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Energy Needs, Options and Environmental Consequences

by

Kirit S. Parikh[*]

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Stanford University
John A. and Cynthia Fry Gunn Building
366 Galvez Street | Stanford, CA | 94305-6015

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[*] Member, Planning Commission, India

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Dr. Kirit S. Parikh
Member, Planning Commission, India

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1. Challenges

India faces formidable challenges in meeting its energy needs and providing adequate and varied energy of desired quality to users in a manner that can be sustained over a horizon of 25 years and at internationally competitive costs. India needs economic growth for human development, which in turn requires access to clean, convenient and reliable energy for all. As we near the 8-10% growth rate that we aspire for, the quantity & quality of energy we need, will increase substantially. Thus the energy challenge is of fundamental importance. The nature and dimension of this challenge becomes clear when we look at the energy scene in the country today.

1.1 The Energy Scene

2. Per capita consumption of energy in India is one of the lowest in the world. Cross-country comparisons of energy use and efficiency are full of pitfalls. (*see Box)* Nonetheless comparisons do provide ball park figures and a rough idea which is of some value in realising the challenge the country faces in meeting its energy requirement.

Box
Pitfalls of Cross Country Comparisons

The relative prices and policies vary. The weights used for purchasing power parity adjustments are usually not appropriate for comparing energy use efficiency. For example, taxi rides from airport to downtown hotel in Mumbai and New York would be of similar length and would consume more or less the same amount of petrol. The value added by that ride in Mumbai will be $2 and in New York $20, whereas the PPP ratio would be around 4.0. Similarly the unit of energy used, tonnes of oil equivalent, aggregates the different fuels using equivalence co-efficients. These co-efficients do not fully reflect the true efficiency of providing a particular energy service. For example a person cooking with wood can get with the available equipment an efficiency of no more than 15 percent whereas one cooking with gas can easily obtain an efficiency of 75 percent. It would be wrong to say that the latter is 5 times more efficient than the former. There is also a further problem of how hydroelectric energy is converted into oil equivalence. The International Energy Agency (IEA) uses a factor of 0.086 to convert a kWhr of hydro electricity to kgoe whereas a kWhr generated using coal at 33% efficiency would be considered as 0.086/0.33 = 0.258 kgoe. Thus the energy/GDP figure would vary depending upon the share of hydro electricity. In the past (see for example *Fuel Policy Committee Report, 1974*) we have used kg of coal replacement as a measure for aggregating fuels. This has its own problems as it requires knowledge of technologies actually used and of potential technologies that use coal. Since the oil equivalence unit has become the international practice, we also use it.

3. India consumed 439 kg of oil equivalent (kgoe) per person of primary energy in 2003 compared to 1090 in China, 7835 in the U.S. and the world average of 1688. India's energy use efficiency for generating Gross Domestic Product (GDP) in Purchasing Power Parity (PPP) terms is better than the world average, China, US and Germany (*see Table 1*). However, it is 7% to 23% higher than Denmark, UK, Japan and Brazil. This may indicate possibility of reduction in the energy intensity of growth in India.

Table 1: *Selected Energy Indicators for 2003*

Region/Country	GDP Per Capita-PPP (US $ 2000)	TPES Per Capita (kgoe)	TPES/GDP (kgoe/$-2000 PPP)	Electricity Consumption Per Capita (kWh)	kWh/$-2000 PPP
China	4838	1090	0.23	1379	0.29
Australia	28295	5630	0.20	10640	0.38
Brazil	7359	1094	0.15	1934	0.26
Denmark	29082	3852	0.13	6599	0.23
Germany	25271	4210	0.17	6898	0.27
India[*]	**2732**	**439**	**0.16**	**553**	**0.20**
Indonesia	3175	753	0.24	440	0.14
Netherlands	27124	4983	0.18	6748	0.25
Saudi Arabia	12494	5805	0.46	6481	0.52
Sweden	27869	5751	0.21	15397	0.55
United Kingdom	26944	3906	0.14	6231	0.23
United States	35487	7835	0.22	13066	0.37
Japan	26636	4052	0.15	7816	0.29
World	7868	1688	0.21	2429	0.31

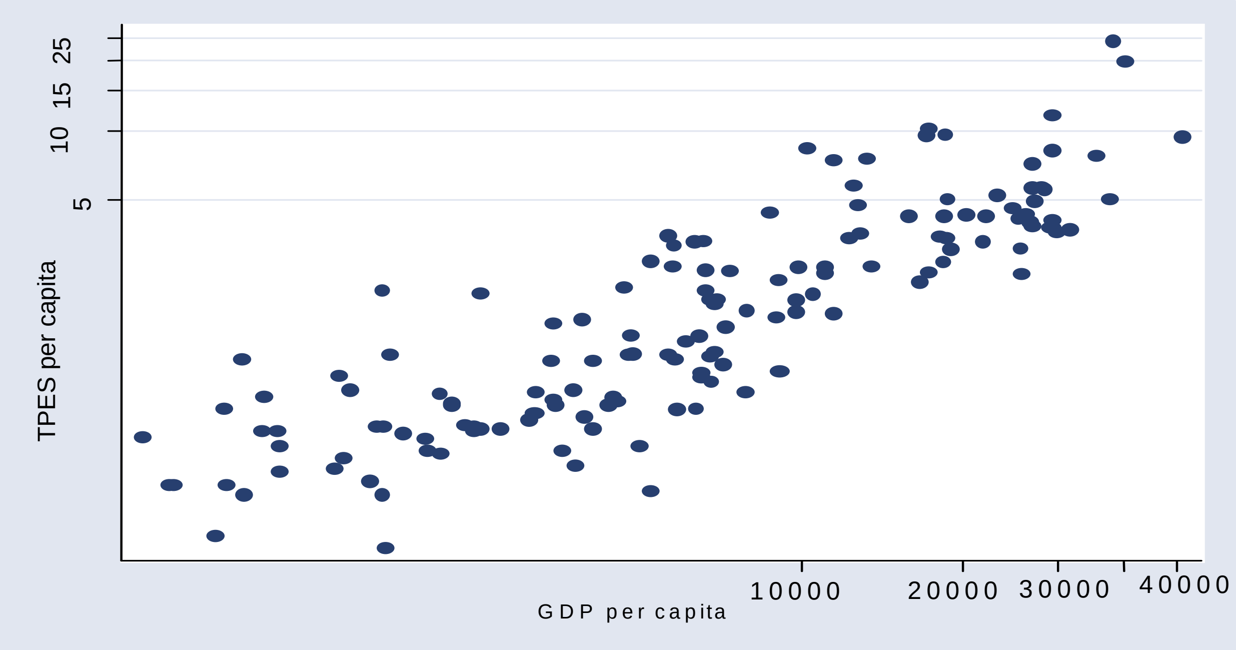
TPES: Total Primary Energy Supply

[*] **Data for India are corrected for actual consumption and the difference in actual and IEA assumed calorie content of Indian coal**

Source: IEA (2005)

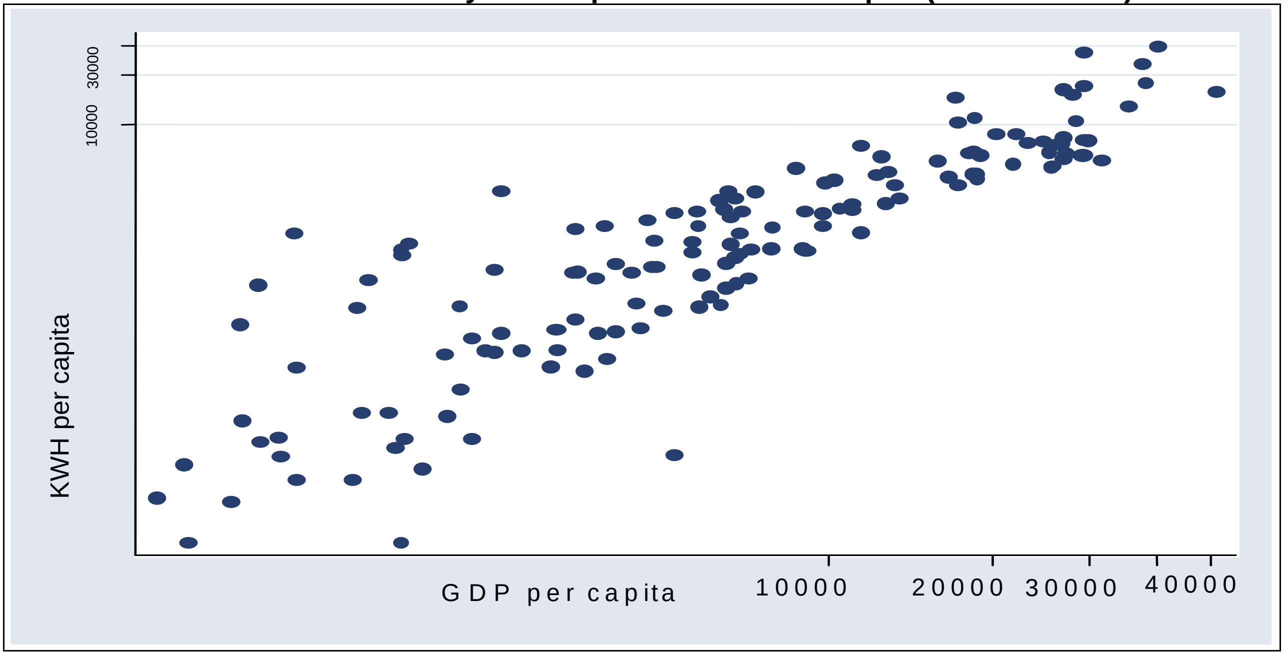
4. In *Figure 1* per capita energy supply is plotted against per capita GDP. *Figure 2* shows the relationship of per capita electricity supply with the level of economic development. *Figures 1 and 2* are plotted on logarithmic scale and thus their slopes indicate elasticity of per capita energy supply w.r.t. per capita GDP i.e. percent change in per capita energy supply for every percent change in per capita GDP. These figures do show that despite the problems of comparability of data across countries, there is some correlation between energy and electricity use and level of GDP.

Figure 1
Total Primary Energy Supply (TOE) Per Capita (2003) vs. GDP Per Capita (PPP US$2000)



Data Source: IEA (2005)

Figure 2
Kilo Watt Hours of Electricity Per Capita vs. GDP Per Capita (PPP US$2000)



Data Source: IEA (2005)

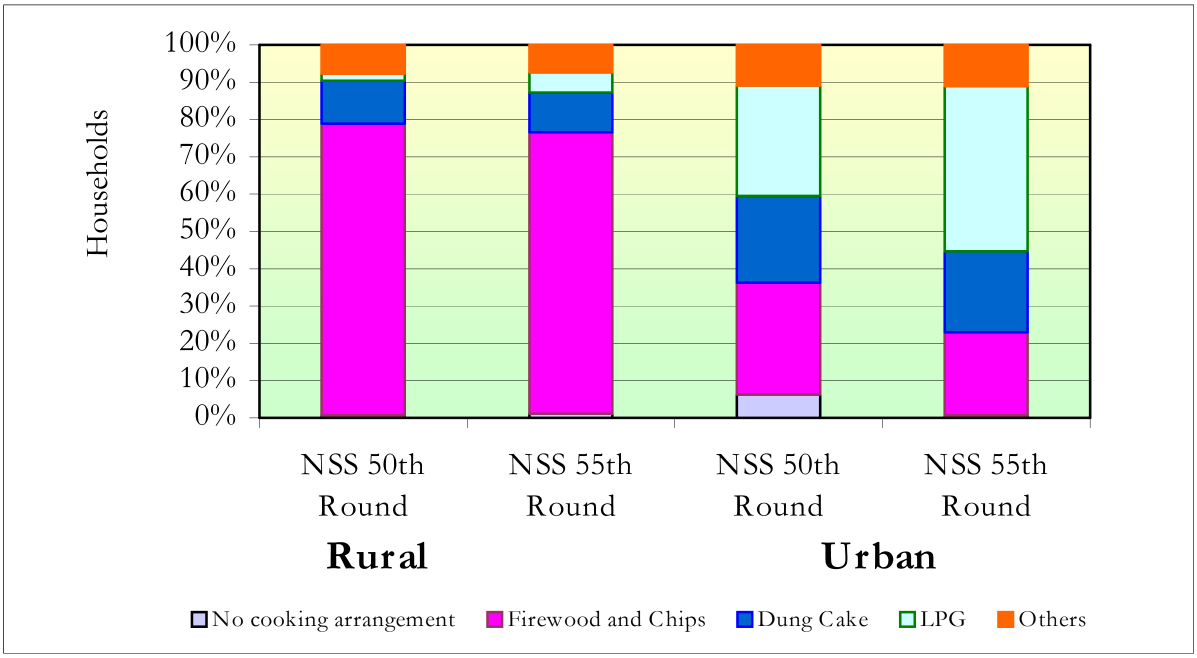
5. If we look at the consumption of electricity - one of the most convenient forms of energy - we see that per capita consumption in India is far below that in other countries. Moreover, access to electricity is very uneven. Even though 85 percent of villages are considered electrified, around 57 percent of the rural households and 12 percent of the urban households i.e. 84 million households (over 44.2% of total) in the country did not have electricity in 2000.

6. A majority of India's people use traditional fuels such as dung, agricultural wastes and firewood for cooking food. These fuels cause indoor pollution. The 1999-2000 55th round of the National Sample Survey (NSS) revealed that for 86% of rural households the primary source of cooking energy was firewood and woodchips or dung cakes. In urban areas as well, more than 20% of all households relied mainly on firewood and chips. Only 5% of the households in rural areas and 44% in urban areas used LPG. Kerosene was used by 22% of urban households and only 2.7% of rural households. Other primary sources of cooking energy used by urban and rural households include coke, charcoal, gobar gas (cow dung gas), electricity and other fuels.

7. *Figure 3* shows that not much change has taken place in rural areas since the 50th round of NSS (1994-95) though in urban households use of LPG has nearly doubled as the availability of LPG, which is subsidised, has increased. The use of LPG is largely constrained by its availability. The impact of subsidy alone is difficult to isolate as LPG is the most convenient cooking fuel and one can imagine that lack of subsidy would have had only a marginal impact on LPG use in the country.

8. What is striking is that very little change has occurred in the pattern of fuel use in rural India and the share of fuelwood and dung is still above 85 percent. Provision of clean cooking fuel to rural population has not been obviously a priority of the Government.

Figure 3
Distribution of Households by Primary Source of Energy Used for Cooking-India



Source: NSSO (2001)

9. The use of traditional fuels for cooking with the attendant pollution and the cost of gathering them imposes a heavy burden on people, particularly women and girls. The need to gather fuels may deprive a young girl of her schooling. Over time, the use of such fuels increases the risks of eye infections and respiratory diseases. Lack of access to clean and convenient sources of energy impact the health of women and girls disproportionately as they spend more time indoors and are primarily responsible for cooking. Women's micro-enterprises (an important factor in household income, as well as in women's welfare and empowerment), are heat-intensive (food processing), labour-intensive, and/or light-intensive (home industries with work in evenings). The lack of adequate energy supply—and other coordinated support—affects women's abilities to use these micro-enterprises profitably and safely. Furthermore, women often face additional barriers in making the best use of available opportunities and obtaining improved energy services. There are social and practical constraints related to ownership and control over productive resources, and women are typically excluded/marginalised from decision-making vis-à-vis the use of these resources. This is worsened by barriers related to illiteracy, lack of exposure to information and training. Thus, the economic burden of traditional fuels is around Rs.300 billion (see *Box*). An energy policy that seeks to be responsive to social welfare must address this fact. It is estimated that in rural North India, 30 billion hours are spent in gathering fuel wood and other traditional fuels annually. Thus the report of the Expert Committee on Integrated Energy Policy (Planning Commission, August 2006) suggests giving an entitlement of 6 cylinders of LPG (~ 85 kg of LNG) per households below poverty line. The subsidy can be justified on the basis of externality on health and environment.

Box

The Burden of Traditional Fuels in Rural India

A study based on an integrated survey covering 15,293 rural households from 148 villages in three states of rural North India and one state in South India shows the importance of clean fuels. Symptoms of diseases related to air and water pollution, expenditure on health and person days lost, demographic and socio-economic information, measurements of air quality in the kitchen, outside the kitchen and the home were collected. Indicators for respiratory functions (Peak Expiratory Flow) were measured for most of the adults present at the time of the survey. The doctors examined a sub-sample of individuals for confirmation of diseases.

The study estimated that

- 96% of households use ***biomass energy,*** *11*% use ***kerosene*** and 5% use ***LPG*** for cooking. Most of them use multiple fuels.
- Forests contribute 39% of the fuel wood need.
- 314 Mt of bio-fuels are ***gathered*** annually.
- 85 million households spend 30 billion hours annually in fuel wood gathering.
- Respiratory symptoms are prevalent among 24 million adults of which 17 million have serious symptoms.
- 5% of adults suffer from Bronchial asthma, 16% from Bronchitis, 8.2% from Pulmonary TB and 7% from Chest infection.
- Risk of contracting respiratory diseases and eye diseases increases with longer duration of use of bio-fuels.

Total economic burden of dirty biomass fuel was estimated to be Rs.299 billion using a wage rate of Rs.60 per day, comprising of opportunity cost of gathering fuel, working days lost due to eye infections and respiratory diseases, and the cost of medicine.

As women are the primary sufferers of the adverse impact of use of biomass fuels, there is a close linkage between gender and energy. Gender and energy issues have remained on the periphery of energy policy, and require greater attention and backing.

Source: Parikh Jyoti et al (2005)

10. The total quantities of traditional fuels used are substantial. *Table 2* presents the data on household energy use. Biomass based fuels dominate particularly in rural areas, where they are used by households in all consumer expenditure categories (*see Figure 4*). This implies that their use would not reduce even with economic growth and rising incomes in rural areas. One may note in *Figure 4* that in kgoe term energy consumption goes down with expenditure from a monthly per capita expenditure level of Rs.425-500 to the level of Rs.775-915. This is because the use of LPG, which is burnt with a comparatively much higher efficiency, increases replacing firewood and chips.

Table 2: ***Household Energy Consumption in India (July 1999 – June 2000)***

Fuel Type	Physical Units			Mtoe		
	Rural	Urban	Total	Rural	Urban	Total
Fire Wood & Chips (Mt)	158.87	18.08	176.95	71.49	8.13	79.62
Electricity (BkWh)	40.76	57.26	98.02	3.51	4.92	8.43
Dung Cake (Mt)	132.95	8.03	140.98	27.92	1.69	29.61
Kerosene (ML)	7.38	4.51	11.89	6.25	3.82	10.07
Coal (Mt)	1.20	1.54	2.74	0.49	0.63	1.12
L.P.G. (Mt)	1.25	4.43	5.68	1.41	5.00	6.41

Source: Derived from NSS 55th Round, (July 1999-June 2000) data, National Sample Survey Organisation, Ministry of Statistics and Programme Implementation, Government of India

Figure 4
Pattern of Household Energy Consumption

Figure 4(a): Monthly Per Capita Household Consumption Pattern Urban India, 2000

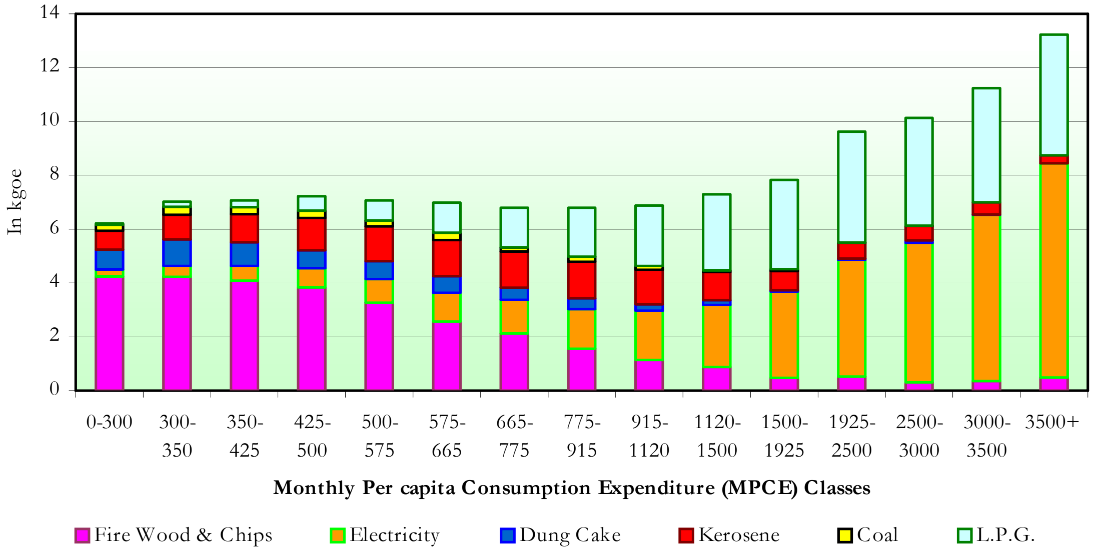
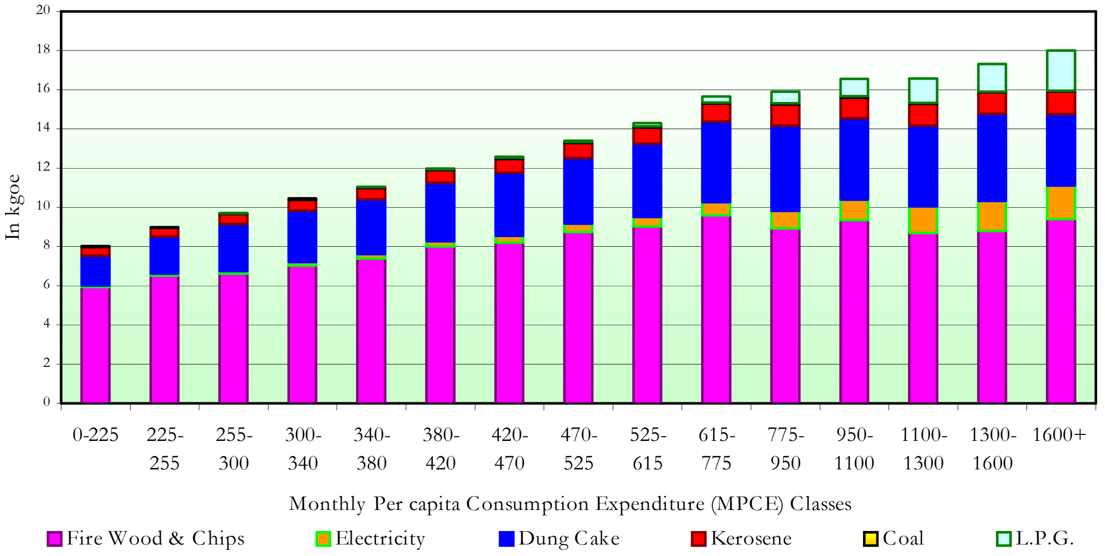


Figure 4(b): Monthly Per Capita Household Consumption Pattern Rural India, 2000

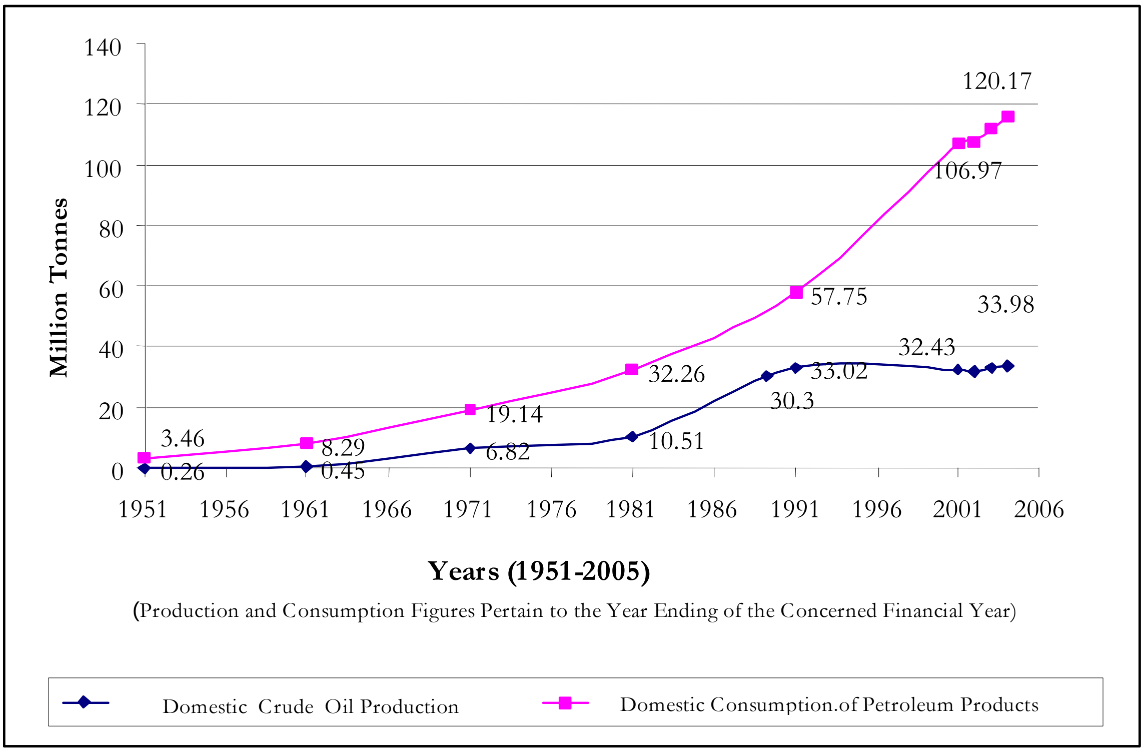


Source: NSS 55th Round, (July 1999-June 2000), National Sample Survey Organisation, Ministry of Statistics and Programme Implementation, Government of India

11. In 2004-05, net of exports, India consumed 120.17 Mt of crude oil products including refinery fuel. Domestic production of crude oil has been between 30.3 Mt to 33.98 Mt during 1990-2005 (*see Figure 5*). Not only has domestic production

stagnated, oil reserves hovered between 700 Mt and 750 Mt during this period. The total oil reserves were 739 Mt in 1990-91 and were estimated to be 786 Mt in 2004-05. The proved reserves to production (R/P) ratio was 23 in 2004-05. We now import 72% of our consumption and our import dependence is growing rapidly. This raises serious concerns about India's energy security, our ability to obtain the oil we need and the impact of constrained supply and the consequent increase in oil prices on our economy.

Figure 5
Domestic Consumption and Production of Crude Oil



Source: Ministry of Petroleum & Natural Gas

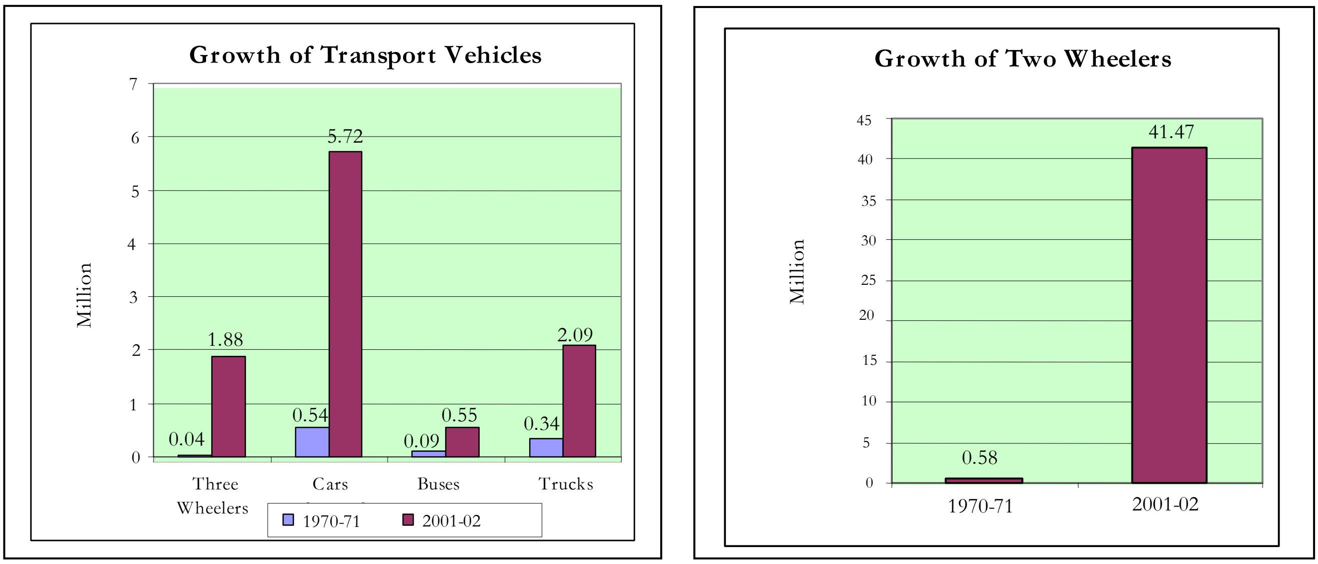
12. The total consumption of petroleum products grew at the rate of 5.7% per annum between 1980-81 and 2003-04. However, growth in consumption has moderated to 2.95% per annum over the last four years (2000-01 to 2004-05). Consumption for petrol and diesel grew at 7.3% and 5.8% per annum respectively between 1980-81 and 2004-05. This was the outcome of the growth of personal motorised transport and the rise in share of road haulage. The numbers of two-wheelers rose from 5,75,893 to 4,14,78,136, three-wheelers from 36,765 to 18,81,085, cars from 5,39,475 to 57,17,456, buses from 93,907 to 5,52,899 and trucks from 3,43,000 to 20,88,918 between 1970-71 and 2001-02 (*Figure 6*). The vehicle population continues to grow at higher than historical rates. However, in the last 5 years growth in consumption of petrol and diesel has been far more moderate at 6.9% and less than 1% respectively. This reflects the improved efficiency of vehicles and better road conditions. *Table 3* gives the decadal growth rates of motor vehicles from 1970-71 to 2001-02***.*** In 2004-05, liquid fuel consumption in the transport sector accounted for 28% of our total petroleum products consumption.

Table 3: ***Growth of Motorised Transport Vehicles***

	1970-71	1980-81	1990-91	2001-2002	Growth Rate
Two-wheelers	575893	2530441	14199858	41478136	15.3%
Three-wheelers	36765	142073	617365	1881085	14.0%
Cars	539475	900221	2266506	5717456	8.2%
Taxis	60446	100845	243748	684490	8.4%
Jeeps	82584	120475	443734	1168868	9.2%
Buses	93907	153909	331096	552899	6.1%
Trucks	343000	554000	1355953	2088918	6.2%

Source: Center for Monitoring Indian Economy Pvt. Ltd. (CMIE)

Figure 6
Growth of Transport Vehicles and Two Wheelers



Source: Centre for Monitoring Indian Economy Pvt. Ltd. (CMIE)

13. Coal has been the mainstay of India's energy supply for many years. Coal consumption increased from 140 Mt in 1984 to over 400 Mt in 2004 with a growth rate of 5.4%. Thermal power plants using coal today account for 57% of our total generation capacity. Indian coal has a high ash content and low calorific value – an average of 4000 kcal/kg compared to 6000 kcal/kg in imported coal. The average calorific value of coal burnt in India's power plants is only about 3500 kcal/kg. The high ash content also results in higher emission of suspended particulate matter (SPM). However, the sulphur content of Indian coal is very low, and emission of SO_2 during combustion is also low. Since SPM is comparatively easy to trap, Indian coal is relatively clean. Despite large reserves of coal domestic supply is tailored to barely meet domestic demand for thermal coal with small quantities being imported. India is not self-sufficient in metallurgical coal and over 65% of the demand is met through imports.

2. <u>Energy Requirements</u>

14. Long-term projections for energy requirements are based on assumptions vis-à-vis the growth of the economy, population growth, the pace at which "non-commercial energy" is replaced by "commercial energy", the progress of energy

conservation, increase in energy efficiency, relative prices and availabilities of different fuels as well as societal and lifestyle changes. It is not surprising, therefore, that available projections differ widely. Yet it is useful to have a set of consistent projections with clearly stated assumptions to outline the broad discussion of the challenges facing us in meeting energy needs as well as to provide a framework for policy formulation.

2.1 Total Energy Needs

15. In order to assess various supply options we need to project energy requirements. This is best done by estimating simultaneously demand functions for various energy sources and forms. Past data are an outcome of supply and demand functions. These in turn shift depending on policies, technical change and structural shifts in the economy. It is difficult if not virtually impossible to estimate a set of demand function from Indian time series data with periods of quotas, rationing, shortages, administered prices and subsidies. Past data can, however, be looked upon as a series of feasible points of energy supply and GDP which are strongly correlated. Any projection based on these feasible points give you feasible combinations without providing any guidance on the underlying policies or prices. Such projections should be adequate to assess broad supply alternatives. We projected total primary commercial energy requirement on the basis of elasticity w.r.t. GDP, which gives a percentage change in commercial energy requirement for one percent change in GDP. The elasticities are obtained from time series data of India's commercial energy use. These elasticities are summarised below:

Table 4: ***Energy Use Elasticity w.r.t. GDP***
(Percent change in Commercial energy use for one percent change in GDP)

Regression Using India's Time Series			
			Per Capita
1.	TPCES w.r.t. GDP (Rs. Crores 1993-94)	1980-81—2003-04	1.08
		1990-91—2003-04	0.82
2.	Electricity Generated w.r.t. GDP (Utilities + Captive)	1980-81—2003-04	1.30
		1990-91—2003-04	1.06
TPCES = Total Primary Commercial Energy Supply			

16. The elasticity for per capita primary commercial energy supply with respect to per capita GDP estimated from the time series data of India comes to 0.82 since 1990-91 which is significantly lower than 1.08 estimated for the period since 1980-81. Similarly the elasticity for per capita electricity generation is only 1.06 since 1990-91 compared to 1.30 for the period since 1980-81. We have used electricity generation rather than consumption because while losses have been rising over time, precise data is not available on technical losses and commercial losses (which includes pilferage, non-billing, and non-collection). Except for technical losses all electricity made available contributes to GDP. However, since even technical losses have been rising (current estimates are upwards of 15%) using electricity generation instead of actual consumption gives higher elasticities. Importantly though, the elasticities in India are falling over time (or with increasing GDP).

17. The energy elasticities of GDP can be reshaped by policy interventions, the relative prices of fuels, changes in technology, changes in end-use efficiency of equipment, the level of the energy infrastructure and development priorities that affect the structure of the economy. Normally, overall elasticity falls over time as is corroborated by the time series data for India's commercial energy consumption. However, there is also a feeling that, for India, the energy elasticity of GDP growth will not fall any further as rising income levels will foster life style changes that are more energy intense. Based on these alternative views two sets of elasticities were used for projecting India's commercial energy demand. The two sets of elasticities used are shown in *Table 5*.

Table 5: *Elasticities Used for Projections*
(TPCES w.r.t. total GDP)

	TPCES 1 (Falling elasticities)	TPCES 2 (Constant elasticities)	Electricity (Falling elasticities)	Electricity (Constant elasticities)
2004-05 to 2011-12	0.75	0.8	0.95	0.95
2011-12 to 2021-22	0.70	0.8	0.85	0.95
2021-22 to 2031-32	0.67	0.8	0.78	0.95

18. To get a feel for how India's energy elasticities compare with other countries, we have estimated these elasticities using cross-country regression based on data of 2003. These are shown in *Table 6*. The elasticity for total primary energy supply, TPES, comes to 0.83 for all countries and to 0.79 for countries with a PPP GDP between $2000 and $8000 (India's GDP in PPP terms based on 2000 dollars was $2732 in 2003 and by 2031-32 might reach the upper end of the range). India's energy elasticity for commercial energy is comparable to the elasticity estimates for TPES using cross country data. The elasticity for electricity consumption comes to 1.24 for all countries and to 1.25 for PPP GDP range of $2000 to $8000. India's elasticity for electricity generation is comparable to that of countries with per capita GDP exceeding $8000 in PPP terms. Importantly, the trend of falling elasticities with rising income levels is demonstrated even by cross-country data.

Table 6: *Energy Use Elasticity w.r.t. GDP from Cross-Country Data of 2003*

1.	TPES (kgoe/capita) w.r.t. per capita GDP ($ PPP 2000)	All Countries	0.83
		2000 <GDP <8000	0.79
		GDP >8000	0.76
2.	Electricity Consumption (kWh/capita) w.r.t. per capita GDP ($ PPP 2000)		
		All Countries	1.24
		2000< GDP <8000	1.25
		GDP >8000	1.09

19. Using the above estimates, commercial energy needs have been projected for different growth scenarios using falling and constant elasticities from *Table 5*. These projections are given in *Table 7*, which also shows population projections by the Registrar of Census. It is noted, though, that the number based on constant elasticities is not used in this report for any comparison.

Table 7: ***Projections for Total Primary Commercial Energy Requirements***

							(Mt of Oil Equivalent)
Year	Population in millions	GDP (Rs. in Billion @ 1993-94 prices)		TPCES (Mtoe) 1		TPCES (Mtoe) 2	
				GDP Growth Rate		GDP Growth Rate	
		8%	9%	8%	9%	8%	9%
2006-07	1114	17839	18171	389	397	394	403
2011-12	1197	26211	27958	521	551	537	570
2016-17	1275	38513	43017	684	748	732	807
2021-22	1347	56588	66187	898	1015	998	1142
2026-27	1411	83145	101837	1166	1360	1361	1617
2031-32	1468	122170	156689	1514	1823	1856	2289

Note: 1. Projections based on falling elasticities with respect to GDP

2. Projections assuming no change in elasticities with respect to GDP

3. It is pointed out that the level of commercial energy consumption shown for 2006-07 is not expected to be achieved as the growth in demand for petroleum products in the first 4 years of the 10th Plan has only been 2.8% per annum. However, over the long-term, the projections may still be valid as incomes and access improves.

2.2 Required Electricity Generation

20. Requirement for electricity generation, (projected using the elasticities of *Table 5*) are shown in *Table 8*. Plan-wise projected electricity generation and capacity additions are shown in *Figures 7* and 8 respectively. These projections show that gross generation required in 2031-32 could ranging from 3880 BkWh to 6020 BkWh and the needed installed capacity from 778 GW to 1204 GW. Others have projected much lower requirement than our lower end projection. Thus EIA (2004), projects 1427 to 2108 BkWh for 2030 for assumed growth rates ranging from 4.4% to 6.4%. These growth rates are very low indeed compared to the performance of the Indian economy over the past decade and what is being targeted in the 11th Five Year Plan. Central Electricity Authority has projected in the 16th electric power survey electricity requirement for 2016-17 based on survey of large consumers. They project a gross requirement at the bus bar of 1319 BkWh for utilities only implying a gross generation including captive generation of 1579 BkWh. This is slightly higher than our lowest projection of 1524 BkWh for 2016-17. The CEA projections in the past have been consistently higher than actuals. **For further analysis we have mainly used the 8% growth rate falling elasticity projection**.

Table 8: ***Projections for Electricity Requirement***

Year	Gross electricity generation requirement (BKwh)				Installed Capacity Required (GW)			
	Based on falling Elasticities		Based on constant Elasticities		Based on falling Elasticities		Based on constant Elasticities	
	@GDP Growth Rate		@GDP Growth Rate		@GDP Growth Rate		@GDP Growth Rate	
	8%	9%	8%	9%	8%	9%	8%	9%
2003-04	633	633	633	633	131	131	131	131
2011-12	1097	1167	1097	1167	220	233	220	233
2016-17	1524	1687	1582	1758	306	337	318	352
2021-22	2118	2438	2282	2650	425	488	456	530
2026-27	2866	3423	3292	3994	575	685	658	798
2031-32	3880	4806	4748	6020	778	960	950	1204

Note: Electricity generation and peak demand in 2003-04 is the total of utilities and non-utilities above 1 MW size. The installed capacity has been estimated keeping the ratio between total installed capacity and total energy required constant at the 2003-04 level. This assumes optimal utilisation of resources bringing down the ratio between installed capacity required to peak demand from 1.47 in 2003-04 to 1.31 in 2031-32.

Figure 7

Projected Gross Electricity Generation Required (BkWh)

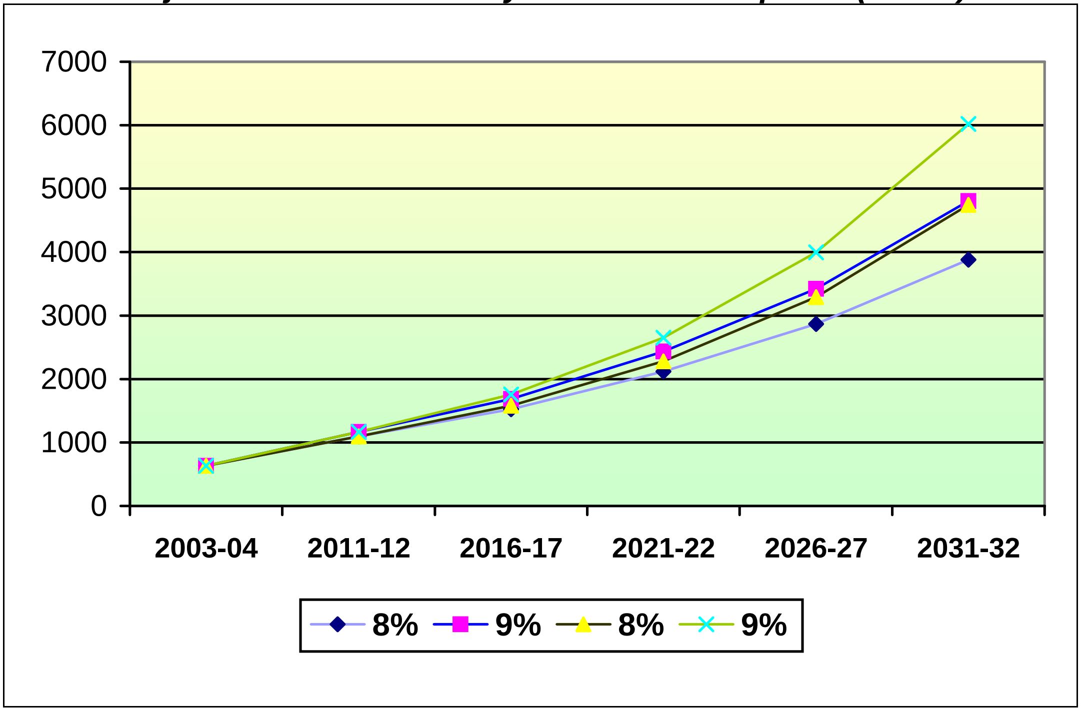
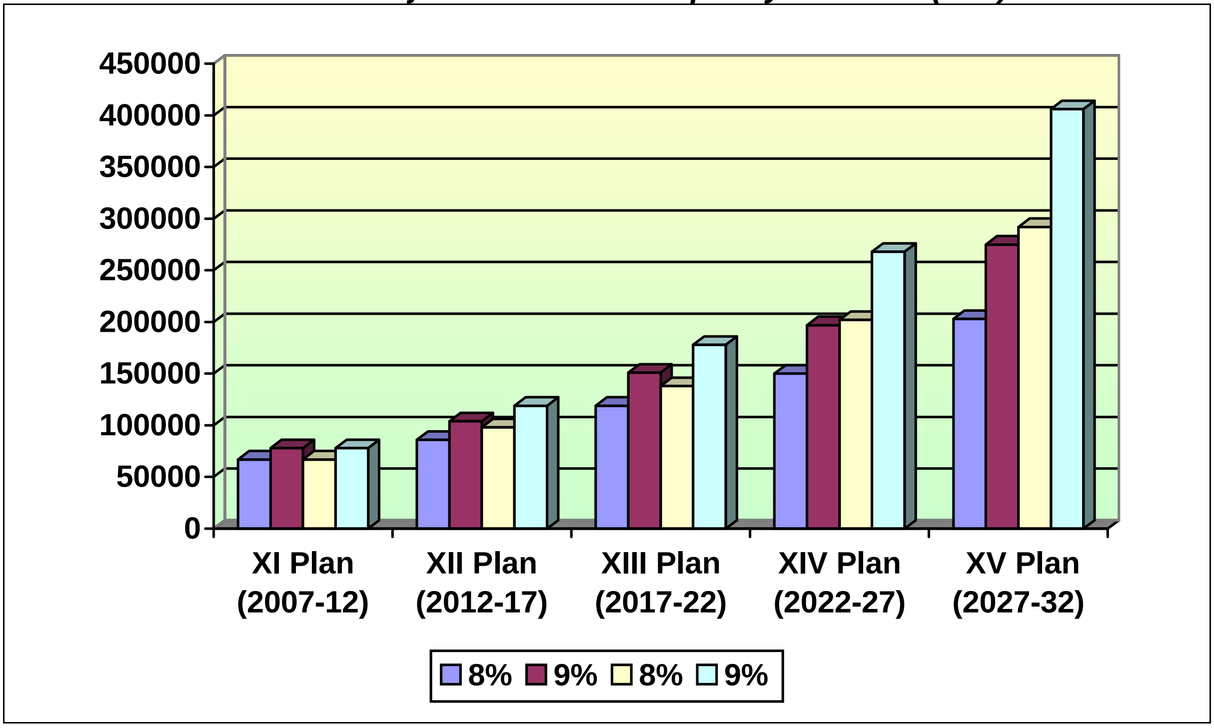


Figure 8

Plan-wise Projected Installed Capacity Addition (MW)



21. Electricity requirements can be met by various alternative fuels. These include coal, nuclear power, hydropower, gas, oil and renewables such as biomass, wind energy, solar energy, etc. In order to understand the broad dimensions of the fuel requirements for power generation, a possible fuel mix scenario has been developed. **The projections of this scenario are summarised in *Table 9*. It is important to note that *Table 9* represents one possible scenario and it should not, in any way, be considered as the preferred scenario.** Also to the extent that

gas, hydro or nuclear capacity cannot be realised as projected in the scenario, coal-based generation will need to fill the gap. In reality, the choice between coal and gas will be guided by economic and commercial considerations including any policy prescriptions for pricing-in certain environmental externalities. The level of gas use projected in the scenario under *Table 9* is based on somewhat optimistic assumptions of gas availability and of its ability to compete with coal on price. Should these assumptions not hold true, coal dependence will increase. More scenarios are given later.

22. The projections in *Table 9* assume exploitation of full hydro potential of 1,50,000 MW in the country, a capacity addition of 63,000 MW from nuclear power sources and a 14,000 MW capacity from wind farms by 2031-32. These scenario assumptions in respect of hydro and nuclear may not be fully realised and are made here in order to characterise the boundaries of alternative choices. Generation from coal-based stations also includes electricity generation from lignite. The scenario also forces gas usage for power generation with gas-based electricity share rising from about 10% to 16% between 2003-04 and 2031-32. As a result of these assumptions, the share of coal-based electricity drops from 72% to 61%. The demand for oil in power sector covers consumption of petroleum products in diesel based plants as well as secondary oil consumption in coal-based plants.

Table 9: ***Sources of Electricity Generation – One Possible Scenario***

Year	Electricity Generation at Bus Bar (BkWh)		Hydro (BkWh)	Nuclear (BkWh)	Renewables (BkWh)	Thermal Energy (BkWh)		Fuel Needs					
								Coal (Mt)		NG (BCM)		Oil* (Mt)	
	8%	9%				8%	9%	8%	9%	8%	9%	8%	9%
2003-04	592	592	74	17	3	498	498	318	318	11	11	6	6
2006-07	711	724	87	39	8	577	590	337	379	12	14	6	6
2011-12	1026	1091	139	64	11	812	877	463	521	19	21	8	8
2016-17	1425	1577	204	118	14	1089	1241	603	678	33	37	9	10
2021-22	1981	2280	270	172	18	1521	1820	832	936	52	59	12	12
2026-27	2680	3201	335	274	21	2050	2571	1109	1248	77	87	14	15
2031-32	3628	4493	401	375	24	2828	3693	1475	1659	119	134	17	20
*	includes secondary oil consumption for coal-based generation												

2.3 Total Commercial Primary Energy Requirement

23. Putting together the various projections discussed above for coal, oil and natural gas for non-power use, the commercial fuel requirement for non-power use are summarised below in *Table 10*.

Table 10: ***Commercial Fuel Requirements for Non-Power Use in Physical Units***

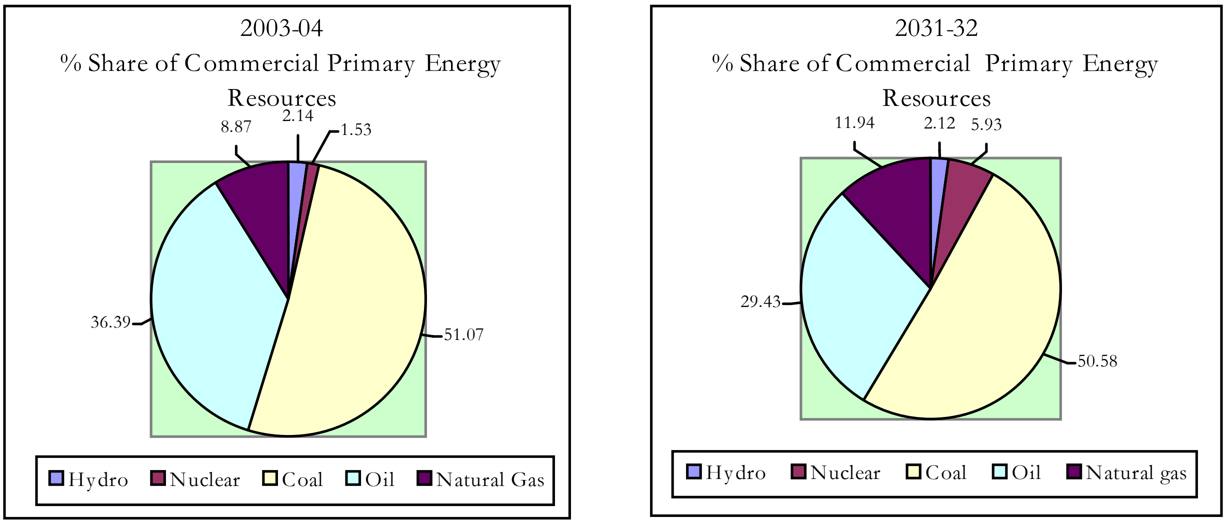
	Non-Power- Coal Mt		Non-Power – Oil Mt		Non-Power- Natural Gas B.Cu.M	
	8%	9%	8%	9%	8%	9%
2003-04	91	91	113	113	20	20
2006-07	123	123	126	142	20	22
2011-12	164	170	158	178	30	32
2016-17	221	237	205	231	38	45
2021-22	299	334	266	299	56	65
2026-27	408	475	351	395	73	93
2031-32	562	684	469	528	100	133
Note:	Estimated fuel requirements of coal, oil and natural gas are for non-power purposes.					

24. Total commercial primary energy requirements based on the scenario drawn for power in *Table 9* and the projections made for non-power oil, coal and gas are summarised in *Table 11* using the common unit of million tonnes of oil equivalent (Mtoe). *Figure 9* below shows the actual percentage shares of various commercial energy sources in 2003-04 and as projected for 2031-32 in the scenario under *Table 11*.

Table 11: ***Projected Primary Commercial Energy Requirements (One Possible Scenario)***

Year	Hydro —Mtoe	Nuclear —Mtoe	Coal— Mtoe		Oil —Mtoe		Natural Gas —Mtoe		TPCES —Mtoe	
			8%	9%	8%	9%	8%	9%	8%	9%
2011-12	12	17	257	283	166	186	44	48	496	546
2016-17	18	31	338	375	214	241	64	74	665	739
2021-22	23	45	464	521	278	311	97	111	907	1011
2026-27	29	71	622	706	365	410	135	162	1222	1378
2031-32	35	98	835	937	486	548	197	240	1651	1858
CAGR (Compounded Annual Growth Rates) -%	5.9	11.2	5.9	6.3	5.1	5.6	7.2	8	6	6.4
Per capita consumption In 2032 (kgoe)	24	67	569	638	331	373	134	163	1124	1266
In 2004 (kgoe)	6.5	4.6	157	157	111	111	27	27	306	306
Ratio 2032/2004	3.7	14.6	3.6	4.1	2.9	3.4	5.2	6.3	3.7	4.1

Figure 9



25. These projections may be compared with projections made by others given in *Table 12*. All the projections of oil and coal are lower than our projections in *Table 11* for 8% growth (with falling elasticities). Only for natural gas in the scenario of *Table 11* the requirement for 2031-32 is 197 Mtoe, which is higher than all projections except one by IRADE-PWC which shows 219 Mtoe for 2029-30. However, IRADE-PWC projections include natural gas equivalent of Naptha. If we look at the combined projections of oil and natural gas our projection exceeds that of IRADE-PWC. The reason for our projections to be higher than all others is that we have taken 8% growth rate of GDP, which seems well within reach and may be even pessimistic.

Table 12: *Projected Energy Requirements by Various Agencies*

Year	Projections by the Various Agencies										
	EIA (2004)			**IEA (2004)**	**IHV –2025 (2000)**	**India Vision – 2020 (2002)**		**Working Group Report of 10th Plan (2001-02)**	**Power & Energy Division's (Planning Commission) Projections (2003-04)**	**IRADe & PWC * (2005)**	
	Reference Case	**High Case**	**Low Case**			**BAU**	**BCS**			**BAU**	**HOG**
Oil (Mt.)											
2024-25	264	324	204	230	368	309	235	232	240	260	347
2029-30				271				276	281	320	465
Natural Gas (Mtoe)											
2024-25	64	74	51	85	128	85	74		107	160	242
2029-30				97					141	219	365
Coal (Mtoe)											
										Coal Vision 2025 (7% GDP)**	**Coal Vision 2025** (8% GDP)**
2024-25		250	197	292	575	398	270	462		470	519
2025		258	201		608						
2030				335					581 (2031-32)		

EIA - Energy Information Administration, USA
IEA - International Energy Agency
IHV - India Hydrocarbon Vision 2025
IRADe - Integrated Research and Action for Development
BAU - Business as Usual
BCS - Best Case Scenario
PWC - Price Waterhouse Coopers
HOG - High Output Growth

* Includes natural Gas & NG equivalent of Naptha

** Projections made by TERI for Coal Vision 2025

Note: As the available projections by the various agencies are for different years, the same have been interpolated or extrapolated to bring them to common years for comparison purposes.

2.4 Non-Commercial Energy Requirement

26. The so-called “Non-commercial” sources of energy, including fuel wood, agricultural waste and dung, are primarily used by households for cooking energy. These are called non-commercial because a major proportion of these are simply gathered by actual users directly as opposed to being traded commercially.

27. Based on the latest data available on household energy consumption from the NSS 55th round covering the year 1999-2000, household demands are projected assuming that income distribution in rural and urban areas remain log-normal with consumption. With economic growth, the mean per capita consumption in different expenditure classes change. It is also assumed that the pattern of fuel use for a particular monthly per capita consumption expenditure class remains the same as observed in the 55th round. This implicitly assumed that prices of various energy sources relative to each other and to other consumption goods remain constant. The projections are summarised in *Table 13*.

Table 13: *The Demand Scenario of Various Energy Items for Household Consumption in India*

(Mtoe)

Year	Fire Wood & Chips		Electricity		Dung Cake		Kerosene		L.P.G.	
	8%	9%	8%	9%	8%	9%	8%	9%	8%	9%
2000	79.62	79.62	8.43	8.43	29.61	29.61	10.07	10.07	6.42	6.42
2006	88.64	88.78	18.17	19.26	36.97	37.33	12.68	12.77	15.85	16.87
2011	94.11	94.05	27.17	29.68	40.42	40.48	14.01	14.02	23.94	26.07
2016	98.44	98.50	38.38	42.28	41.93	41.35	14.84	14.70	33.11	35.93
2021	102.06	102.46	50.39	54.78	41.79	40.87	15.16	14.93	41.63	44.16
2026	104.64	105.07	61.37	64.95	40.95	40.28	15.17	14.93	48.11	49.63
2031	106.39	106.59	69.72	71.80	40.47	40.21	15.12	14.96	52.27	52.89

28. It should be noted that the requirement of electricity, kerosene and gas for household consumption are included in the projection given in *Table 11*. The impact of the Rajiv Gandhi Grameen Vidyutikaran Yojana (RGGVY), which targets provision of electricity to all by the year 2009-10, will alter the demand for electricity. To account for this impact, household demands are projected from 2009-10 onwards using the energy use pattern of only those households in the NSS 55th round sample, which had electricity. These are given in *Table 14*.

Table 14: *The Impact of Electrification on the Demand Scenario of Various Energy Items for Household Consumption*

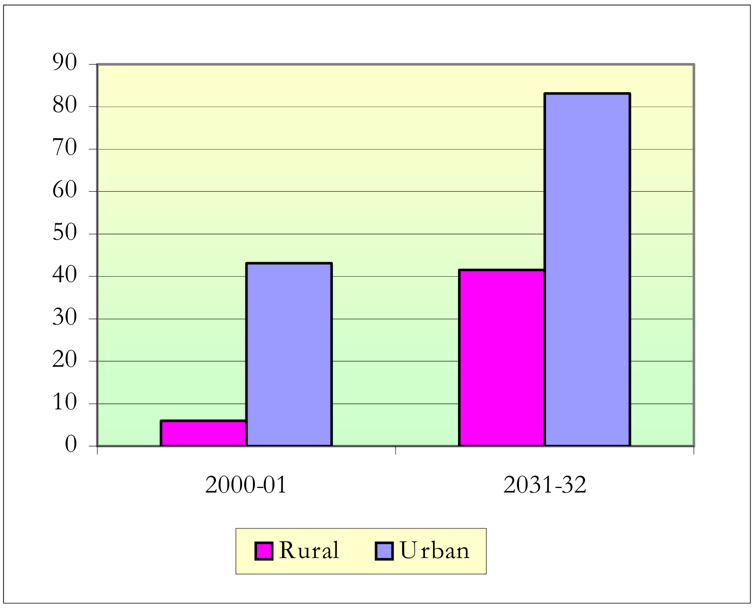
(Mtoe)

Year	Fire Wood & Chips		Electricity		Dung Cake		Kerosene		L.P.G.	
	8%	9%	8%	9%	8%	9%	8%	9%	8%	9%
2011	87.90	88	31.13	33.63	31.03	31.16	13.18	13.16	25.27	27.36
2016	92.59	93.02	42.58	46.51	32.21	31.53	13.82	13.64	34.30	36.95
2021	96.85	97.67	54.89	59.35	31.45	30.28	13.98	13.71	42.45	44.72
2026	100.01	100.72	66.19	69.86	30.00	29.12	13.88	13.61	48.55	49.88
2031	102.08	102.41	74.82	76.95	29.14	28.78	13.76	13.59	52.49	53.05

29. The differences are substantial only in 2011 and 2016, as even without the acceleration in rural electrification planned under RGGVY, most of the households will have been electrified by 2019-20. A comparison of *Tables 13* and *14* for the year 2011 electrification shows that for 8% growth scenario electrification increases consumption of electricity from 27.17 to 31.13 Mtoe, decreases kerosene consumption only marginally from 14.01 to 13.18 Mtoe and decreases substantially dung consumption from 40.42 to 31.03 Mtoe. This is rational. As long as kerosene is available, especially subsidised kerosene, what is saved from lighting is used as fuel for cooking and the consumption of dung as cooking fuel goes down. This substitution makes sense as kerosene is a more convenient cooking fuel and the dung saved has greater value as fertiliser. The use of LPG for cooking will increase over time. *Figure 10* shows this.

Figure 10

Percentage of Households Using LPG



30. The impact of other components of Bharat Nirman is difficult to assess. If we assume that the programme better road connectivity will increase rural incomes by 1% every year, then the differences for the 8% and 9% growth rate column in *Table 14* give some idea of resulting changes in demand. Better roads could lower cost of delivery of kerosene and LPG. However, since these fuels are subsidised and their prices do not include specific delivery costs the impact would be negligible. In 2031, the total household requirement changes by some 3 percent (5 Mtoe) with a 1% higher growth rate.

31. It may be noted that the household demand for non-commercial energy (firewood, chips and dung cake) increases from around 109 Mtoe in 2000 to around 131 Mtoe in 2031. The additional requirement is expected to be met from agricultural residue and increased livestock activity that can be expected with 8-9% growth rates. In any case our goal should be to progressively substitute these traditional fuels with cleaner and more convenient fuels.

32. It is pointed out that apart from being used as household fuel, non-commercial energy is also used in the unorganised small and cottage sector for end-uses such as brick kilns, pottery, jaggery, etc. It is estimated that such consumption of non-commercial fuels was around 23.5 Mtoe in 2003-04. With easier availability of coal, gas and fuel oil growth in this segment is projected to be a sluggish 3.0% per annum. Use of non-commercial energy by the unorganised sector is thus expected to reach 54 Mtoe by 2031-32.

33. Based on the commercial energy requirement projected in *Table 11* and the non-commercial energy requirement projected in *Table 14* together with the non-commercial energy use by small industries as detailed in *Paragraph 32*, the total primary energy is shown in *Table 15*.

Table 15: ***Total Primary Energy Requirement (Mtoe)***

Year	TPCES		TPNCES*		TPES	
	8%	9%	8%	9%	8%	9%
2006-07	389	397	153	153	542	550
2011-12	496	546	169	169	665	715
2016-17	665	739	177	177	842	916
2021-22	907	1011	182	181	1089	1192
2026-27	1222	1378	184	183	1406	1561
2031-32	1651	1858	185	185	1836	2043

* This includes household requirement as per *Table 14* and consumption by small industries as per *Para 32*.

34. The challenge facing the country is to ensure that the energy needed to sustain an 8 to 9% growth rate becomes available. To put the requirement in perspective, per capita energy use in other countries in 2003 is compared with India's projected needs for 2032 in *Table 16*.

Table 16: ***Per Capita Energy Requirements in Selected Countries (2003)***

	TPES (kgoe)	Electricity Consumption (kWh)	Oil (kgoe)	Gas (Cu.m.)	Coal (Kg)	Nuclear (kWh)	Hydro (kWh)
India 2003-04	439	553	111	30	257* (375)	16	69
India 2031-32 (projected @ 8% GDP growth)**	1250	2471	331	149	925* (1388)	256	273
World Average (2003)	1688	2429	635	538	740	403	423
OECD (2003)	4668	8044	2099	1144	1651	1924	1076
U.S.A. (2003)	7840	13066	3426	2176	3410	2624	948
China (2003)	1090	1379	213	32	1073	32	215
South Korea (2003)	4272	7007	2264	627	1541	2570	101
Japan (2003)	4056	7816	2146	845	1247	1859	816

* Per capita coal consumption of India has been estimated based on the calorific value of hard coal used internationally (6000 kcal/kg) to maintain uniformity. The figures in brackets are the actual per capita consumption based on Indian coal with a calorific value of 4000 kcal/kg.

** Based on numbers estimated in *Tables 9, 11* and *15*

Source: IEA (2005)

35. India's per capita consumption of energy in its various forms in 2003-04 is well below that of developed countries and the world average in 2003. Even in 2032, the per capita consumption in India from various sources of energy will be well below the 2003 level of per capita consumption in respect of

developed countries. In fact, as seen from *Table 16* India's projected level of per capita energy consumption in 2032, will be less than 74% of the world average in 2003. Since our projected per capita GDP in PPP dollar is more than 50 percent higher than world average in 2003, the projections imply significant improvement in energy efficiency — or that we have used very low elasticites.

36. One should note that these projected needs are based on past trends from the demand side based largely on the projection of income. They assume that energy prices will remain on the trend lines. They also assume that progress in energy efficiency and energy conservation, replacement of non-commercial energy and societal and lifestyle changes will continue as per historical trends. There are, of course, opportunities to accelerate or alter the pace of the trends. The projected energy requirements can be reduced substantially with accelerated improvement in energy efficiency and conservation, which should be considered as the most important supply options since they have the potential to reduce consumption by 20-25%. Also, if the country moves to internationally competitive free market prices, the relative fuel mix will change. Yet India is constrained by availabilities of energy resources and the range of options available can be mapped out without taking into account impact of price rationalisation. This is considered when the supply options are explored later in the report.

37. These projections and the scenarios in the next section provide broad guidelines to potential investors, and may supplement their own assessments of the demand levels in various energy sub-sectors.

38. What are the alternative supply options? To what extent can demand be met based on domestic resources? To what extent imports would be needed? These questions are addressed in the next section.

3. **Energy Supply Options**

39. Strategies to meet our energy requirement are constrained by country's energy resources and import possibilities. Unfortunately, India is not well endowed with natural energy resources. Reserves of oil, gas and Uranium are meagre though we have large reserves of thorium. While coal is abundant, it is regionally concentrated and is of low calorie and high ash content, though it has the advantage of a low sulphur content. The extractable reserves, based on current extraction technology, remain limited. Hydro potential is significant, but small compared to our needs and its contribution in terms of energy is likely to remain small. Further, the need to mitigate environmental and social impact of storage schemes often delays hydro development thereby causing huge cost overruns.

3.1 **India's Energy Reserves**

40. India's Hydro-Carbon Energy Reserves are summarised in *Table 17*.

Table 17: *India's Hydrocarbon Reserves*

Resources	Unit	Proved	Inferred	Indicated	Production in 2004-05	Net Imports in 2004-05	Reserve/Production Ratio	
							P/Q	(P+I)/Q
		(P)	(I)		(Q)	(M)		
Coal (as on 1.1.2005)	Mtoe	38114	48007	15497				
Extractable Coal[**]	Mtoe	13489	9600-15650		157	16	86	147-186
Lignite (as on 1.1.2005)	Mtoe	1220	3652	5772				
Extractable Lignite	Mtoe	1220			9	-	136	136
Oil (2005)	Mt	786[*]	-	-	34	87	23	23
Gas (2005)	Mtoe	1101[*]	-	—[1]	29	3 (LNG)	38	38
Coal Bed Methane	Mtoe	765	-	1260-2340				
In-situ Coal Gasification[2]		?	?					

[*] Balance Recoverable Reserves

[1] Indicated Gas resource includes 320 Mtoe claimed by Reliance Energy but excludes the 360 Mtoe of reserves indicated by GSPCL as the same have not yet been certified by DGH.

[2] From deep seated coal (not included in extractable coal reserves)

[**] Extractable coal from proved reserves has been calculated by considering 90% of geological reserve as mineable and dividing mineable reserve by Reserve to Production ratio (2.543 has been used in 'Coal Vision 2025' for CIL blocks); and range for extractable coal from prognosticated reserves has been arrived at by taking 70% of indicated and 40% of Inferred reserve as mineable and dividing mineable reserve by R:P ratios (2.543 for CIL blocks and 4.7 for non-CIL blocks as per 'Coal Vision 2025').

Note:

Conversion factors:
1 Million Tonne of Coal = 0.41 Mtoe
1 Million Tonne of Lignite = 0.2865 Mtoe
1 Billion Cubic Meter of Gas = 0.9 Mtoe
1 Million Tonnes of LNG = 1.23 Mtoe

Source: Respective Line Ministries

Nuclear

41. India is poorly endowed with Uranium. Available Uranium supply can fuel only 10,000 MW of the Pressurised Heavy Water Reactors (PHWR). Further, India is extracting Uranium from extremely low-grade ores (as low as 0.1% Uranium) compared to ores with up to 12-14% Uranium in certain resources abroad. This makes Indian nuclear fuel 2-3 times costlier than international supplies. The substantial Thorium reserves can be used but that requires that the fertile Thorium be converted to fissile material. In this context, a three-stage nuclear power programme is envisaged. This programme consists of setting up of Pressurised Heavy Water Reactors (PHWRs) in the first stage, Fast Breeder Reactors (FBRs) in the second stage and reactors based on the Uranium 233-Thorium 232 cycle in the third stage. It is also envisaged that in the first stage of the programme, capacity addition will be supplemented by electricity generation through Light Water Reactors (LWRs), initially through imports of technology but with the long-term objective of indigenisation. PHWR technology was selected for the first stage as these reactors are efficient users of natural Uranium for yielding the plutonium fuel required for the second stage FBR programme. The FBRs will

be fuelled by plutonium and will also recycle spent Uranium from the PHWR to breed more plutonium fuel for electricity generation. Thorium as blanket material in FBRs will produce Uranium 233 to fire the third stage.

Table 18: ***The Approximate Potential Available From Nuclear Energy***

Particulars	Amount	Thermal Energy		Electricity	
		TWh	GW-yr.	GWe-Yr.	MWe
Uranium-Metal	61,000-t				
In PHWR		7,992	913	330	10,000
In FBR		1,027,616	117,308	42,200	5,00,000
Thorium-Metal	2,25,000-t				
In Breeders		3,783,886	431,950	1,50,000	Very large

Source: Department of Atomic Energy

42. The pace of development of nuclear power is constrained by the rate at which plutonium can be bred and Thorium converted to fissile material. If India is able to import nuclear fuel, the process can be accelerated. Two possible growth paths of nuclear power are summarised in *Table 19*. It may be noted that India has been operating a fast breeder test reactor of 40 MW for decades and based on the knowledge and experience derived from it a 500 MW commercial fast breeder reactor is under construction. Thus there is little technological uncertainty on the second stage of India's nuclear programme. The Thorium using reactors have yet to be developed. In any case the projected capacity up to 2030 is not based on Thorium using reactors.

Table 19: ***Possible Development of Nuclear Power Installed Capacity in MW***

Year	Unit	Scenario		Remarks
		Optimistic*****	Pessimistic	
2010	GWe	11	9	These estimates assume that the FBR technology is successfully demonstrated by the 500 MW PFBR currently under construction, new Uranium mines are opened for providing fuel for setting up additional PHWRs, India succeeds in assimilating the LWR technology through import and develops the Advanced Heavy Water Reactor for utilising Thorium by 2020.
2020	GWe	29	21	
2030	GWe	63	48	
2040	GWe	131	104	
2050	GWe	275	208	

***** It is assumed that India will be able to import 8,000 MW of Light Water Reactors with fuel over the next ten years.

Source: Department of Atomic Energy

Renewable Energy Resources

43. Given the limited amount of domestic conventional energy sources, renewable energy resources gain significance in the Indian context. India's renewable energy resources are summarised in *Table 20*. It may be noted that many renewables require land. The potential energy generated is assessed independently for each option. If all such options are developed together the combined potential may be less than the sum due to a paucity of available land for energy generation as other competing land uses may dominate.

Table 20: *Renewable Energy Resources*

Resources	Unit	Present	Potential	Basis of Accessing Potential
Hydro-power	MW	32,326	1,50,000	Total potential assessed is 84,000 MW** at 60% load factor or 1,50,000 MW at lower load factors
Biomass				
Wood	Mtoe/year	140	620*****	Using 60 million Ha wasteland yielding (20) MT/Ha/year
Biogas	Mtoe/year	0.6******	4	In 12 million family sized plants
		0.1	15	In community based plants if most of the dung is put through them.
Bio-Fuels				
Bio-diesel	Mtoe/year	-	20*****	Through plantation of 20***** million Ha of wasteland or 7***** million hectares of intensive cultivation
Ethanol	Mtoe/year	<1	10	From 1.2 million hectares of intensive cultivation with required inputs.
Solar				
Photovoltaic	Mtoe/year	-	1,200	Expected by utilising 5 million Ha wasteland at an efficiency level of 15 percent for Solar Photovoltaic Cells
Thermal	“		1,200	MWe scale power plants using 5 million Ha
Wind Energy	Mtoe/year	<1	10	Onshore potential of 65,000 MWe at 20 percent load factor
Small Hydro-power	Mtoe/year	<1	5	

***** The availability of land and inputs for getting projected yields is a critical constraint

****** based on 50 percent plants under use

Source: Respective Line Ministries

3.2 Supply Scenarios

44. *Table 11* outlines one possible energy mix scenario. This scenario assumes that electricity generation will be based on the full development of hydro and nuclear potential of the country and the use of gas to the extent of 16%. Possible fuel-wise substitution should be taken into account in considering supply options. With respect to oil for transport use, it cannot easily be replaced in significant quantities unless there are technological breakthroughs or large-scale shifts to public transport in place of personal vehicles or to freight movement by railroads in place of trucks. Other than for power generation demand for natural gas is in the production of fertilisers and chemicals where it cannot be economically substituted. With coal and natural gas there is a clear substitution possibility. Such a substitution will depend on the relative availability and price of coal/gas.

45. To explore the consequences of different alternatives and their quantitative significance a number of scenarios have been developed using a multi-sectoral, multi period optimising linear programming model[*]. The linear programming model used above obtains the least-cost solution in term of present discounted value of investments and variable costs subject to constraints over ten 5-year periods from 2000 till 2050. It also has sub-periods characterising peak, intermediate and base load during summer and winter seasons. Power demand is characterised for three regions: (a) near coal mines, (b) distant coastal regions and (c) the rest. Options at distant coastal regions include transmission from pithead plants and load centre based generation using domestic coal or imported coal. The amount of pithead generation is restricted due to environmental reasons. In the case of hydro, India's full potential of 1,50,000 MW is taken as exploited by 2031-32

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[*] The model developed by Observer Research Foundation (ORF) was upgraded and the scenarios developed under the guidance of Dr. Kirit Parikh by a team from ORF.

in most scenarios. Nuclear capacity of 63,000 MW is assumed to be realisable by 2031-32. As regards gas, in some scenarios the model is forced to have a 16% share for gas-based power generation by 2031-32. A model scenario critically depends on the set of assumptions, parameters and constraints, and in particular on the relative costs and prices of the alternatives available, the discount rate and the projected requirements. Requirements have been specified in terms of billion units of electricity, billion tonne-kilometre of freight traffic, and billion passenger-kilometre of passenger traffic. The freight and passenger traffic projections have been made using elasticities with respect to GDP of 1.0 and 0.8, estimated using time series data from 1930 to 2000. The "optimality" of the solution is contingent on the various inputs/assumptions detailed herein. The importance of the model is that each solution provides a consistent scenario. It should be noted that the model does not suggest preferred scenarios. They are in fact extreme options to define the feasible space for alternate policy choices. Thus when 1,50,000 MW of hydel by 2031-32 is estimated, it does not mean that given the various social, political and environmental constraints we will in fact fully develop our hydel resources to reach this estimate. The scenario does, however, show what the implications are for energy supply if we were able to develop the full hydro potential.

46. These scenarios are described in *Table 21*. They are designed to assess the importance of critical policy options for meeting energy requirements. **These scenarios are designed to map out extreme points of feasible options and none of them should be looked upon as a preferred scenario.** *Table 22* summarises the results of the scenarios. *Figure 11* shows this graphically. Period-wise details for three selected scenarios are given in *Figures 12 to 14*.

Table 21: *Some Energy Supply Scenarios for 8% GDP Growth*

Scenario		Description
1.	Coal-Based Development	Most electricity generation by the most economical option – which turns out to be primarily coal.
2.	Maximise Nuclear	Nuclear development as per the optimistic scenario of *Table 19* is forced by constraints
3.	Forced Hydro	Development of the entire (1,50,000 MW) domestic hydro potential by 2031-32 is forced by constraints.
4.	Maximise Hydro & Nuclear	Both nuclear and hydro as in 2 and 3.
5.	'4' plus forced Natural Gas	16% of electricity generation from gas forced by constraints. This is comparable to the scenario of *Table 9* & *11*.
6.	'5' plus Demand Side Management	Demand side management reduces electricity demand by 15 percent.
7.	'5' plus Higher Coal Power Plant Efficiency	*Thermal Efficiency of future coal power plants increased to 38-40 percent for super critical boilers. from 36 percent for the present 500 MW
8.	'6' plus Coal Power Plant Efficiency	Both DSM and coal efficiency together.
9.	'8' plus higher freight share of Railways	Railways freight share which is specified exogenously increased from 32 percent to 50 percent.
10.	'9' plus vehicle efficiency increased	Fuel efficiency of all motorised vehicles increased by 50 percent By changing specific fuel consumption.
11.	'10' plus renewables	30,000 MW wind power, 10,000 MW of solar power, 50,000 MW of biomass power, 10 Mt of bio-diesel, and 5 Mt of ethanol by 2031-32 forced through constraints.
*	Thermal efficiency of coal-based plants refers to gross thermal efficiency based on gross generation and is equal to the ratio of gross heat output to gross heat input.	

Table 22: ***Scenario Summaries for 8% GDP Growth — Fuel Mix in Year 2031-32***

Mt of Oil Equivalent (Mtoe)

Scenario No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Scenario Description	**Coal Dominant Case**	**Forced Hydro**	**Forced Nuclear**	**Forced Nuclear+Hydro**	**Forced Nuc+Hyd+ GAS**	**Forced Nuc+Hyd+GAS+ DSM**	**Forced Nuc+Hyd+GAS+ Coal eff.**	**Forced Nuc+Hyd+GAS+ DSM+ coal eff**	**Forced Nuc+Hyd+GAS+ DSM+ coal eff+ rail share up**	**Forced Nuc+Hyd+GAS+DSM +coal eff+rail share up+transport eff**	**Scenario 10+Forced Renewables**
Crude Oil	486	485	486	485	486	486	485	485	447	361	350
Natural Gas	104	105	104	105	197	174	191	171	171	171	150
Coal	1,022	953	998	929	835	715	818	698	701	707	632
Hydro	13	35	13	35	35	35	35	35	35	35	35
Nuclear	76	76	98	98	98	98	98	98	98	98	98
Renewables	2	2	2	2	2	2	2	2	2	2	87
Non-commercial	185	185	185	185	185	185	185	185	185	185	185
Total	1,887	1,840	1,885	1,839	1,837	1,695	1,813	1,673	1,639	1,558	1,536
Total without non Commercial	**1,702**	**1,655**	**1,700**	**1,654**	**1,652**	**1,510**	**1,628**	**1,488**	**1,454**	**1,373**	**1,351**
Crude Oil	25.7%	26.4%	25.8%	26.4%	26.4%	28.7%	26.8%	29.0%	27.3%	23.2%	22.8%
Natural Gas	5.5%	5.7%	5.5%	5.7%	10.7%	10.3%	10.5%	10.2%	10.5%	11.0%	9.8%
Coal	54.1%	51.8%	52.9%	50.5%	45.5%	42.2%	45.1%	41.7%	42.8%	45.4%	41.1%
Hydro	0.7%	1.9%	0.7%	1.9%	1.9%	2.0%	1.9%	2.1%	2.1%	2.2%	2.2%
Nuclear	4.0%	4.1%	5.2%	5.3%	5.3%	5.8%	5.4%	5.9%	6.0%	6.3%	6.4%
Renewables	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	0.1%	5.6%
Non-Commercial	9.8%	10.1%	9.8%	10.1%	10.1%	10.9%	10.2%	11.1%	11.3%	11.9%	12.0%
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**	100

Figure 11
CO_2 From Energy Use in Alternative Scenarios in Year 2031-32

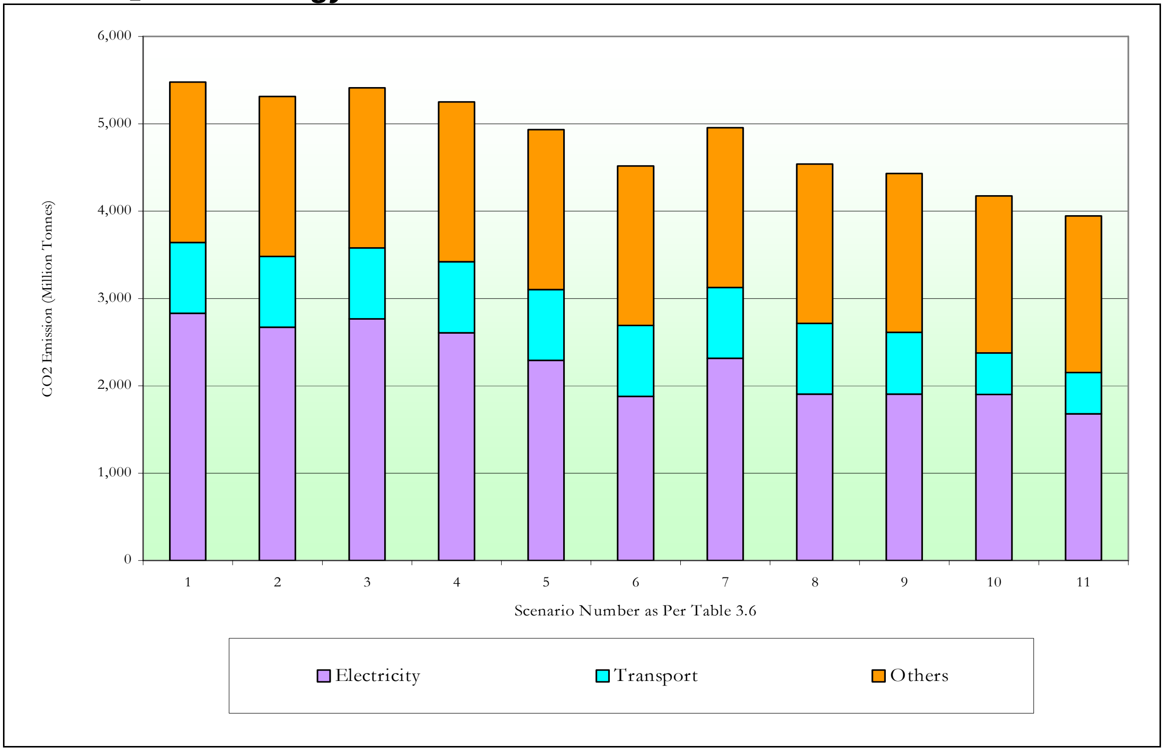


Figure 12
Coal Dominant Scenario 1 - Fuel Mix Year-Wise

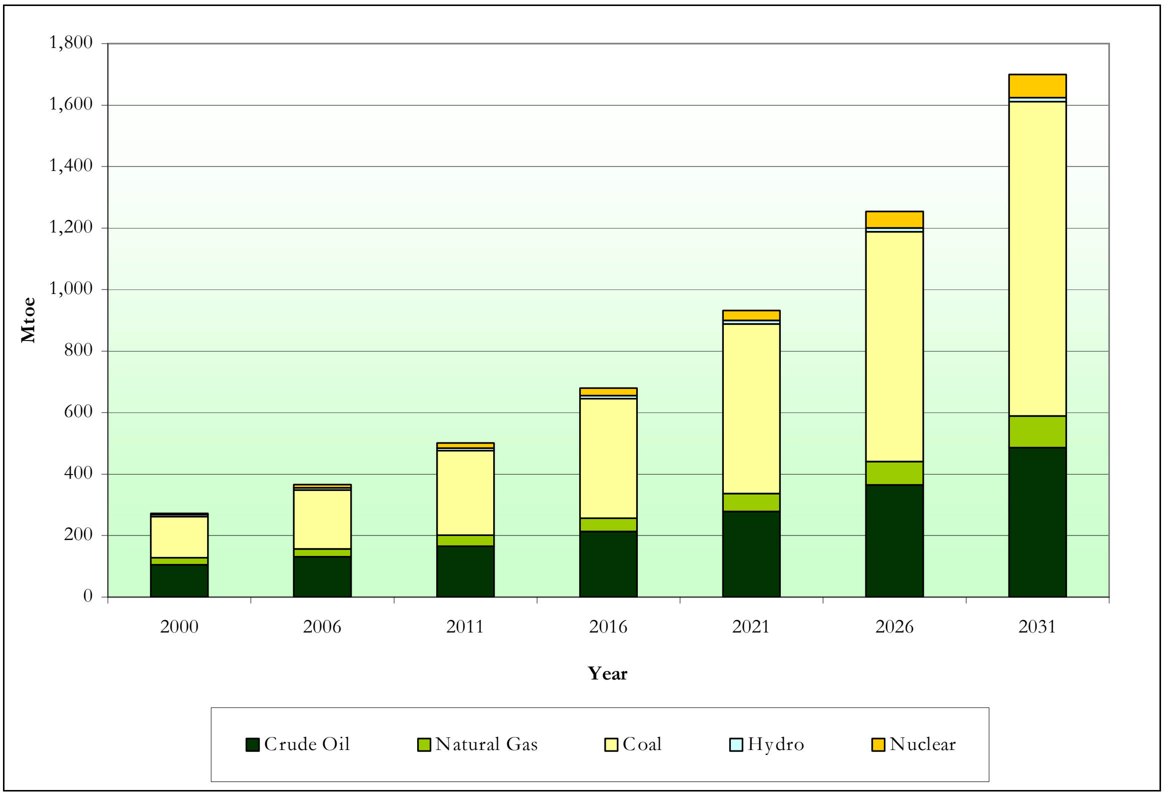


Figure 13
Forced Hydro, Nuclear and Gas Scenario 5 - Fuel Mix Year-Wise

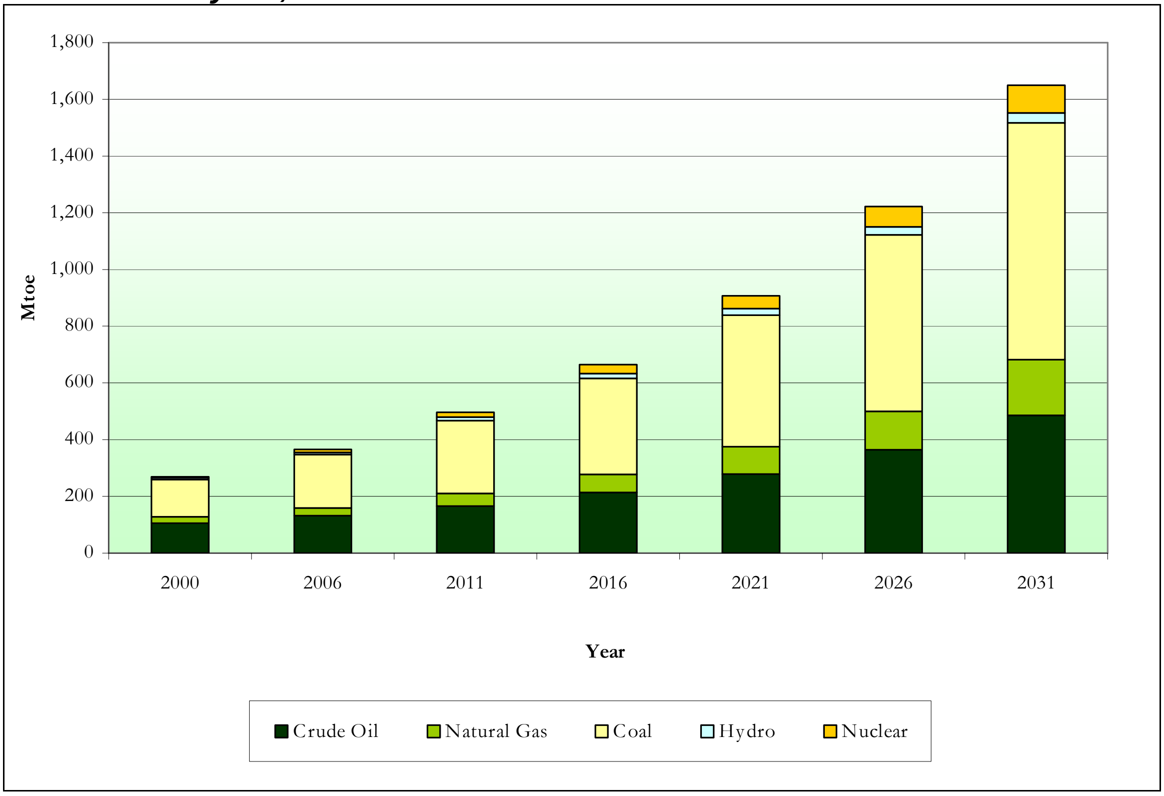
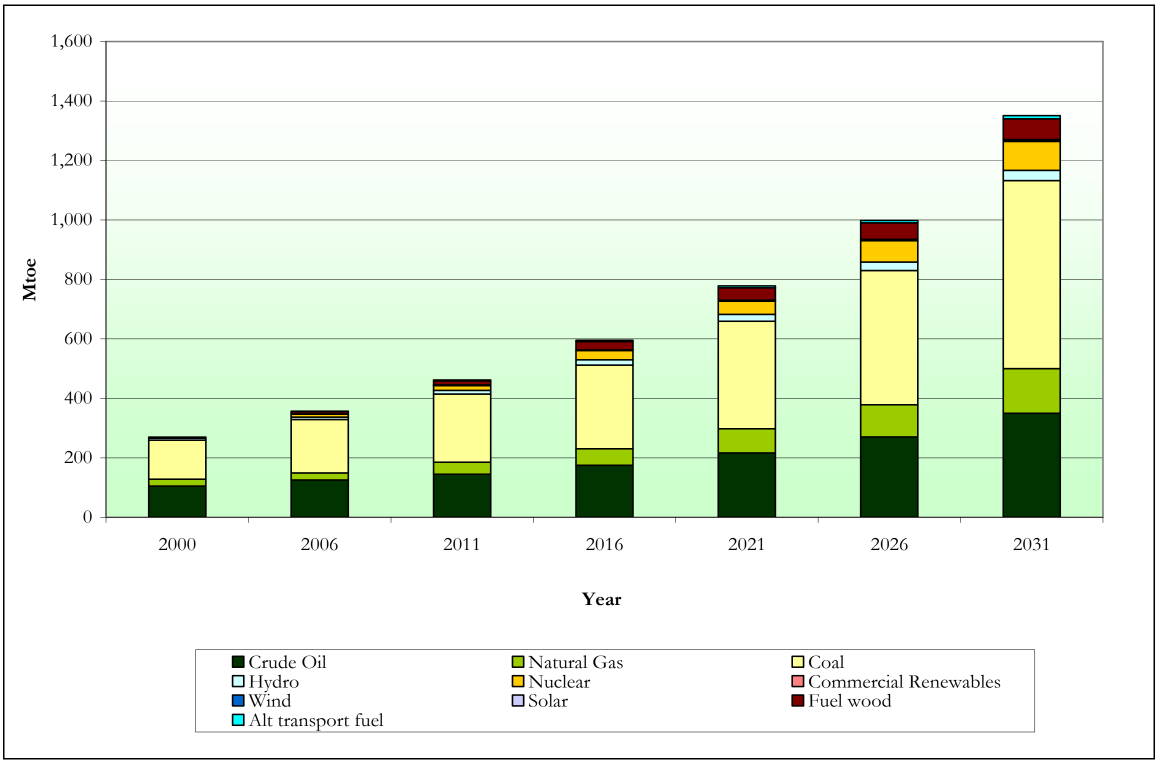


Figure 14
Forced Renewables Scenario 11 - Fuel Mix Year-Wise



47. The modelled scenarios help us in assessing the significance of various options. They also suggest our likely dependence on energy imports. The level of imports depend on the level of domestic production. Given our resources shown in *Table 17*, domestic production of oil and gas will depend critically on new finds. If we don't make major new discoveries, our production can increase only marginally. We can only guess what the production will be and be ready for the worst. Thus we assume that we can produce by 2031-32 only 35 Mtoe of oil per year and around 100 Mtoe of natural gas including coal bed methane. Our production of coal is constrained by our ability to successfully use our ample domestic resources. The main hurdle could be an inability to expand production at the needed pace, environmental constraints due to attendant deforestation and the social problem of resettlement of project affected people. At a modest growth rate of production of 5.5 percent per year - a rate slightly higher than what has been achieved over the previous 25 years - the production of coal and lignite by 2031-32 will be around 1400 Mt. Based on these assumptions, our import needs for the various scenarios will be as shown in *Table 23*. Thus, with an 8% GDP growth rate an import dependence for energy in 2031-32 could be as low as 29 percent and as high as 59 percent. Increasing coal production and associated infrastructure of transport, as well as improving energy use efficiency in generation and use are critical if we are to reduce our dependence on imported energy.

Table 23: ***Ranges of Commercial Energy Requirement, Domestic Production and Imports for 8 percent Growth for year 2031-32***

Fuel	Range of Requirement in Scenarios	Assumed Domestic Production	Range of Imports*	Import (Percent)
	(R)	(P)	(I)	(I/R)
Oil (Mt)	350–486	35	315–451	90–93
Natural Gas (Mtoe) including CBM	100–197	100	0-97	0-49
Coal (Mtoe)	632-1022	560	72-462	11-45
TCPES	1351-1702	—	387-1010	29-59
* Range of imports is calculated across all scenarios as follows:				
Lower bound =Minimum requirement – Maximum domestic production				
Upper bound = Maximum requirement – Minimum domestic production				

3.3 Energy Supply Options

48. The major choices are use of alternative fuels in the power sector and in modes of transport. *Table 23* shows the generation capacities in scenario 11 (renewables scenario) from different sources and the load factor for each type of plants for the year 2031-32. This is an extreme scenario where all options for power generation other than coal, are pushed to their limits. We have also assumed high plant load factors for biomass gasification and combustion, and somewhat lower factors for conventional plants. It gives the minimum coal requirement.

Table 23: ***Generation Capacities and Load Factors in Scenario 11***

Source	Capacity (MW)	Plant Load Factor (%)
Coal	269997	67
Natural Gas	69815	27
Coal Bed Methane	27778	36
In-situ Coal Gas	22,222	36
Nuclear	63060	68
Hydro	150153	30
IGCC Pet coke	3137	68
Wind – Onshore	32141	20
Wind – Off-shore	1200	25
Biomass Gasification	1200	75
Biomass combustion	50000	70
Solar	10000	17.5
Total	700703	50

49. It is seen that even under scenario 11, coal is the dominant fuel with a share of 51% in electricity generation and a share of over 41% in the energy mix. Gas-based generation constitutes only 11% of electricity generation capacity in scenario 11. The capacity factor of gas plants remains 31% showing that they are mainly used for peaking. Scenarios were also generated with alternative prices of natural gas and it is found that natural gas is not selected when the gas price is US$ 4.5 per MMBtu or higher even for peaking power as long as the coal price remains at or below US$ 2.27 per MMBtu (i.e. $45 per tonne of imported coal with 6000 kcal/kg). The low load factor for hydro plants is an outcome of the limited availability of hydro energy. It may be noted that the possibilities of importing hydro power from Nepal, Bhutan and Myanmar have not been considered. The economically exploitable potentials are estimated to be 44,000 MW and 16,000 MW from Nepal and Bhutan respectively. Of these only import from Bhutan is on track. In any case the development of full 150000 MW assumed in a number of scenarios can be considered as partly domestic and partly in neighbouring countries. Also, no specific gas imports through a pipelines is considered, we do provide for gas imports amounting to 97 Mtoe as shown in Table 23.

50. The results of the scenarios in the context of the brief review of energy resources show the following:

(a) Any supply strategy over the coming decades will have to emphasise India’s major resource, i.e. coal. Coal is the most abundant domestically available primary energy resource other than thorium and solar insolation. In the “coal-based development” scenario, the total demand for coal increases from 172 Mtoe in 2004-05 to 1022 Mtoe in 2031-32. Measured in Mt of Indian coal with 4000 kcal/kg, the requirement of coal will thus increase from 406 Mt in 2004-05 to 2555 Mt in 2031-32. The quality of Indian coal is deteriorating progressively. A 5% deterioration over the next 25 years would raise the coal requirement to 2689 Mt by 2031-32 in terms of Indian coal. This order of increase may call for a massive rise in coal imports unless domestic production increases correspondingly. This would increase our energy dependency on imports. Additionally, since use of coal is associated with the environmental problems of mining and local air pollution, apart from CO_2 emission; coal use must be accompanied by appropriate environmental measures and use of clean coal technologies. Even under the least coal intensive option, domestic coal production would need to rise to 1580 Million Tonnes.

(b) A massive effort is clearly needed to expand domestic coal production. Given that, at present, coal mines take 8 years to develop and Coal India suffers from several problems, it is doubtful that Coal India can meet this need. Opening up the coal sector to private mining and use of the best technology are unavoidable. Captive mining as permitted at present alone will not suffice. We must build a consensus to allow changes in the coal sector to happen sooner rather than later. In any event, massive investments would be needed to enhance the rail infrastructure to move large quantities of domestic coal. Alternate coastal/river transportation of coal may also have to be pursued aggressively.

(c) As seen from *Table 23* high quality coal (6000 kcal/kg) import needs could range from 120 million tonnes to 770 million tonnes by 2031-32. To put this in perspective, currently less than a billion tonnes of high quality coal equivalent is traded internationally out of a production of about 4.8 billion tonnes of equivalent high quality coal. This will require the development of appropriate port infrastructure as well as the development of end-use (power, steel and cement) at coastal locations to avoid double handling and inland transportation of imported coal.

(d) Development of hydropower as a clean power source has to be given due priority. Full development of hydro potential while technically feasible, will require timely resolution of issues of water rights, resettlement of project affected people and environmental concerns. These issues can be and must be resolved satisfactorily. The irrigation and flood control benefits of hydro-power and its operational flexibility can justify the higher costs of hydel plants. It is pointed out that India needs to create water storage capacity. Its storage per capita at $207 m^3$/capita is one of the lowest in the world and compares poorly with the corresponding levels of $1964\ m^3$/capita and $1111\ m^3$/capita in the US and China respectively.

(e) Though nuclear energy can make only a modest contribution over the next 25 years, longer term consideration of even a modest degree of energy self-sufficiency suggests the need to pursue the development of nuclear power using Thorium. Despite the many delays and disappointments in achieving set targets of nuclear energy development in the past, this is an option we cannot afford not to pursue. Today the PHWR is economically competitive with coal-based plants at certain locations.

(f) If the import of 6,000 MWe of LWR reactors does not materialise, the installed nuclear capacity by 2031-32 will be 48,000 MW instead of 63,000 MW. The impact on the various scenarios will, however, be marginal and none of the policy conclusion would be affected. We have not depended on large scale import of LWRs due to the uncertainties involved. Imported LWRs could be an important option if the FBR and Thorium reactor routes not materialise or are found to be uneconomical. Energy security concerns may leave us no option other than full pursuit of the FBR and Thorium routes.

(g) The optimistic nuclear development scenario as envisaged is contingent on 6,000 MW of additional import of LWRs whose plutonium could be used in FBRs along with the plutonium from the 10,000 MWe reactors using our own Uranium. Import of the additional 6,000 MW of LWRs (and associated fuel) depends upon the handful of countries constituting the Nuclear Suppliers' Group (NSG). If the sanctions by the NSG are removed and India is able to import Uranium and nuclear power plants, nuclear power can play a much bigger role in the power sector. The capacity growth then would not be constrained by *Table 19*. However, if energy security concerns are our primary driver towards nuclear, then import of LWRs, even though more economical, may have to be limited to restrict our dependence on energy imports.

(h) Full development of hydro potential and realisation of the optimistic nuclear scenario by 2031-32 reduce coal requirement by some 93 Mtoe (232 Mt of Indian coal) from the level of 1022 Mtoe projected in the coal dominant scenario. This scenario implies total electricity generation capacity of 7,75,500 MW in 2031-32 of which hydro capacity will be 1,50,000 MW, and nuclear capacity will need to expand from the present 3,660 MW to 63,000 MW.

(i) If we assume no dramatic new finds of oil occur in the country, our oil imports will be around 315 to 451 Mt in 2031-32. This is about four to five times of what we import today. Assuming that world trade over this period will grow from 2.4 billion tonne (Bt) today to 4 Bt by that time, India's imports will constitute 7.9 to 11.3 percent of global trade.

(j) A disturbing fact that emerges from the study of various scenario is that even if India somehow succeeds in raising the contribution of renewable energy by over 40 times by 2031-32 inclusive of a renewable power capacity of 1,00,000 MW (compared to 6,161 MW as on March 2005); the contribution of renewables to our energy mix will not go beyond 5.6% of total energy required in 2031-32. This is consistent with various projections worldwide that shows that the fossil fuel dependence of the world as a whole will continue to rise till 2031-32.

3.3.1 Energy Efficiency and Demand Side Management

51. India's conventional energy reserves are limited and we must develop all available and economic alternatives. Simultaneously, a major stress must be laid on energy efficiency and conservation, with particular emphasis on efficiency of electricity generation, transmission, distribution and end-use. Clearly, over the next 25 years energy efficiency and conservation are the most important virtual energy supply sources that India possesses.

(a) India cannot deliver sustained 8% growth over the next 25 years without energy and water, and these two together shall, in turn, pose the biggest constraints to India's growth. The energy intensity of our growth has been falling and is about half what it used to be in the early seventies but there is significant room to improve. In 2003 India consumed 0.16 kilogram of oil equivalent per dollar of GDP expressed in purchasing parity terms. This compares to 0.23 in China, 0.22 in US and a world average of 0.21. However Denmark, United Kingdom and Japan are at or below 0.15. One should note that cross country comparisons are full of pitfalls. For example, if the share of hydel energy is higher in the total energy mix, energy intensity would be lower. Even then, these comparisons do suggest that perhaps energy intensity can be brought down by 20% in India. A number of studies in India has confirmed this, for example Parikh, Jyoti et al (1994) looks at 12 specific technical options and finds large scope for gains from Demand Side Management (DSM), with costs that are well below costs of supplying power.

(b) The most energy efficient scenario from our model shows an aggregate energy requirement of 1536 Mtoe in 2031. This scenario is 19% more efficient than the most energy intensive scenario. With a projected population of 1.468 billion, the per capita total primary energy supply (TPES) in the most energy efficient scenario comes to 1046 kgoe/year. This is comparable to China's per capita TPES in 2003. Even in the most energy intensive scenario the per capita TPES in 2031-32 is only 1285 kgoe. This compares with the 2003 world average per capita energy consumption of 1688 kgoe. Thus while the projected total energy requirement may look large, it is perhaps not large enough for the GDP growth assumed.

(c) Efficiency of coal power plants themselves can be improved substantially. The average gross efficiency of generation from coal power plants is 30.5%. The best plants in the world operate with super critical boilers and get gross efficiency of 42%. Germany is even claiming gross conversion efficiency of 46%. It should be possible to get gross efficiency of 38-40% at an economically attractive cost for all new coal-based plants. This alone can reduce coal requirement by 111 Mtoe of coal (278 Mt of Indian coal). Thus a very high priority should be given to developing or obtaining the technology for coal-based plants of high efficiency.

(d) If Demand Side Management (DSM) options are pursued to reduce demand for electricity through energy efficient processes, equipment, lighting and buildings so that electricity demand is reduced by 15% by 2031-32, a reduction of 152 Mtoe (381 Mt of Indian coal) in coal requirement takes place. Studies have shown that economically attractive options of DSM exist to attain such reductions. Energy efficiency and DSM should have a very high priority.

(e) Since domestic oil supply has stagnated at a low level and requirements are growing, oil use efficiency, conservation and substitution by other forms of energy are major options to reduce oil imports. The same is true of gas, though the prospects of finding gas look somewhat brighter. Since no economic substitutes are obvious for the transport sector at least till 2031-32, energy efficiency of vehicles and use of mass transport have to have high priority. If the energy efficiency of all motorised transport vehicles is increased by 50%, (an efficiency level that is already achieved in the world today) our oil requirement will go down by some 86 Mt by 2031-32. If on the other hand railways are able to win back the freight traffic they have lost to trucks and manage to carry 50 percent of freight billion tonne kilometre (Bt-km), then oil requirement can go down by 38 Mt. These two initiatives in the transport sector can, together, reduce our oil requirement by over 25% from the most oil intensive scenario in 2031-32.

(f) Urban mass transport is much more fuel efficient per passenger kilometre compared to private vehicles. Mass transport also reduces road congestion and air pollution. Thus development of urban mass transport systems of quality and convenience that can attract passengers will contribute significantly to energy conservation.

(g) If both energy efficiency of coal generation and DSM are pursued together along with higher freight share by Railways and a push for renewables, coal demand could come down by over 38% from the coal dominant scenario to 632 Mtoe (1580 Mt of Indian coal).

3.3.2 Implications for Investment Needs

52. Apart from the challenges of physically supplying different forms of energy discussed above, the investment requirement also show a need for purposive action. The electricity generation, transmission and distribution sector alone is estimated to require an investment of Rs.60 to Rs.70 trillion in 2005 rupees. The total energy sector investment could well amount to Rs.100-110 trillion in 2005 rupees inclusive of related infrastructure.

53. An economy growing at 8% should have little difficulty in mobilising the needed resources particularly with public private partnerships. The main challenge, however, is to create efficient and financially viable energy sub sectors so that investors have the incentives to invest in a competitive set up where consumers' interests are simultaneously protected.

4. Environmental Consequences

54. What would be the environmental consequences of energy use to sustain 8 percent growth? From the global point of view carbon emissions are the main concern. From the local point of view the various types of degradation of natural resources are important. Experience in many industrialised countries has shown that it is possible to deal with local environmental problems effectively. We will therefore look at carbon emission.

4.1 Carbon Emissions

55. Estimates of CO_2 generated from energy use in different scenarios are shown in *Figure 11* Between Scenarios 1 (coal dominant scenario) and scenario 11 (with all efficiency and DSM measures and renewables) the difference is nearly 35%.

56. The carbon emission implications of our scenarios are significant. Twenty-five years from now the CO_2 emissions would rise from 1 billion tonnes at present to 5.3 billion tonnes per year by 2031-32 in the high coal use projection and 3.8 billion tonnes in the low coal and renewable projection. The US emissions today are in excess of 5.5 billion tonnes of CO_2! In per capita terms, however, India's carbon emission in 2031-32 will be 2.5 to 3.5 tonne of CO_2 compared to more than 20 tonnes in US and 4.5 tonnes of global average in 2004.

5. In Conclusion

57. India needs to develop all its energy resources to meet the requirement for 8% growth. Coal will remain the dominant fuel. Energy conservation through energy efficiency and demand side management is the second most important option to meet its "requirements.

58. India needs at least the environmental space implied by the energy efficiency renewable scenario. Alternatively the world must open up new options through technology such as developing cheap and efficient photovoltaics and battery technologies and provide these technologies as global public goods.

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