015	2020	AAGR 90-05	AAGR 05-20
TRANSPORT					**1,056**	**1,199**	**1,446**	**1,964**	**2,716**	**3,830**	**5,119**		
Transport	driver	$V_{t,j,k}$	t=pass, j=two wheelers, k=gasoline	k unit	8,811	15,556	29,690	50,225	56,933	84,914	121,368	12.3%	6.1%
Transport	driver	$K_{t,j}$	t=pass, j=two wheelers	km/yr	9,000	6,750	6,300	6,300	6,300	6,300	6,300	-2.3%	0.0%
Transport	intensity	$EI_{TR\ t,r,j,k}$	t=pass, j=two wheelers, k=gasoline	km/l	40	48	60	68	73	74	75	3.5%	0.7%
Transport	driver	$V_{t,j,k}$	t=pass, j=pass car, k=gasoline	k unit	956	1,527	3,421	4,788	6,602	12,031	19,728	11.3%	9.9%
Transport	driver	$K_{t,j}$	t=pass, j=pass car	km/yr	9,000	9,000	8,000	8,000	8,000	8,000	7,500	-0.8%	-0.4%
Transport	intensity	$EI_{TR\ t,r,j,k}$	t=pass, j=pass car, k=gasoline	km/l	8.86	9.80	12.00	12.83	13.50	13.80	14.00	2.5%	0.6%
Transport	driver	$V_{t,j,k}$	t=pass, j=pass car, k=diesel	k unit	0.00	25	324	2,175	3,492	9,007	19,728		15.8%
Transport	driver	$K_{t,j}$	t=pass, j=pass car	km/yr	9,000	9,000	8,000	8,000	8,000	8,000	7,500	-0.8%	-0.4%
Transport	intensity	$EI_{TR\ t,r,j,k}$	t=pass, j=pass car, k=diesel	km/l	0.00	0.00	14.00	14.00	14.00	14.00	15.09		0.5%
Transport	driver	$V_{t,j,k}$	t=pass, j=MPV, k=diesel	k unit	152	275	869	1,497	2,133	4,445	8,337	16.5%	12.1%
Transport	driver	$K_{t,j}$	t=pass, j=MPV	km/yr	10,000	9,000	8,000	7,800	7,800	7,800	7,500	-1.6%	-0.3%
Transport	intensity	$EI_{TR\ t,r,j,k}$	t=pass, j=MPV, k=diesel	km/l	6.20	6.86	8.40	8.52	8.73	8.95	9.18	2.1%	0.5%
Transport	driver	$V_{t,j,k}$	t=pass, j=three wheelers, k=gasoline	k unit	591	993	1,730	2,583	3,943	5,927	7,397	10.3%	7.3%
Transport	driver	$K_{t,j}$	t=pass, j=three wheelers	km/yr	35,500	35,500	35,500	35,500	35,500	35,500	35,500	0.0%	0.0%
Transport	intensity	$EI_{TR\ t,r,j,k}$	t=pass, j=three wheelers, k=gasoline	km/l	16.93	21.31	26.83	32.26	34.00	35.00	37.00	4.4%	0.9%
Transport	driver	$V_{t,j,k}$	t=pass, j=buses, k=diesel	k unit	298	423	559	772	852	941	1,038	6.5%	2.0%
Transport	driver	$K_{t,j}$	t=pass, j=buses	km/yr	65,000	60,000	55,480	55,000	55,000	55,000	52,000	-1.1%	-0.4%
Transport	intensity	$EI_{TR\ t,r,j,k}$	t=pass, j=buses, k=diesel	km/l	3.00	3.40	3.57	3.93	4.10	4.30	4.50	1.8%	0.9%
Transport	driver	$V_{t,j,k}$	t=freight, j=heavy truck, k=diesel	k unit	350	525	731	971	1,571	2,372	3,521	7.0%	9.0%
Transport	driver	$K_{t,j}$	t=freight, j=heavy truck	km/yr	60,000	60,000	55,000	55,000	55,000	55,000	55,000	-0.6%	0.0%
Transport	intensity	$V_{t,j,k}$	t=freight, j=heavy truck, k=diesel	km/l	2.70	2.98	3.21	3.51	3.60	3.69	3.78	1.8%	0.5%
Transport	driver	$K_{t,j}$	t=freight, j=light truck	k unit	410	724	846	1,019	1,635	1,991	2,346	6.3%	5.7%
Transport	driver	$V_{t,j,k}$	t=freight, j=light truck, k=diesel	km/yr	25,000	20,000	20,000	20,000	20,000	20,000	15,000	-1.5%	-1.9%
Transport	intensity	$K_{t,j}$	t=freight, j=light truck	km/l	3.26	3.57	4.07	4.42	4.53	4.64	4.76	2.1%	0.5%
Transport	driver	$Q_{t,r}$	t=pass, r=air	M pass-km	15,253	20,856	26,212	40,999	65,849	92,357	128,327	6.8%	7.9%
Transport	driver	$S_{t,r,k}$	t=pass, r=air, k=kerosene	%	100%	100%	100%	100%	100%	100%	100%	0.0%	0.0%
Transport	intensity	$EI_{TR\ t,r,j,k}$	t=pass, r=air,k=kerosene	MJ/pass-km	3.60	3.50	3.50	3.48	3.39	3.39	3.22	-0.2%	-0.5%

Sector	Variable Type	Name		Unit	1990	1995	2000	2005	2010	2015	2020	AAGR 90-05	AAGR 05-20
Transport	driver	$Q_{t,r}$	t=freight, r=air	M ton-km	675	642	582	7,262	12,798	17,949	25,175	17.2%	8.6%
Transport	driver	$S_{t,r,k}$	t=freight, r=air, k=kerosene	%	100%	100%	100%	100%	100%	100%	100%	0.0%	0.0%
Transport	intensity	$EI_{TR\ t,r,j,k}$	t=freight, r=air, k=kerosene	MJ/ton-km	18.90	18.02	18.02	17.90	17.46	17.46	16.60	-0.4%	-0.5%
Transport	driver	$Q_{t,r}$	t=pass, r=water	M pass-km	6,364	8,809	9,681	10,009	10,999	12,087	13,282	3.1%	1.9%
Transport	driver	$S_{t,r,k}$	t=pass, r=water, k=diesel	%	100%	100%	100%	100%	100%	100%	100%	0.0%	0.0%
Transport	intensity	$EI_{TR\ t,r,j,k}$	t=pass, r=water, k=diesel	MJ/pass-km	0.37	0.40	0.40	0.37	0.36	0.36	0.34	0.0%	-0.5%
Transport	driver	$Q_{t,r}$	t=freight, r=water	M ton-km	42,689	54,876	77,542	99,157	141,264	201,253	286,717	5.8%	7.3%
Transport	driver	$S_{t,r,k}$	t=freight, r=water, k=diesel	%	100%	100%	100%	100%	100%	100%	100%	0.0%	0.0%
Transport	intensity	$EI_{TR\ t,r,j,k}$	t=freight, r=water, k=diesel	MJ/ton-km	0.30	0.26	0.22	0.20	0.20	0.20	0.19	-2.7%	-0.5%
Transport	driver	$Q_{t,r}$	t=pass, r=rail	M pass-km	306,282	348,385	457,022	517,212	536,018	555,508	575,706	3.6%	0.7%
Transport	driver	$S_{t,r,k}$	t=pass, r=rail, k=coal	%	22%	1%	0%	0%	0%	0%	0%		
Transport	driver	$S_{t,r,k}$	t=pass, r=rail, k=diesel	%	42%	64%	56%	51%	42%	34%	25%	1.2%	-4.6%
Transport	driver	$S_{t,r,k}$	t=pass, r=rail, k=electricity	%	36%	35%	44%	49%	58%	66%	75%	2.1%	2.8%
Transport	intensity	$EI_{TR\ t,r,j,k}$	t=pass, r=rail, k=coal	MJ/pass-km	1.20	1.20	0.00	0.00	0.00	0.00	0.00		
Transport	intensity	$EI_{TR\ t,r,j,k}$	t=pass, r=rail, k=diesel	MJ/pass-km	0.24	0.17	0.15	0.15	0.15	0.15	0.14	-3.1%	-0.5%
Transport	intensity	$EI_{TR\ t,r,j,k}$	t=pass, r=rail, k=electricity	MJ/pass-km	0.12	0.12	0.10	0.08	0.08	0.08	0.07	-2.7%	-0.5%
Transport	driver	$Q_{t,r}$	t=freight, r=rail	M ton-km	251,476	275,899	315,520	362,973	399,760	440,276	484,899	2.5%	1.9%
Transport	driver	$S_{t,r,k}$	t=freight, r=rail, k=coal	%	2%	0%	0%	0%	0%	0%	0%		
Transport	driver	$S_{t,r,k}$	t=freight, r=rail, k=diesel	%	60%	49%	44%	40%	33%	27%	20%	-2.7%	-4.5%
Transport	driver	$S_{t,r,k}$	t=freight, r=rail, k=electricity	%	38%	51%	56%	60%	67%	73%	80%	3.1%	1.9%
Transport	intensity	$EI_{TR\ t,r,j,k}$	t=freight, r=rail, k=coal	MJ/ton-km	3.00	3.60	0.00	0.00	0.00	0.00	0.00		
Transport	intensity	$EI_{TR\ t,r,j,k}$	t=freight, r=rail, k=diesel	MJ/ton-km	0.23	0.18	0.14	0.11	0.11	0.11	0.11	-4.8%	0.0%
Transport	intensity	$EI_{TR\ t,r,j,k}$	t=freight, r=rail, k=electricity	MJ/ton-km	0.11	0.10	0.09	0.08	0.08	0.08	0.08	-2.1%	0.0%
Transport	Motor Gasoline		t=pass, r=road, j=two wheelers	PJ	69	76	108	162	170	251	353	5.9%	5.3%
Transport	Motor Gasoline		t=pass, r=road, j=pass car,	PJ	34	49	79	103	136	242	366	7.8%	8.8%
Transport	Diesel		t=pass, r=road, j=pass car,	PJ			7	45	72	183	358		14.8%
Transport	Diesel		t=pass, r=road, j=MPV	PJ	8	12	29	45	61	124	221	11.8%	11.2%
Transport	Motor Gasoline		t=pass, r=road, j=three wheelers,	PJ	43	57	79	99	143	208	246	5.7%	6.3%

Sector	Variable Type	Name		Unit	1990	1995	2000	2005	2010	2015	2020	AAGR 90-05	AAGR 05-20
Transport	Diesel		t=pass, r=road, j=bus	PJ	236	272	317	394	417	439	438	3.5%	0.7%
Transport	Diesel		t=freight, r=road, j=heavy truck	PJ	284	386	458	555	876	1,290	1,868	4.6%	8.4%
Transport	Diesel		t=freight, r=road, j=light truck	PJ	115	148	152	168	263	313	270	2.6%	3.2%
Transport	Kerosene		t=pass, r=air	PJ	55	73	92	143	223	313	414	6.6%	7.4%
Transport	Kerosene		t=freight, r=air	PJ	13	12	10	130	223	313	418	16.7%	8.1%
Transport	Diesel		t=pass, r=water	PJ	2	3	4	4	4	4	5	3.1%	1.4%
Transport	Diesel		t=freight, r=water	PJ	13	14	17	20	28	39	53	3.0%	6.8%
Transport	Coal		t=pass, r=rail	PJ	80	4	0	0	0	0	0		
Transport	Coal		t=freight, r=rail	PJ	15	0	0	0	0	0	0		
Transport	Diesel		t=pass, r=rail	PJ	31	38	40	39	33	27	20	1.6%	-4.4%
Transport	Diesel		t=freight, r=rail	PJ	35	25	19	16	15	13	11	-5.1%	-2.6%
Transport	Electricity		t=pass, r=rail	PJ	13	15	20	20	24	29	32	3.0%	3.1%
Transport	Electricity		t=freight, r=rail	PJ	11	14	16	18	21	26	31	3.5%	3.9%

pass.: passenger

Annex 10. Total Sector Final Energy Use and Projections

Sector	Unit	1990	1995	2000	2005	2010	2015	2020	AAGR 90-05	AAGR 05-20
RESIDENTIAL	**PJ**	**2,897**	**3,288**	**4,030**	**4,854**	**5,825**	**6,861**	**7,864**	**3.5%**	**3.3%**
electricity		141	177	323	551	935	1,499	2,313	9.5%	10.0%
kerosene		242	292	408	506	589	635	580	5.0%	0.9%
LPG		96	156	313	488	749	1,087	1,485	11.4%	7.7%
wood		2,415	2,657	2,981	3,300	3,542	3,630	3,477	2.1%	0.3%
TRANSPORT	**PJ**	**1,056**	**1,199**	**1,446**	**1,964**	**2,716**	**3,830**	**5,119**	**4.2%**	**6.6%**
electricity		24	29	36	38	46	55	63	3.2%	3.5%
diesel		715	887	1,013	1,242	1,709	2,314	3,023	3.7%	6.1%
motor gasoline		154	194	295	412	515	835	1,202	6.8%	7.4%
kerosene		68	85	102	273	447	626	832	9.7%	7.7%
Coal		95	5	0	0	0	0	0		

Annex 11. Total Sector Primary Energy Use and Projections

Sector	Unit	1990	1995	2000	2005	2010	2015	2020	AAGR 90-05	AAGR 05-20
Primary Factor		3.97	4.16	4.73	4.22	4.05	3.88	3.72	0.4%	-0.8%
RESIDENTIAL	PJ	3,312	3,843	5,228	6,619	8,668	11,176	14,140	4.7%	5.2%
electricity		558	738	1,527	2,324	3,787	5,824	8,598	10.0%	9.1%
kerosene		242	292	408	506	589	635	580	5.0%	0.9%
LPG		96	156	313	488	749	1,087	1,485	11.4%	7.7%
wood		2,415	2,657	2,981	3,300	3,542	3,630	3,477	2.1%	0.3%
TRANSPORT	PJ	1,126	1,290	1,578	2,086	2,855	3,987	5,291	4.2%	6.4%
electricity		94	119	168	160	185	212	234	3.6%	2.6%
diesel		715	887	1,013	1,242	1,709	2,314	3,023	3.7%	6.1%
motor gasoline		154	194	295	412	515	835	1,202	6.8%	7.4%
kerosene		68	85	102	273	447	626	832	9.7%	7.7%
Coal		95	5	0	0	0	0	0		