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High Economic Growth, Equity and Sustainable Energy Development of India

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Abstract

India has been experiencing sustained high economic growth in the recent years. However, there exists substantial amount of unacceptable poverty among the people in the country. The expressions of symptoms of such poverty include among others inadequate educational and health attainment of the people and lack of access to basic amenities like modern clean energy, safe water and sanitation which are crucial determinants of capability development. There exists in fact significant amount of energy poverty among the people, particularly in the rural India which has more than 70% share of its population, in the form of use of traditional inefficient biomass as the primary fuel with injurious health effect and the lack of connectivity of the households with electricity. The eleventh five year plan of India which has recently been initiated has taken the approach of inclusive faster growth for the development of the Indian economy. This paper analyses the implications of this high inclusive growth in respect of the twin challenges of environmental sustainability of the energy use required by such growth and the removal of energy poverty, which have to be addressed in India's energy planning. The paper defines the concept of sustainable development and points out its resource accounting implications in respect of energy related resource use. It focuses in this context on the instrumental role of the efficiency of energy use and energy supply, fuel composition and technology in determining the strength of the linkage between the GDP growth and the growth of energy use and that between the energy use and the pollution intensity of energy.

The paper also defines, on the other hand, the notion of energy poverty and discusses the problem of equity and energy development in a dual society like that of India. It then reviews the past trend and pattern of energy use and the future projections of energy requirement and supply with special reference to the twin issues of equity and environmental sustainability. In this context it makes a decomposition analysis of the past energy use and CO2 emissions in India for examining its environmental sustainability and if economic reforms of India could make any impact on it. It makes further a brief review of the methodologies of projections and policy planning for the future energy sector development in India as existing in the recent literature. Finally, the paper discusses certain selected issues of energy security and macroeconomic viability of such energy development in the background of the sustained steep rise of oil prices and high cost of carbon free new technologies. It concludes by highlighting certain policy issues relating to pricing, technology and institution for the attainability of inclusive growth and particularly for meeting the gaps in such attainment that would possibly remain as per the existing alternative projections for the future. However, this paper does not pay any special attention to the climate change related global policy issues that would affect India and gives priority to the national level issues relating to energy equity and energy related environmental sustainability of Indian development

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1. Introduction

Energy plays a crucial role in both economic growth and human development. In view of the recent experience of sustained rise in global oil prices, geopolitical turmoil and the secular trend of growing greenhouse gas (GHG) emissions, energy economics till now has focussed mostly on issues relating to the challenges of energy security and global environmental sustainability. The policy research in the area has mostly been concerned with the reduction of CO2 emissions, fossil fuel demands, imports and the associated economic cost without sacrificing economic growth. The energy sustainability issue therefore zeroed in on mainly (a) de-linking the Gross Domestic Product (GDP) from the growth of energy use by improving energy efficiency and (b) de-linking the energy use and the carbon emission by the diversification of choice of energy resources towards more of carbon free or less carbon intensive fuels.

So far as the local environmental externalities of energy use is concerned , the mind set of energy economists being oriented mainly towards the global concerns for climate change, induced them to explore the possibilities of co-benefits of mitigation of GHG emissions and local pollution through policy linkage. The control of local emissions has been at least implicitly viewed mostly as a bonus from the abatement of CO2 emissions. However, most of the developing countries view the challenge of development for poverty removal and human development as far more important in the short and medium run policies than the control of climate change. The recent high economic growth of China and India have been the causes of global environmental concern because of their significant share in the growth of CO2 emission , although their shares in the total annual absolute flow of such emissions as well as their per capita emissions of the gases are far too small compared to that of the industrialized parts of the world.(see Table1).

With more than 1 billion population, Indian economy experienced a sustained annual rate of growth of 8.5% in the last 3-4 years while China's growth has been above 10% per annum in the recent years. Since the introduction of economic liberalisation in 1991 as evidenced in the rising share of trade in GDP among others and the structural adjustment reforms, the Indian economy has experienced an overall trend annual growth rate of 6% during the last 15 years of the period of reforms (1991-2005) (See Tables 1 & 2). This growth has also been accompanied by some reduction of poverty and definite improvement in the indicators of human health and educational development. (See Table 3). This development has required the use of primary commercial energy resources to grow at the rate of 5.6% in India during the period since 1991 and particularly at the rate of 4.8% in the recent years since 2000, reaching the level of 379 million tonne of oil equivalent in 2005. The Carbon Dioxide emission has been 347 million tonnes of carbon equivalent as per the latest estimate available for 2003.

In spite of the developmental experience of the recent decades and particularly the acceleration of growth in the recent years , more than one fourth of India's population still live in an unacceptable condition of poverty as they are deprived of adequate livelihood which can ensure the meeting of their basic minimum needs. The head count poverty ratio for India declined from a high of 54.9% in 1973-74 (when it was first estimated by the government of India) to 36.0% in 1993-94. As per the latest estimate based on the National Sample Survey Organisation (NSSO) survey 61st round on the monthly consumption expenditure for 2004-05 (which is comparable in methodology to that of 1993-94), the poverty ratio has shown a further decline to 27.5%. However the pace of such poverty reduction has been quite slow in India at a meagre 0.8 percentage point per year. At this pace India will take another 30 years to achieve the current poverty level of less than 4% of China.

The achievement of India in the attainment of level of human development as per many of the indicators of quality of life relating to education, wealth, energy use, water supply, sanitation etc. has also been substantially lower than those of the competing developing economies like China and the average of the industrialised countries. This has been due to the fact that a large number of people are excluded from participation in the process of development and are deprived from sharing the benefits of growth .The life expectancy, education and overall index of human development have been respectively 0.64, 0.61, and .611 for India for 2004, while the cut off value of such indices for high human development is considered to be 0.8 .The low quality of life of the Indian people is also reflected in the pattern of energy use in India. The per capita uses of modern commercial energy and electricity have been 530 kg. of oil equivalent (oeq) and 457 kwh in 2004 while the world averages for these have been 1792 kg oeq and 2606 kwh respectively. With 17%of world's population, India has in fact accounted for 5.2% of world's total commercial energy use in 2005 and 4.8% of CO2 emission in 2003 ,as per the latest available estimates for the latter. (See Table 1).

In view of the tardy progress of India in poverty reduction and the persistence of socio economic disparities among the people in spite of the experience of the robust economic growth after the turn of the century, the Approach Document of the Eleventh Five Year Plan of India (Planning Commission 2006b) for the period 2007-08 to 2011-12 has decided to accelerate the annual GDP growth rate to 9% and make the growth process more inclusive. The "inclusiveness" has implied the fast removal of poverty , generation of employment and equitable distribution of benefits of growth and particularly human capability development through education, health, and other basic amenities like clean energy, safe water etc. It is now a consensus that high growth is a necessary though not a sufficient condition for poverty removal, and for making the development process inclusive as it can create conditions for the generation of enough savings, taxes and inflow of foreign resources to finance the additional requirements of the inclusiveness of growth and for the greater employment opportunities.

At the present juncture of India's development, the high inclusive growth as targeted requires immediate acceleration of growth of agriculture in order to get the economy out of the agricultural stagnation and its productivity crisis as well as a greater emphasis on the growth of the manufacturing industry for the faster pace of industrialization and concomitant urbanisation and motorisation of the economy. All these would require massive investment in energy and transport infrastructure and high growth of primary commercial energy resource use as per the business as usual (BAU) scenario which builds into itself the current trend of improvement in energy efficiency induced by the policies to continue in the future. The energy planners and policy researchers have simulated various future energy scenarios for India for alternative policy interventions with the implications of environmental sustainability different from that of the BAU scenario.

In view of the recent growth experience and the various projections of energy requirement of India , the global concern for the adverse impact of such Indian development on the global environment is however quite real. One basic problem is that the pollution intensity of energy use of an economy is often determined by its energy resource endowment as given by its natural environment in the interest of both minimisation of development cost and energy security. Since coal of low quality is the major energy resource to rely upon for the supply of primary commercial energy, a serious challenge arises for India in respect of planning the environmentally sustainable development of its energy sector to support the targeted inclusive high economic growth with energy security.

However, in the context of energy planning, one needs to keep in view two basic issues specific for developing countries like India having substantive amount of unacceptable poverty. First, both the global society as well as the Indian society are characterised by the dualism arising from the divide between the rich and the poor in respect of income, pattern of consumption, energy use and their environmental consequences (Reddy 1997). The rich pollute the environment by the wasteful use of commercial energy intensive goods and services resulting in harmful emissions while the poor degrade the natural environment by directly over harvesting the resources and living at its expense. The rich are responsible for CO2 emission from automobile emissions and emissions from power generation. The poor are responsible for deforestation or forest degradation due to over harvesting the forest woods, grazing common lands etc for cooking fuels and fodder. They are also responsible for the diversion of forest land for agricultural use in an economy with highly skewed distribution of ownership of land. The degradation of such natural resources in turn affect the poor most. There has been no research done on the distribution of the income class-wise contribution of the people of a society to the different kinds of pollution and degradation of the natural environment because of the lack of the requisite data.(Reddy1997). While, the emissions caused by the rich of the world are having global as well as local externalities, they are more concerned about the adverse global changes for which they are mainly responsible. This concern arises because of the threat of sustainability of the long run capitalist development as per the Business As Usual (BAU) scenario. The poor would be more affected by the pollution and mostly local externalities caused by mainly the rich due to the adverse health effects as they are more vulnerable to diseases. The requirement of development for poverty alleviation and improvement of the quality of life of the masses, an inclusive growth programme would require primary attention to the control of local pollution and conservation of natural resources which are crucial for the health and livelihood of the common people. The global environmental issues would be viewed as important by the developing countries like India particularly if the reciprocal externalities from climate change affect them seriously too. However, it is not surprising for them to view the problem of control of such emissions as one of obtaining a bonus from local pollution control through policy linkages rather than the other way round.

The second important aspect of the energy –environment related problem is that so far as energy use is concerned, the poor of India as well as those of the world suffer from energy poverty due to the lack of access to modern energy services like electricity, or to clean cooking fuel like LPG (Birol 2007, Barnes and Toman 2006). About 1.6 billion people in the world have no electricity connection in their homes. Again about 2.5 billion people (i.e. 40% of world's population) have to rely on the biomass of fuel wood, dung-cake and agricultural residue without any conversion for meeting their cooking needs. The share of the traditional fuel consisting of fuel wood, dungcake, agricultural wastes etc, still constitutes to be about 30% of the total primary energy supply of the Indian economy. A major part - 90% of such non-commercial energy resources is used by the households for meeting its cooking needs only. In India with 71.5 % of its people living in villages, 84% of the rural households and 23% of the urban households have to depend on biomass for cooking as per the NSS Survey 61st. round for 2004-05. For the lighting need, 51.4% of the rural households and 7.7% of the urban households are denied access to electricity either due to income poverty or due to the lack of adequate investment in energy infrastructure. (NSSO 2007).

Besides, the meeting of the basic needs of food, shelter, education and health services for all lies at the heart of any meaningful strategy of inclusive growth as characterised by poverty alleviation and human capability development. The availability of high quality commercial energy and appliances for cooking and electricity for lighting would have a dramatic impact on the quality of life of its people. The day finishes earlier without electricity and the children have to struggle to read in candle light and inefficient kerosene lamp to prepare for their next day's school homework. The use of the traditional fuel in country *chullah* generates adverse indoor air pollution affecting the health of women and children who are mostly exposed to it. The collection of biomass takes away time and opportunity of their earning income. The access to modern energy services is in fact a crucial requirement for not only food and shelter but also for the health and education and capability development of the people. (Birol 2007)

These modern energy services have in fact a high marginal value contribution to human welfare in the context of broader socio-economic development. If we define energy poverty to be either lack of connectivity with electricity or reliance on biomass as primary fuel for cooking and water and space heating or both, the removal of such poverty would be of critical importance for the human development and improvement of quality of life. It is unfortunate that energy economics as of today has paid only marginal attention to this issue of energy poverty. (Birol 2007). The central theme of this paper is the energy economics and planning of India's high economic growth with special reference to the issues of environmental sustainability of energy use and supply as well as those of energy poverty removal for human development

This paper addresses the major issues relating to the demand and supply side efficiency of energy and fuel choice and makes a decomposition analysis of the past pattern of energy consumption to assess the de-linking of economic growth with energy use and that of decarbonisation of energy. While the paper refers to a few recent economy wide studies on the future projections of energy use and emissions in India, it makes a closer analysis and review of the past trend and pattern of energy usages in India and of the future projections of the energy requirement and supply as made by the Expert Committee on the Integrated Energy Policy for India of the Planning Commission (Planning Commission 2006a) This review discussion is oriented more towards the challenges to be faced in energy planning and policies for environmental sustainability and energy poverty removal than the choice of environmental policy instruments as such for the purpose. While the paper discusses the impact of energy use on CO2 as an important part of energy – environment linkage, it does not focus the discussion as such on the Green House Gas (GHG) mitigation and climate change. It is oriented towards the local or national level impact of emissions of all kinds from energy and the removal of energy poverty.

2. Energy, Optimal Pollution and Economic Growth.

Energy is an item of life support for our economy and society. It is a basic need of all households throughout the world for cooking food, lighting, space heating and cooling and private transportation and several other amenities. Energy is also universally required as an input directly or indirectly in the production processes of any economy. All energy is provided by energy resources or energy carriers which are drawn from the source of the natural environment. Modern use of energy services requires however conversion of these energy resources as available in the natural environment into more convenient form that can more easily or efficiently serve the human needs. The examples are the conversion of coal or oil or gas into electrical or propulsion energy and that of biomass into biogas for lighting or heating. Such conversions often require substantive amount of capital and involves some energy loss and other costs. The poorer people often depend heavily on the direct use of biomass like fuel wood, cow-dung, agro waste for meeting the basic needs with little conversion because of their problem of affordability of paying for such costs.

The conversion of energy resource into modern energy services and the use of the latter involves two kinds of environmental disturbances due to the law of material balance and the entropy law of thermodynamics. The first source of disturbance is the process of extraction of the energy rich resource, its refinement and its transportation to a point of use. The other disturbance arises from the disposal of the residuals of energy conversion and of the use of the refined or converted final energy after combustion –atmospheric gases (CO, CO2, SO2, NOX etc), solid wastes, particulate matters and unusable heat particularly for fossil fuels. The disposal of the waste residuals involves cost. They often generate serious negative externalities at the local, regional or global level adversely affecting the health of the humans and the primary productivity of the terrestrial eco-system, if the rate of such residual waste flow exceeds the average absorbing capacity of the latter. Such environmental damage would involve costs which need to be internalised for the assessment of social cost of fuel use. In a market driven economy part of the environmental damage would be abated which would involve costs for meeting the prevailing environmental standards or taxes as imposed. Thus, the environmental cost of energy would conceptually comprise (a) the cost of abatement and (b) the damage value of the unabated emissions. The market transactions would however reflect the damage value to the extent the polluters are required to pay taxes or buy permits for the unabated emissions.

There exists however a wide spectrum of energy carrier resources- fossil fuels, biomass, uranium, hydro-resources, wind flow and solar radiation etc – available in the nature, each having different extraction and conversion cost, efficiency of use and environmental impact. The environmental and energy economics would warrant such choice of energy resource mix and that of technology of their conversion and final use that the integrated social cost of energy for supporting a given growth path –high or low –is minimised. The availability of energy resources for the economy, the international supply prices of traded energy and the cost of technology of energy conversion and use in the primary or final form would determine such optimal choice of energy resource and technology mix.

There exists here a problem of consistency of a given growth trajectory and the evolution of energy prices as the latter would be required to efficiently support the former for the rational allocation of resources. The macroeconomic overall growth and its structure may, in fact, in turn be affected by the energy prices, taxes and costs themselves, if the social cost of energy to income ratio becomes high or significant at the aggregate or sectoral levels. In the case of large effect of energy price variation on the economic system a complete dynamic general equilibrium formulation would in fact be required for deriving the sustainable growth trajectory which would take account of the economy-energy-environment interactions in optimising inter-temporal social welfare.

There has in fact been some econometric enquiry into the nature of causal inter-dependence among the growth of energy, income and energy prices in the context of India and other countries using time series analysis of co-integration and vector error correction model based Granger causality. (Asafu-Adjaye 2000, Paul and

Bhattacharya 2004).While the study of Asafu –Adjaye study points to the unidirectional Granger causality running from income and prices to energy consumption in the long run, the analysis of Paul and Bhattacharya arrives at the result of existence of bi-directional causality between energy and income without of course considering prices into the model.

3. Energy Resources, Sustainable Availability and Environmental Effects

3(a). Fossil fuels.

The energy system of India primarily consists of the energy carriers –fossil fuel, hydro and nuclear resources, and biomass. (See Chart 1). The use of these resources would generate two kinds of effects for the economy with sustainability implications –(a) depleting effects on the stock of natural resources and (b) degrading effects of the different phases of fuel or resource cycle on the natural environment. (Velthuijsen et al 1999) . There are also other non-conventional renewable resources which can emerge as significant resources in India's future energy balance. The current pattern of energy use in India is heavily dependent on fossil fuels - coal, oil and natural gas – which would be depleted faster with any acceleration of growth of economic output. As of 2005, while the share of primary commercial energy in the total primary energy supply in India has been 70.6%, the share of fossil fuel in the same has been 68%. In the total commercial energy, the coal resource had the dominant share of 55%, followed by oil 34% and gas 8% . The shares of hydro and nuclear resources in the total primary commercial energy supply have been 2.27% and 1.19% respectively in the same year.

Table 5 gives the deposits of reserves of fossil fuels and their respective reserve to production ratios which are indicative of the sustainability of the resource supply. The reserve to production ratio indicates that India has 86 years of production of coal as proved coal deposits while she has deposits of only 23 years of production requirement as proved deposits for crude oil and 38 years of similar requirement for gas.

However, if one compares the reserves with the annual energy requirement, the self sufficiency index (production to total supply ratio) for oil has been declining over time, its value being 29 % in 2005. India is also a net importer of coal because of the inferior quality of coal, particularly of coking coal, the import dependence in 2005 being 12% of the requirement. It is the deteriorating coal quality which is going to contribute to India’s increased dependence on coking coal in future particularly in the interest of the competitiveness of the Indian steel industry.

While coal is the most abundant fossil fuel and commercial energy resource, it has unfortunately the most disruptive effect on the environment. The extraction of coal often gives rise to acid mine drainage and toxic effluents which pollute water streams and rivers. The combustion of coal on the other hand produces particulates, CO2, SO2, NOX, particulate matters, and hydrocarbons as air pollutants, and fly ash, sludge and toxic heavy metals, and insoluble inorganic materials as solid wastes. Of these, CO2 and NOX are greenhouse gases , while SO2, NOX and acid drainage have destructive impact on the primary productivity of the eco systems due to effects of acidification of forests , soil and water bodies. Besides, the air pollutants and water bodies have adverse health impact on the humans. The inferior quality of Indian coal- particularly due to high ash makes its environmental impact per unit of oil equivalent of coal obtained worse than that of the internationally traded coal. The air pollution problem of oil cycles is virtually the same as that of coal, the difference lies only in the amount of emission per unit of oil equivalent of energy. The refining of oil generates waste water carrying toxic heavy metal contents. The solid waste arising in oil cycle is negligible as compared to the coal cycle. Natural gas on the other hand has mainly an air pollution effect due to CO2, SO2, and other hydrocarbons like methane. Natural gas is the cleanest among the fossil fuels. Coal in fact generates 11% more CO2 than oil and 67% more CO2 than natural gas.

3(b) Hydro electricity

Among the renewable modern energy forms, hydroelectricity has been the most important one in all countries. The water in storage or flowing along a gradient is the resource which is used to generate the electrical energy, involving substantive use of capital. The same is true for wind, tidal, solar and other forms of non-conventional energy. The flow of such renewable resource for generating electricity or heat, or their converted final energy forms have also an upper bound per unit of time as all of them are driven by solar energy and involves substantive use of capital and costs which vary across the resources. Table 6 gives the potential of hydro electricity and other renewable energy resources in terms of maximum annual flow of energy it can supply. India’s hydel resource potential is estimated to be 84000 MW at 60% load factor. The installed hydel capacity of the utility system as in 2005 has been about 32,326 MW which was operated at 29% load factor. In view of the low load factor due to the limitation of the water resources, the economics of small hydel plant of less than 25 MW capacity would work out better for peaking power than that of the large storage dams. Besides, most of the future hydel resource potential to be developed in India are in the North Eastern region, Himachal Pradesh, and Uttaranchal. This implies the importance of fast development of the integrated national power grid for taking advantage of the full hydel potential for sustainable energy supply (Planning Commission 2006a).

Of the commercial non-fossil fuel resource, hydel resource is a clean one in respect of air quality compared to the fossil fuel resources. However, the construction of dam or storage for the purpose causes destruction of land and modification of the ecosystem. The submergence of large areas of land in the catchment area for water resource of a river basin has adverse dislocating effect on human settlements, wild life habitats, forests, and biodiversity loss, etc. The deforestation in the energy catchment area of such river basins has also led to serious soil erosion and siltation of the reservoir and downstream rivers and channels resulting in floods during the monsoon season in India. The environmental impact of hydel project is however site specific. It is difficult to generalise and arrive at some representative impact measure in quantitative terms for this option. However, case studies of environmental impact assessment have been found to be useful for evolving sustainable development policy of hydel capacity for meeting the energy need.

3(c) Nuclear Energy

Nuclear energy represents a different technology and different implications regarding exhaustibility although the basic energy resource like uranium or thorium is non renewable. It is in fact a vital component of the energy industry of the world and is going to be of increasing importance in India in the future. Unfortunately India is poorly endowed with low grade uranium which can supply fuel upto the requirement of 10,000 MW Pressurised Heavy Water Reactors (PHWR). The uranium content of India’s low grade ore is 0.1% while the same is 12-14% in the major sources abroad making the process costlier.(Planning Commission 2006a). India has substantive reserve of thorium which has to be converted into fissile material through breeding to uranium 233for any energy generation.

India has developed a programme of three stage development of nuclear power : the first stage with PHWR, the second stage with Fast Breeder Reactor (FBR), and the third stage with reactors based on uranium 233-thorium 232 cycle. (Planning Commission 2006a, Kakodkar 2004). It is envisaged that the plutonium fuel and the recovered uranium from the PHWR of the first stage will provide the major fuel for the second stage. Thorium will be used as a blanket material in the breeder reactor to produce uranium 233 for the fission in the third stage. Table7 shows the potential availability of nuclear energy which is quite large for the third stage. However, it is also envisaged that the PHWR of the first stage would be supplemented by some Light Water Reactor (LWR) based on the import of technology and fuel to produce enough plutonium for the second stage. If the nuclear programme is successful, then the nuclear option can provide large amount of clean energy. The success of this programme would however depend on India’s ability to import nuclear fuel overcoming the political constraints at home and abroad.

Among the non-fossil fuel resources, nuclear energy is a clean energy option in terms of air pollution and has no other significant environmental impact except those relating to the safe disposal of the radioactive wastes and low-level radiation from reactors. The mining and enrichment process of uranium however causes some contamination of surface and ground water with radioactive elements of minerals which is also a source of health hazard. An issue of safety of course arises from the risk of accidents due to possible malfunctioning of the nuclear reactor or due to accidents caused by factors beyond the control of the management. The relative significance of such accidents vis-à-vis other accidents in terms of expected value of damage needs to be assessed for the sustainability of the nuclear option.

3(d) Biomass energy

Biomass constitutes more than a quarter of the total primary energy supply even as of today in India. It is only a negligible fraction of such biomass including wastes that is converted today into biogas or electricity. Energy conversion technologies for biomass in traditional country ovens are highly inefficient and the harmful gaseous emissions (CO, HC, particulate matters) cause problems of health for women and children in the households in the lower income classes who are exposed to these emissions. The indoor pollution causes respiratory infections and diseases leading to premature deaths. According to the estimates of World Health Organisation (2006), 1.3 million people, mostly women and children in developing countries, die every year prematurely due to the use of bio-mass which is a threat of health next in order of magnitude to only malnutrition, HIV/AIDS and water borne diseases (WHO, 2006).

Besides, valuable time and effort are devoted by mostly women and children for biomass fuel collection sacrificing the opportunity cost of a productive earning employment. In India , a case study points out that 85 million households spend 30 billion hours annually in fuel wood gathering (Parikh, et.al 2005).

Over harvesting of biomass, particularly fuel wood as collected from forests may have the adverse impact of deforestation. In poorer regions of India, particularly in the Himalayan regions where access of the people to commercial energy is limited, there has been degradation of forests due to over use (Baland et al.2006). A decrease in forest area or its degradation due to the lowering of crown density would adversely affect the carbon sequestration and would contribute to the accumulation of the stock of CO2 in atmosphere and therefore to the global warming.

3(e) Non conventional Energy

Although India depends on the renewable biomass for 30% of her total primary energy requirement, this resource is used with low efficiency and without any conversion directly by the households causing health risks for them. The sustainable energy development for inclusive development will have to target the replacement of polluting biomass by cleaner modern energy with higher efficiency. Apart from the conventional commercial energy like electricity, kerosene and LPG, there exists the potential of development of **n**on-conventional new renewable technologies using solar, wind and biomass resources to provide clean energy. The biomass resource itself can be converted into environmentally clean fuel like biogas by way of wood or dung gasification . In view of the inevitable dependence on biomass for cooking fuel, this option of biomass conversion has assumed importance of policy significance as a strategy for rural energy development. It is possible to organise both family sized and community sized plants if a critical minimum dung of animals can be mobilised for the plant involving voluntary cooperation of all the stakeholders in an incentive compatible way (Parikh and Parikh 1977).

Apart from the animal wastes, plant biomass can also produce biogas as well as liquid fuel. Bio -diesel from plants like Jatropa , Karanj, and Mahua and **from** ethanol are economically viable options which can reduce India's oil dependence provided sufficient waste lands can be mobilised or good quality land can be diverted for such use. The potentials of such bio fuels for India are given in Table 6. However, the land use change for the development of such options can have important socio economic effect (e.g, impact on food security) which needs to be factored in before taking any decision on the large scale implementation of such option.

Finally, wind energy and solar thermal as well as photo voltaic energy for electricity have also substantive potential in India as indicated in Table 6. Wind power can be generated from the energy potential of on shore wind flow but only at a low load factor of about 20%. The solar thermal, on the other hand, is an economically feasible option mainly for water heating. The solar power is still a high cost option (Rs. 20 /kwh). Even if further R& D effort reduces the cost of solar photo voltaic option as is hopefully expected , it would require substantive use of land. (Planning Commission 2006a)

However, of all the non conventional energy options, hydro , wind and dung based biogas have the advantage of no significant land use diversion, while the solar power and any plant based fuel would require land which may have high social opportunity cost if it impinges on the food security of the country. The exploitation of such options would therefore require careful land use planning for maintaining inter sectoral balance for maximising the social welfare of the people.

4. Economic effects of Limitation of Resources

Since the energy system of India is predominantly based on fossil fuel (Chart 2) causing depletion of our domestic stock of such renewable resources, India is being increasingly dependent on imported energy – mainly for oil – with the acceleration of economic growth (Table8). This has become particularly acute because of the growth of requirements of oil not matching with the growth of supply from domestic production due to inadequate accretion of reserves through discovery. There has been no significant discovery of hydrocarbon reserves in India after the discovery of Bombay High excepting that of gas in the Krishna-Godavari basin and in Gujarat, in spite of large investments in the last two decades. As a result , the crude oil production in India has stagnated although only one third of India's potential oil bearing structure has been explored for development. New technology may be required to be developed involving high cost to overcome the geological barriers of deep drilling both on shore and off shore to exploit those oil potentials and increase the volume of domestic proved reserves which are economically viable.

India's energy industry will in fact have to face conditions of increasing marginal cost of extraction and supply of fossil fuel -both oil and coal-per unit of energy in oil equivalent unit with the acceleration of its demand as induced by high GDP growth. The reason behind such likely rise in cost is that either more difficult geological structure will have to be developed for exploitation or fuel resource of inferior quality (like high ash or high sulphur coal or heavy oil, etc.) will be left for extraction with cumulative extraction of stocks.

The cost of renewable energy like hydel power is again site specific. For any positive time discount rate , the electricity industry will have to move on to hydel project of higher real cost per unit of energy over time as the water resource of each hydel potential of lower order of cost gets projectised and fully utilised for meeting the growing demand for electrical energy for supporting high growth. As the rational allocation of resources in India would equate the marginal cost of supply of energy from the domestic sources with the import price of energy, the supply side sustainability of resources and India's energy security will be highly dependent on the future movement of the world oil prices in a liberalised regime.

There has been a steep rise in the global oil prices index which has been partly due to the rise in the global demand fuelled by the growth of the developing countries, and partly due to the growing market imperfection and geo-political developments. Such rise in global oil prices with which all energy prices are globally linked would raise the real cost of development with any acceleration of GDP growth rate unless energy and GDP can be decoupled. The real price of oil had risen for India at the phenomenal rate of 25% per annum during 1971-1980 followed by a decline at the rate of 4.3% per annum during 1980-95. However it has again risen sharply at the rate of 10% per annum during the last one decade since 1995. (See Table 8)

5. Economic Effects of Environmental Degradation due to Energy use

We have also observed that the fuel cycles of the energy carriers of the Indian energy system has a wide range of environmental impact comprising air pollution, water pollution, forest, and soil and land degradation. These impacts are often distributed widely over space and time making both the physical impact assessment and its monetisation challenging. In view of the dominance of the policy considerations for abating global warming and climate change in the entire discourse of environmental sustainability of energy use and supply, the focus of research and discussion has been on the reduction of CO2 emission. While the assessment of CO2 impact of any strategy of energy sector development for supporting macroeconomic growth has been highly important, some physical and monetary accounting of emissions of other pollutants, like SO2 ,NOx, TSP and hydrocarbons have also attracted some attention, though not adequate ,particularly in the context of assessment of health effects of emissions for the Indian energy system .

The estimation of social cost of safety of nuclear power and that of dislocation of human settlements and the land use change of hydel projects have been addressed only in the context of project evaluation to the extent necessary for obtaining clearance. Academic research in the area has been limited and not involved adequately rigorous economic analysis as reflected in the literature of environmental economics in the Indian context. The true cost of externalities of the fuel cycle of energy carriers affecting the environment, people and the economy thus need to be assessed for resolving the problem of sustainable fuel policy.

In view of the difficulty of monetisation of many of the physical damages of these externalities generated in the resource cycle , the policies of environmental control in India have been mostly formulated in terms of setting physical standards and norms (See Central Pollution Control Board website reference) for the various emissions for different sectors and other regulations including the environmental enactments (Sankar 1998) requiring environmental clearance of projects and not really on explicit market based instruments of taxes or permits for the purpose as yet. Such standards and norms are often set on the basis of scientific, legal and socio-economic considerations on the basis of the data on hybrid physical-monetary accounts as available. The development of a hybrid physical monetary satellite account of resource depletion and environmental degradation for an economy has also been recommended by the UN's approach for integration of environmental and economic account (United Nations Statistical Division 2003) and has been found to be useful for policy analysis.

While there have been a large number of studies mainly on CO2 arisings and their mitigation costs from the energy source in the Indian context to be listed, the studies on monetising the value of damage cost of such pollution at local level are relatively limited. Some of these studies of monetising damage have been done in the sectoral context of emission arising from fuel burning, while some others have been attempted to evaluate the damage of air pollution as such irrespective of the source or the causal factor (Brandon and Homman 1995). Kumar and Rao 2004 estimates the health cost of SO2 emission of a power plant. Sengupta and Mandal 2005 estimated the cost of health damage of automotive pollution from all major emissions. Parikh et al 2005 estimates the damage cost value of indoor pollution from biomass cooking fuel. Murty et al.2004 on the other hand has estimated the value of reduced air pollution irrespective of the identity of the source.

Most of the country level studies for India on the economic impact of the variations in GHG emissions have been worked out in a partial or general equilibrium framework through simulation for alternative policy intervention for mitigation of emissions. Such macro level studies do not necessarily provide the precise monetised value of variation in the consequent environmental damages. It is only the result of some sensitivity analysis or the values of some of the dual variables of the model which may be indicative of the monetised value of the damage due to pollution. However, such shadow values of damage obtained from the macro model may not be precise enough for use in the micro economic context of any project evaluation for environmental control. It is in fact the hybrid data of the physical impact of the damage of emissions and the monetary values of economic benefits from the reduction of emissions which often provide the basis of inference regarding the trade off between the developmental and environmental benefit and policy choice.

6. Adjustment in national account system due to energy depletion and degradation of the natural environment.

It is to be noted here that an ecosystem is affected by the absolute load or concentration of pollution and that the marginal cost of damage of pollution rises with rise in the absolute load of pollution. With the rise in energy use as driven by economic growth, the marginal damage cost is likely to rise over time and with the scale of use of energy. The rise in the cost of fuel resource because of cumulative depletion and that of environmental externalities would thus have an eroding feedback effect in the process of economic growth itself. The rise in the marginal integrated social cost of fuel use of the energy system has thus a cannibalising effect on the economic system as the second law of thermodynamics of energy and the limited capacity of the source and the sink of nature would make their effects felt in changing the patterns of resource allocation sooner or later (Commoner 1982). The increasing proportion of economic resources of the economy will have to be allocated for supporting the energy system with rise in the growth rate which would ultimately result in rise in energy cost to income ratio of the economy. The sustainable resource and economic accounting at macro-level warrants such adjustment of the conventional national income accounting that it can take account of the depletion of the natural capital and the degradation of the natural environment.

Given the capital theoretic result of the equality between the optimal value of inter-temporal social well being and that of the initial capital stock of an economy comprising both the man made assets and the natural resource and environmental capital, the conditions of weak sustainability as defined in environmental economics would require that the genuine investment comprising the total value of investment in all such capitals together should be non-negative (Dasgupta 2001, Dasgupta et al 2000). For the estimation of the true rate of growth , sustainable income and genuine savings at the macro-level, it is necessary to adjust both the GDP and the Gross Investment not only for the depreciation of man-made capital , but also for the depletion of minerals and fossil fuels and for the degradation of the natural environment due to pollution. The World Bank's data base of World Development Indicators (World Bank 2007), in fact shows the time series estimates of genuine savings for the different years with the details of components of adjustment for the depletion of resources on a few major accounts. In the definition of genuine savings as indicated in the formula given below , educational expenditure is considered by the World Bank as an investment in human capital and therefore as a use of savings on the one hand, and the energy depletion, mineral depletion and damages due to CO2 and particulate emissions as depreciation of natural capital on the other.

Genuine Savings =Gross National Savings –Consumption of Man made Fixed Capital + Educational Expenditure –Energy Depletion –Mineral Depletion-Forest Depletion –CO2 damage –particulate damage

Of these adjustments, the adjustments due to energy depletion, CO2 damage and particulate emission have been mostly on account of use of energy resources in the economic system. A large part of forest depletion is also accounted for the use of fuel wood. Table 9 shows the energy related resource depletion and environmental degradation along with the overall genuine savings as estimated by the World Bank for the different years. For 2005, these estimates, as proportion of Gross National Income have been found to be 4.831 % for energy depletion, 1.3 % for CO2 damage, 0.741 % for particulate damage, and 0.569 % for net forest depletion. Thus out of the 29.7% of Gross Domestic Savings, 9.19% is the share of consumption of fixed capital, while another 7.4% needs to be deducted to take account of energy related factors of environmental sustainability in the calculations of genuine savings and investment. The depletion of natural capital on account of energy would thus reduce the sustainable growth potential of the Indian economy. It may be further noted from Table 9 that the rate of adjustment of savings on account of the cannibalising impact of the total energy related depletion has grown over time from 6.53% in 1990 to

7.44% of Gross National Income in 2005, which has been a period of economic reforms and acceleration of pace of economic growth of the Indian economy.

7. Efficiency analysis of energy use and supply for sustainability.

The primary energy resource use in India has depended largely on the aggregate size of the economy, population and composition of energy resources as supplied by the extractive activities of these resources from the natural environment and by their net import from the rest of the world. The composition of fuel has been an important factor for the aggregate measure of energy use which ultimately determines the extent of the environmental stress as this measure in oil equivalent unit varies widely with the energy resources composition due to the widely varying efficiencies of conversion and final use.

The environmental effect of a macroeconomic growth process depends on the growth of volume of energy requirement to support the growth and the energy resource mix of the energy system. Apart from the fact that the environmental effect of the fuel cycle differs across the energy carriers, the efficiency of delivering energy services varies across fuels, end uses and its associated technologies. While the energy industry converts the primary energy resources into more efficient forms of final energy (like crude oil into oil products, coal, oil and other resources into electricity etc.), the non-energy producing sectors and the household sector make the final use of such converted energy in inputs for production or for consumption (See Chart1). It has to be remembered here that it is not only the effect of growth but also the inclusiveness of development requiring specifically the removal of energy poverty among others which would create the upward pressure on the scale of energy use and pollution. The challenge of sustainability is essentially to counter this upward pressure on scale by weakening the link between the growth and the energy use and that between the energy use and the pollution arising by improving energy efficiency on both the demand and the supply side of the energy industry. Sustainable energy planning for high growth is to build into the plan the maximum use of the potential of such efficiency improvement vis-à-vis the BAU policy scenario by new policy interventions.

8. Equity Issues : Economics of Energy Transition

While the concern for environmental sustainability focuses on the reducing of energy consumption and emissions, the challenge of inclusive growth requires energy efficiency to be combined with energy equity by removing energy poverty of the households. As inclusive high growth is based on the principle of “universalism” in the distribution of benefits of growth (Anad and Sen 2000). The energy planning and policy needs to address the issues of equity and empowerment of the socio-economically poor section of the population in the context of energy supply and use in the households of India. Tables 23-26 show how the people belonging to the rural areas, and poor states are being left behind in enjoying the higher quality of life by way of access to and affordability in terms of spending on the modern energy services as per the NSSO 61st round survey data. These cross section observations broadly correspond to the hypothesis of the upward movement along the energy ladder with development. Besides, Chart 9 based on World Bank 2002 as obtained from Barnes and Toman 2006, shows how poorer people have to spend higher proportion of their meagre income on energy in spite of suffering from energy poverty .

With the growth in income and greater availability of more efficient fossil fuel and electricity at lower unit cost of end use energy service, households make use of increasing share of cleaner and efficient fuels like LPG, electricity etc. leading to rise in their consumer’s surplus (Barnes and Toman 2006). Pachauri and Spreng (2004) has (replace ‘has’ by ‘have’) in fact estimated the energy efficiency of various fuels and appliances and worked out the price per unit of useful energy for biomass traditional fuels and commercial fuels for India. This shows how modern commercial fuels are cost-effective in the choice of meeting a given requirement of energy services in terms of lighting, cooking, space heating in appropriate unit, by the choice of device, fuel and associated pollution removal technology. The major problem for the poor is the first time cost of use of a cheaper fuel for obtaining connectivity and buying equipment, which causes the problem of access for them.

The use of cleaner fuels like LPG or electricity for cooking and lighting would again help the households to achieve better health and educational attainments and develop capabilities for higher income. The dynamic externalities of use of higher-grade fuel as one moves up along the energy ladder would thus in turn raise the household income and raise further the demand for cleaner and efficient energy forms. This would further raise both the consumer's surplus and the material level of well-being by expanding the options of use of various modern appliances reducing both monetary cost and time cost of energy collection and use. Contrary to the common belief, the percentage of energy used by the households would not decline with development but would rise in the initial phase of income rise when a household rises above the poverty line and move upwards along the income ladder.

9. Trend and Pattern of Energy Use in India

9(a) Primary Energy Resources

The institutional and structural changes brought about by the economic reforms of India are of substantive importance for the analysis of environmental sustainability of India's energy system. The total primary energy resource use increased at an annual average rate of 4.1% in the pre-reform period 71-90, and at the rate of 2.84% in the post reform period 1991-2005. The share of non-commercial combustible biomass traditional fuel has declined throughout this period from a high share of 61% in 1971 to 49% in 1990 and to 38% in 2003. (See Table 4 & 10, Chart 2) As more than one third of gross energy used has thus been obtained from biomass and bio- waste till recently without any conversion and out of which 90% in turn was used by the household as fuel for cooking and space heating, this dependence has had serious implication of the environmental stress both in the form of forest depletion and health cost of poorer households. It is to be noted that the absolute level of such fuel grew at the trend rate of 1.5% per annum over the period 1971-03. As the income poverty, as well as the lack of adequate supplies of modern energy services due to the deficiency of energy infrastructure have been the factors behind such dependence on inferior biomass fuel, the cross country comparative data given in the Table 1 indicate India's relative level of energy poverty in terms of quantity and quality.

With economic growth, the total commercial energy resource supply of India has grown at the trend rate of 5.8% in the pre –reform and 4.8% in the post reform period. This has implied a total GDP-elasticity of primary commercial energy use of 1.30 for the pre-reform and 0.78 for the post reform period as estimated using the yearly time series data for the concerned periods by the author using auto regressive conditional heteroskedasticity regression model giving GDP elasticity of primary and final energy. (See Table 4) The substantive drop of the GDP elasticity value below 1.00 indicates significant improvement of efficiency in the use of primary energy in the economy in the post reform period.

However, the share of the most polluting fuel ,i.e. coal in the total primary commercial energy supply has remained mostly in the range of 55-60% in the entire period 1971-2005. (See Table 11 and Chart 3). The share of primary oil (crude oil production + crude oil import + imported petroleum products) has remained also relatively stable during the same period, in spite of the volatility of the world oil prices. While the share of oil in the total primary commercial energy was 36.6% in 1971, it has been 34% in 2005 (Table 11). Finally, as a net importer of energy, the share of net import of energy in total primary commercial energy supplies has increased from around 17% in 1990 to 32% in 2005 in the post reform period to provide support to the accelerated growth (See Table 8). However, it is the share of primary gas which increased substantially from 0.931% in 1971 to 7.6% in 2005 because of supply side factors of discovery and increased supply from the newly found gas reserves throughout the period (See Table 11). The share of all fossil fuel together has remained around 95% in the entire 35-year period under reference. It is the failure in raising the share of hydro and nuclear power in the total electricity generation which has been responsible among others, for the environmental pressure of air pollution by this high dependence of India’s energy system on fossil fuels and contributing also to India’s problem of energy security. The non-conventional technology based energy supply has been until now able to make only a non-zero share of at the most 0.14% as attained in 2005.   It is a matter of far cry to expect any significant support from such non-conventional energy sources for the sustainability of high growth of the Indian economy in the near or medium term. (See Table 11 and Chart 5 for the growth of Primary and Final Commercial Energy and that of corresponding CO2 emission.)

9(b) Final Energy Use

As per the energy balance of 2005, a share of 82% of primary energy resources was converted into final energy in the forms of electricity and petroleum products and the balance 18% of the primary resource –mostly coal and natural gas had direct final use in various industries . The total delivery of final energy in oil equivalent unit through conversion has been around 37% of the total primary energy supply to the economy in 2005 (See Table 10). The loss in conversion, handling and transportation of energy has remained in the range of 29% to 37% in the entire period of 1971-2005. These losses are supposed to be more than compensated by the benefit of final energy supply for various end uses. The total supply of such final commercial energy services as provided to the non-energy sector grew at the annual rate of 4.7% during the pre-reform years and 3.4% during the post reform period. The total GDP elasticity of final energy has been estimated by this author to be 1.09 and 0.56 for the pre-reform and post reform periods using the time series data and ARCH model of regression (See Table 4). These drops in elasticity imply changes in any combination of the factors of sectoral structure, fuel composition and technology of the economy raising the level of energy efficiency.

9(b)(i) Electricity

Of the different forms of final energy, electricity has been the most important one from the point of view of the efficiency of use, convenience, cleanliness in use and the integrated cost of supply and use. The gross generation of electricity had increased at the trend rate of 8% per annum in the pre-reform and 5.7% in the post –reform period. (See Table 4) However a substantial part of gross electrical energy generated in India is lost in auxiliary consumption, transmission and distribution before reaching the final user. (See Table 14) The estimate of such loss has been 32% in 2005. The final consumption of electricity in the non-energy sector has in fact grown at the trend annual rate of 7.5% in the pre-reform period and 4.5% in the post reform period. The GDP –elasticity of the generation and the final use of electric energy has been respectively 1.00 and .75 in the post reform period. These represent a substantive drop from the elasticity values of 1.8 and 1.7 for the generation and the final use of electricity respectively during the period 1971-80. (See Table 4, See also Chart 4 for the growth of absolute level of supply of final electrical energy delivered to consumers of non-energy sector).

While electricity is a high quality clean fuel used widely across every segment of the economy and society , the power sector would cause pollution and involve substantial material and energy loss in the process of its generation. This would have implications in respect of environmental stress as per the principle of material balance between resource and waste flows between the power industry and the natural environment. It is therefore the supply side efficiency of the electricity sector which is of significant importance for environmental sustainability as distinct from the demand side efficiency of its use in the rest of the economy

9(b)(ii) Direct Use of Fossil Fuels

Among other fuels, the absolute level and share of final use of coal declined during the post reform period as its direct use for steam and heat was replaced by oil, gas and electricity. The share of coal in final energy use in fact declined from 51.6% in 1971 to 34.7% in 1990 and 19.0% in 2005. The share of final use of oil and gas, on the other hand, increased substantially from the respective figures of 38.4% and 0.59% in 1971 to 53.4% and 7.01% in 2005. (See Tables 12, Chart 4). Table 15 shows the distribution of each commercial primary fossil fuel between the direct use and electricity generation.

10. Sectoral Analysis

The total final energy use of an economy is driven fundamentally by the individual producing sectors- agriculture, industry and services including transport and the household sector. However, for the purpose of energy analysis, the transport sector including the share of private transport owned and operated by the household as part of its consumption activity, is considered separately from the services because of its significant share in the total energy use in the economy.

10(a) Sectoral Distribution of Fuel Use

As the environmental sustainability of the energy system depends on the fuel choice and the energy usage per unit of sectoral activity of production or consumption, it is important to analyse the sectoral distribution of energy use, the sectoral fuel composition of final use, along with the sectoral structure of the economy itself. Tables 17 & 18 provide these data regarding the fuel-wise sectoral distribution of final energy consumption and sector-wise fuel composition for the years 1971, 1990 and 2005. The industry had the largest share of 52.1% in final energy consumption in 2005, followed by transport 18.6%, residential sector 16.7% , agriculture 7.2% , and commercial and public services 5.5 % in 2005. The charts 7 & 8 show the sectoral distribution of the total final commercial energy supply and that of the total primary direct and indirect use (through power) of energy including the share of traditional fuels.

10(b) Sectorwise Fuel composition

The fuel composition of the energy use varies widely across the different sectors. The efficiency of use of fuels and the functions performed by them in the different sectors being different due to the specificities of technology and appliances, the share of final use of a given fuel in oil equivalent unit does not indicate the relative significance of a fuel in terms of useful energy service provided or work done. Nevertheless, since the environmental pressure created by a fuel depends ultimately on the gross energy used in the process in oil equivalent unit, the fuel composition as per oil equivalent unit is also of some significance for the environmental and industrial policies. The share of oil in the total final energy at the economy level is the largest being 53%, followed by electricity 21% and coal 19% . (See Table 18).

Coming to the individual sectors, for the transport, oil itself has the share of 96% of its total requirement , electricity and natural gas having also small shares of 2.4% and 1.8% respectively although having the potential of larger shares in future under an appropriate policy regime. The energy requirement for the agricultural sector being mainly for irrigation and land preparation, electricity has been the dominant fuel having a share of 58% in its fuel composition, oil meeting the balance 42% of the sectoral final energy need. The commercial and public services mainly use electricity for energy whose share in the composition has come down recently to 50.4% in 2005 and depends on the direct use of coal to meet the balance of its requirement as per the IEA data. The reporting of the data in the Energy Balances for India in the IEA publications of recent years require further scrutiny regarding the reason for the absence of oil consumption for this service sector and for all of its direct fossil fuel use being shown against coal. This goes against the expected notion of lower carbon intensity of direct energy use by service sector. If the reported data are correct, this changing pattern of fuel composition of this sector raises concern for the implied rising carbon intensity of energy use by it, particularly in view of the high share of services in the GDP of the Indian economy (See Table 18).

Finally , the residential sector depends mainly on the traditional fuel for 79% of its total energy requirement, while of the balance 21% as supplied by the commercial energy, 13% has been the share of oil and only 6% that of electricity. (See Table 18, which gives the shares of fuels in the final commercial energy consumed by the sector).

10(c) Direct and Indirect Sectoral Use of Primary Energy Resources

While electricity is a clean fuel, its generation involves emission of air pollutants and solid waste. The sectoral fuel composition of final energy indicates how a given sector has access to cleaner and more efficient fuels like natural gas or electricity. However, any use of electricity by a consuming sector would cause generation of pollution in the electricity plants and their neighbourhood. The higher efficiency of electricity to do a given work compared to that of the primary fuels in their direct use would imply both the integrated energy use of the final consumer sector including the share of the power and the associated integrated pollution load to be lower for the substitution of the direct use of other fuels by electricity. Besides, the direct use of energy through electricity would also localise a large part of pollution to the power generating stations compared to widely dispersed arising of pollution reducing possibly both the number of people exposed to pollution at the places of energy production and energy use . However, this geographic redistribution of pollution load would lead to the emergence of more of large point sources of pollution with higher ambient concentration. Besides, the global and regional externalities of energy use like the effects of global warming or acid rain are often the same irrespective of how geographically pollution is distributed.

For all the primary energy resources the use of which is ultimately responsible for the energy related pollution, each sector would directly and indirectly account for the pollution arising as per the usage of electricity and the fuel composition of power generation. It is in fact important to ascertain both the total of direct and indirect use of a given primary fuel resource across sectors as well as the composition of the total direct and indirect primary energy resource use by a sector for the purpose of policies for energy related environmental control. The sectorwise share of the indirect use of energy through power in its total direct and indirect use of energy as well as the sectoral distribution of the latter for the aggregate economy are shown in Table 19. It is the energy intensity of such total direct and indirect energy use including the share of power which would be relevant for the macro level analysis of the dynamics of energy efficiency and energy sustainability of India.

11. Specific Sectoral Issues

11(a) Electricity

In the sectoral balance of primary energy the pattern of its direct usage by the non energy sectors would reflect the demand side efficiency while their use by the electricity or oil refinery would indicate the supply side efficiency. The overall primary energy intensity of the economy which is indicative of the strength of linkage between energy and growth is thus determined by the efficiency of energy on both the demand and supply side of the economy. The Tables 10 and 14 and Chart5 show the ratio of final energy to commercial energy over time in the aggregate economy and the shares of losses due to total conversion, own consumption and T&D losses in the total primary energy used in the power sector. The major share of the losses and the costs involved in the energy system in the process of conversion, transport and delivery of energy has been due to the electricity sector.

However, it is also to be remembered here that decline in the ratio of final energy to primary energy also indicates conversion of greater share of primary energy into the forms of electricity and substitution of direct use of primary energy by electricity and substitution of non-commercial energy by commercial energy. However, both these substitutions contribute to the higher efficiency of final energy use depending on the technology and device of energy use in the end use sector. This warrants that the sustainability analysis needs to be an integrated one of energy supply and use combined with the choices of technology, devices, pollution removal process to minimise the integrated social cost of meeting the needs or demand of the ultimate need of energy services, rather than fuels, for supporting a high or low growth.

Of the total primary energy use in electricity generation, it is in fact a share 68.6% that was lost in the conversion process of gross generation in 2005. The own power consumption of the electricity plants accounted for a further loss of 6.9% of gross electricity generated and the transmission and distribution accounted for a loss of 24.8% of electrical energy despatched at busbar in 2005. All these imply as high a total loss as of 78.5% of primary energy resource before it is actually reaching the consumer (See Chart 6). This flags the importance of the role of electricity in the energy sustainability of an economy. While the fuel composition of the final energy of a non-energy sector is indicative of the cleanliness of energy use, the fuel composition of the electricity sector is a crucial determinant of the cleanliness and carbon dependence in the supply side of the energy system of India.

However, the share of coal-the most polluting fuel in electricity generation has increased over time from 49% in 1971 to 66% in 1990 and 69% in 2005. While the share of oil in power generation has marginally declined, that of gas has increased from 0.57% in 1971 to 3.47% in 1990 and 8.94% in 2005 (See Table 13). Among the carbon free primary resources, while the share of nuclear resource increased marginally during 1971-2005 from 1.8% to 2.5%, that of hydro declined substantially from 42.22% in 1971 to 24.7% in 1990 and 14.31% in 2005 (See Table 13). The Table 16 on the other hand shows the primary fuel composition as an input in the aggregate power generation. The share of hydro resources declined because of the long gestation and high capital cost on the one hand and the big social and political resistance to such project due to environmental problems arising from the dislocation of human settlements and serious biodiversity loss for the submergence of the dam area. In view of the global politics of nuclear energy and historically India's non-participation in the nuclear non-proliferation treaty agreement has stood in the way of obtaining any collaboration in nuclear power project. The entire indigenous development of this technology in power generation, the financial resource limitation of the Indian state as well as the poor quality of uranium resources have constrained the pace of expansion of nuclear energy. The fuel mix of generation of electric power in India has thus been largely supply driven. The abundance of coal reserves, though of inferior quality, and the accretion of gas reserves over the 35-year period has made the power generation growingly dependent on these two resources. The electricity has had a share of 75.5 of all supplies of coal, 44.5 of gas and 6.4% of oil of total primary supplies.

11(b) Transport Sector

Transport service is a basic infrastructural service which is a universal necessity and it requires energy as the prime driver for any mode of transport –

railway, roadway, airways and waterways. It is worth noting a few points of concern relating to the pattern of growth of India's transport sector and its energy use. The GDP elasticities of the freight and the passenger traffic were estimated by the Expert Committee on the Integrated Energy Policy of the Planning Commission (Planning Commission 2006a) to be 1.0 and 0.8 respectively implying the requirement of high growth of freight and passenger traffic service with high GDP growth. The challenge of environmental sustainability of the growing transport sector has been due to the non-substitutability of oil in road transport and the growing share of road traffic in the total traffic in India. The fuel efficiency of rail traffic service is substantially higher for both passenger and freight traffic. In a case study of comparative modal efficiency between the road and the rail for selected railway sections and the competing highway sections for intercity transport of freight and passenger, the present author estimated the energy saving to be 89% for every tonne km. freight traffic for rail with electric traction in plain terrain(New Delhi-Mughalsarai section) and 83% for rail with diesel traction in similar terrain (Lucknow-Gorakhpur section) (Sengupta 2001). For the passenger traffic in passenger km, the extent of similar savings is 33% for electric traction and 41% for diesel traction in the same rail-road sections. However, while the per capita passenger transport service and freight traffic intensity of GDP have substantively increased over time , unfortunately the share of the relatively unsustainable mode of road transport increased in passenger traffic from 64% in 1971-72 to 87% in 2006-07 and that in freight traffic increased from 31% in 1971-72 to 62% in 2006-07. This has caused serious pressure on oil demand resulting in both the problem of energy security and environmental pollution.

Urban transport, on the other hand, is the single largest source of urban air pollution in India causing substantive health damage from the emissions of CO, HC, NOX and PM10 , the latter having the most damaging effect in value terms . With high economic growth, industrialisation, urbanisation and motorisation of the economy, some cities in India are experiencing explosive growth in private automobile ownership resulting in rise in the share of the private transport in the total urban passenger traffic. The oil usage and road space requirement per passenger km being lower for public transport because of the higher passenger-loading factor, the substitution of the private transport by public transport can substantively reduce the pressure on oil consumption and emissions. The recent growth of India's middle class due to rising urban income and educational opportunities and decision of the government to expand the highways would tend to push the road passenger traffic and the share of private transport to be higher implying higher environmental pressure and higher health cost due to automotive pollution. Sengupta and Mandal 2005 estimated the saving of health cost for 35 urban agglomerations to be substantive for the up-gradation of the quality of motor gasoline and HSD undertaking appropriate investment for refinery up-gradation. The study used the health cost parameters from the study of Delucchi for US cities (Delucchi 2000 and Delucchi et al 1999) with appropriate adjustments for population density, income and purchasing power parity for the Indian condition. Since automotive pollution is the single largest source of urban air pollution, the findings of Murty and Gulati 2004 which estimated the benefit of reduced air pollution in terms of willingness to pay, using a generalised method of hedonic property prices as well as hedonic travel cost, are also significant for being noted in this context. All such studies have warranted the raising of the share of the railway in particularly the freight traffic, the share of public transport in urban traffic, the quality of fuel and the standards of vehicular emissions for the environmental sustainability of transport development.

12. Delinking Economic Growth and Growth of Energy Consumption.

The empirical theory of the Environmental Kuznet's Curve (Sander et al 1999) expects that with growth in per capita income, the energy intensity of production and the pollution intensity of energy will increase initially and decline beyond a stage of development. It is expected that in the initial phase of industrialisation and development of infrastructure, the sectoral share of GDP will change in favour of the industries with higher energy and pollution intensity. However, the sectoral share of the service sector which is less energy and pollution intensive increases at the expense of the industrial sector beyond a threshold of development in terms of per capita income. This can be explained in terms of changes in the pattern of demand for goods and services as indicated by the behaviour of their income elasticities. Again, with the rise in per capita income, the preference of the people for environmental services vis-a –vis other goods and services rises and gets reflected in the higher environmental standards of the economy which would induce reduction in the pollution intensity of energy and the products . The financial affordability of the people to invest for the development of cleaner fuels and technology and in R& D also rises with the rise in the rate of savings at higher per capita income. The costs of new technology also decline due to the higher R&D efforts in terms of investment and its rate of success at such stage of development. However, the level of per capita income or the stage of the development in terms of such maturity at which the downturn in energy or pollution intensity curve is anticipated to take place varies from economy to economy dependant on the government policies and institutions. We digress to a decomposition analysis of the overall energy and pollution intensity of GDP of the Indian economy to analyse the respective roles of structural change and technological progress in the link between growth and energy related environmental pressure.

13. Decomposition Analysis of Energy Use and Emissions.

13(a). Decomposition of Energy Use

As the environmental pressure created by energy depends on the absolute amounts of energy used and the pollution load generated , a common method of sustainability analysis of macroeconomic growth has been that of decomposition of such absolute totals by their drivers using the following identity (Ang 1999).The total energy (E) and any pollutant emissions like CO2 at the aggregate economy level can be decomposed as the product of population (P), per capita GDP (y), energy intensity (e), and CO2 or any other pollution intensity of energy (a)

E =P*y*e

CO2=E*c

Again, *e* and *c* can be decomposed as follows:

$e = \sum_i e_i y_i$, where e_i and y_i are energy intensity and sectoral share in GDP of sector i.

$c = \sum_j f_j c_j$, where c_j and f_j are carbon intensity of energy and share of fuel j in energy at aggregate economy level.

$c = \sum_i e_i (\sum_j f_{ji} c_j) y_i$, where f_{ji} is the share of fuel *j* in a unit of energy used by sector *i*. or equivalently

$c = \sum_j c_j (\sum_i f_{ji} e_i y_i)$.

In continuous time, the rate of growth of CO2 will thus be the sum of the rates of growth of population, per capita GDP , energy intensity and CO2 intensity of energy. While the growth of population and y together provide the effects of change of scale of the economy on the energy and the environmental pollution, the change in energy intensity of GDP is driven by the structural effect due to the change in the sectoral composition of GDP as well as that of technological change represented by the changes in sectoral energy intensities.

As pollution is a by -product of output or GDP at macro level, depending mainly on the fuel and the associated technology used, one can similarly decompose the effects of change of carbon intensity of energy into the fuel composition effect and the carbon or pollution intensity effect of the individual fuels. The carbon intensity of a given fuel (though largely stable) may change because of the change in its internal quality composition, or due to the statistical errors in the compilation of data. Thus while the change in the aggregate energy intensity is the effect of structural change of the economy and that of energy conserving technical change, the overall carbon intensity of energy is mainly the effect of fuel composition and fuel quality. We may refer to the following identities for such decomposition of energy intensity and CO2 intensity.

However, as the energy intensity of a sector depends on the fuel composition itself along with technology and the carbon intensities of individual fuels are supposed to be stable over time unless the quality of the fuels changes significantly, it is worth focussing on the decomposition of the changes of the energy intensity for the aggregate primary and final energy forms into the structural effect and the technological effect and estimation of the changes in the carbon intensity of energy due to fuel composition .

In the development process of India, the primary energy intensity of GDP had increased by 20.2% over a 19-year pre-reform period, while it declined by 28.8% over the 15 year post reform period. (These are implicit in the data as per the results of the Divisia Method of Decomposition Analysis (Ang 1999), the structural change pushed up the primary energy intensity as implicit in Table 20 at an annual rate of 0.8% and the energy intensity had increased only at the annual rate of 0.18% during the pre reform period. In the post reform period, the structural adjustment caused little change in energy intensity contributing only an annual increase of 0.04% per annum on this account. On the other hand, the technological changes brought about by the increased industrial competitiveness and the inflow of foreign investment and technology due to liberalisation contributed to the decline of energy intensity at the rate of 2.3% per annum as implicit in Table 20.

In this decomposition analysis the primary energy intensity of a given end use sector was based on the direct use and the share of indirect use of primary energy resources through its power consumption, electricity having 55% share of the total primary energy use in the economy. The results of the decomposition analysis of the total primary and the fuel wise final energy use by the non- energy sector of an economy, on the other hand, as presented in Table 20 and 21, show quite clearly that the structural changes effect contributed to the rise of the final energy intensity of GDP in both the pre-reform and the post-reform period, except for electricity. However, the upward structural effect has been moderated in the post-reform period. In the case of electricity, the structural effect reduced the electrical energy intensity of GDP. The technological effect of fuel substitution and energy conservation on the other hand, contributed to the reduction of the energy intensity for the direct use of coal, oil and total final energy, while the similar contribution of electricity has been moderate comparatively. In the pre-reform period, the technological effect had raised the electricity intensity of the over all GDP substantively simply because electricity was penetrating the economy and replacing coal and oil in many areas of production during this period. The moderate decline of the electrical energy intensity due to the technological adjustment effect in the post reform period also reflects the fuel substitution of other forms of energy by electricity and the extension of the area of use of energy service by electricity as a continuing process although the greater marketisation and integration with the global markets induced material and energy efficiency for cost competitiveness.

13(b). Decomposition of Pollution Intensity of Energy

The changes in the overall intensity of any pollutant due to primarily changes in fuel composition have been of much smaller order as compared to the variation in energy intensity. The CO2 intensity of primary energy in power sector, for example, increased substantially during the pre-reform period while the same effect of rise was much more moderate during the post reform period.(See Table 22).For the aggregate economy, there has been little change in the over all CO2 intensity of energy during the entire period 1970 to 2005 although the total effect of CO2 intensity was on the rise in the CO2 in the pre-reform period because of the substantial substitution of the non-commercial energy by the commercial energy and particularly the penetration of electricity into the economy.

14. Energy – Environment – Economy Modelling

There has been substantive work done on the analysis of sustainability of the environment –energy-economy interaction in the Indian context. Such work based on mathematical modelling of sustainable choice for energy use in the dynamic context of a growing developing economy has been mostly application of modelling framework developed for assessing the environmental and economic impact of economic growth and mitigation of greenhouse gas emissions in the context of climate change. The dynamic multisectoral global models of resource allocation developed for the purpose of simulating different scenarios for the alternative energy policy interventions for environmental control, were adapted for country level energy policy analysis for India for the attainability of environmental sustainability. There have been two classes of such models for country level application as for India –the top down and the bottom up model (Garg et al 2001). The top down models are essentially computible dynamic general equilibrium models based on market optimism of rational allocation of resources, generating a reference energy-emission scenario following the Business As Usual path and then examining alternative policy interventions for greater efficiency on the demand and the supply side of energy markets for reducing the burden of environmental stress relative to growth. Such top down models those of second generation models (Edmonds et al 1993, Crassous et al 2006) assume that the energy and other prices would drive the substitution of one fuel with the others and that between energy and capital leading to the optimal choice of devices and processes through efficient functioning of the market. This has warranted such level of aggregation of sectors, goods and processes that the models do not enter into the details of choice of end use devices to meet the demand for the energy service for any end use sector.

The bottom up models on the other hand like Markal or AIM / END USE models (Fishbone et al 1981, Kainuma et al 2003) on the other hand focus on the optimisation of the energy flow from the extraction of energy resource to the final use of energy service including the conversion and the transportation of energy at the different stages of its transformation till the disposal of the residual waste and pollution abatement removal process with a view to minimise the total discounted cost of meeting the demand of each type of energy service for the different sectors.

While the top down models endogenise the feedback effects of the energy and the macroeconomic sectors on each other to generate the long run scenarios , the bottom up models are demand driven where the macro economic factors like economic growth, population, structural change , trade pattern and institutional factors, and government policies are exogenously given for the simulation of each policy scenario. However, the Markal model formulation as widely used does not enter into the details of choices of end use device and technology processes for a given end use sector while optimising the energy flow in the reference energy –economy system. The AIM/ END USE type model on the other hand is based on technological optimism as it presumes the existence of an efficiency gap in a market driven techno-economic system and enters into the details of choices for any given end use sector from among the alternative types of fuel use , devices, and technologies including those of associated pollution abatement. These models are essentially developed in a partial equilibrium framework and do not consider the feedback effects of choices of fuel-mix and energy use on the macroeconomy through their impact on costs and prices. This class of energy-environment-economy models formulated at country level initially focussed on the pollutions having global externalities only. However, these models have been used later to examine the impact of alternative macroeconomic growth and policy scenarios for local emissions too.

15. Application of Models for the Future Energy Scenarios of India

There have been several applications of the Markal and the AIM/End Use model framework separately or in an integrated way within soft link between them to examine the future GHG and local emissions for the alternative growth and the CO2 and SO2 emission mitigation scenarios (Garg et al 2001, Pandey et al. 2003). AIM/End Use Model also has been extensively used to examine the spatial distribution of pollution arising between the large point sources and the area sources

(Kapshe et al 2003). As per such studies, as 60% of CO2 and SO2 emissions would arise from the industrial and urban centres, power plants which have become hot spots of pollution due to unbalanced regional development induced by the acceleration of growth of the Indian economy and uneven geographic distribution of energy resources. On the other hand, Garg, et al 2003b also generated the projections of methane and NO2 emissions arising mostly from the activities relating to agriculture and livestock which are widely dispersed spatially for a reference and alternative mitigation scenarios to evaluate them for policy purpose. The Markal model along with the AIM/End Use model as soft linked has also been used to assess the mitigation potential of renewable energy technologies for the Indian power sector (Ghosh et al 2002) and to explain the extent of co-benefits of CO2 and SO2 mitigation policies in India (Pandey and Shukla 2003).

There have also been applications of a dynamic recursive general equilibrium models like IMACLIM-R in Indian context to examine the global and local environmental effects of high growth and of alternative emission abatement policies taking account of their macroeconomic feedback in equilibrium. Shalizi (2007) uses the result of such model to examine the feasibility and optimality of the extent of decoupling the link between growth of GDP and energy and that between growth of energy and emission in the context of high growth of India and China taking into account the feedback effects on the macro economy.

16. The Projections of Energy Requirement by the Expert Committee on Integrated Energy Policy of the Planning Commission

The long term projections of energy requirement of an economy is based on a complex set of factors comprising the future rate of growth of GDP, change in sectoral structure of the economy, population growth, growth of urbanisation and transport infrastructure, the pace of replacement of non commercial energy by commercial energy, the pace of energy conservation through improved efficiency and the change in fuel mix. The Expert Committee of the Planning Commission on the Integrated Energy Policy (Planning Commission 2006a) has provided the projection of the total energy requirement for an inclusive growth of the Indian economy at the GDP growth rate of both 8% and 9%, assuming some normative GDP elasticity of the total primary commercial energy requirements which is alternatively taken to be constant and falling over time. As per the falling elasticities, the report has indicated a consistent set of projections of the total gross electricity generation and capacity requirements, fuel/technology wise generation mix, energy resource needs for power , direct non-power requirement of coal, oil and natural gas, household’s requirement of biomass fuels and finally arrive at the projections of requirements of total primary energy resources, total primary commercial energy resources and non-commercial energy resources with fuel wise break-up. A summary version of these projections with mostly 9% GDP growth and falling aggregate GDP elasticities of total primary commercial energy resources and that of electricity are given in Tables 27-29 which are of environmental significance (See also Charts 10 – 12). While interpreting the numbers, one has to remember that the fuel mix for power generation underlying the projections of Table 28-30 is based on one possible scenario which is consistent with meeting the peak load and energy requirement of electricity for 9% GDP growth. The choice of fuel mix for electricity generation (Table 29) is not to be interpreted as the preferred scenario of the Expert Committee or the Planning Commission as it is not a least social cost dynamic model based solution for the choice of fuel and technology mix. These projections imply the comparative shares of the individual fuels and their change from the base year data as indicated in Table 27-29 and Charts 10 -12.

As per the projection of energy requirement by the Expert Committee, the fossil fuel, and particularly coal, will remain the dominant primary energy resource for India over the time horizon upto 2031-32. The share of coal declines from 54.9% in 2005 to 50.4% which is not at all a major fuel switch over more than 25 year horizon. The fossil fuel share is shown at almost 95% of the total primary commercial energy in 2031-32. However the share of traditional biomass energy resources is projected to go down to 9.1% from the present approximate share of 30%. While the share of hydro in the total primary commercial energy resource as well as in electricity generation would go down over time , the shares of nuclear and natural gas are required to grow respectively from 1.2% and 7.6% to 5.3% and 12.9% of the total supply of primary commercial energy resources over the planning horizon up to 2031-32. Their respective shares in electricity generation would also have also to move correspondingly. This implies the possibility of no significant delinking between the growth of GDP and that of energy, and the rigidity of fuel mix not permitting significant decarbonisation. The committee in fact used the results of a multiperiod, multisector linear programming model of cost optimisation to simulate alternative energy supply scenarios given the potential availability of energy resources and of the spectrum of technologies over the planning horizon up to 2031-32. As electricity uses more than fifty percent of the primary commercial energy resources and offers substantive scope of fuel substitution, and also as the transport sector is the dominant consumer of oil and a major source of urban pollution, the model was used to solve for the least cost fuel and technology choice for a number of alternative policy options. These options are designed to reduce the adverse environmental externalities in alternative ways while meeting the given requirements of energy services in the different sectors of the economy and keeping in view such sector specific issues. These scenarios were designed to generate the extreme points of feasible solutions of supply and use of various energy resources (Planning Commission 2006a).

If there is no other compulsion and no costs of externalities are considered , the coal based development of the energy sector was found to be the least cost option for supporting the targeted growth as per the results. However, the concern for weakening the link between the growth of GDP and the energy use and that between the energy use and the pollution arising induced the consideration of the options of forcing full development of hydro, maximisation of use of nuclear potential, the use of gas to generate 16% of electrical energy (where natural gas is supplemented by coal bed methane and in –situ coal gasification), demand side management to reduce electricity demand by 15% , the attainment of higher conversion efficiency of thermal power generation to 38-40% from the pre-existing level of 36% for 500 MWE plants, rise of railways’ share in freight traffic from 32% to 50%, increase of fuel efficiency of motor vehicles by 50%, and forced utilisation of the renewable potentials to the extent of 3000 MW of 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. The extreme points were generated by certain combinations of these options in policy space and given in the report. It is one of the extreme point solution which forces the maximum use of the nuclear potential, the entire domestic hydro potential of 1,50,000MW and the use of gas for 16% of gross power generation (i.e., maximum use of the potential of conventional commercial carbon free and gas resources) which generated the solution and provides the basis of energy requirement calculation in the long run as mainly highlighted in the report. There has also been an extreme point solution which is based on the consideration of all the policy options together to make a maximum use of all the potential of clean energy resources in power generation including renewables and that of the potential of demand side management, including that of the transport sector. Table 30 provides the comparative solution of the three scenarios of coal based development, maximisation of potential conventional clean resources and the most environmentally clean policy option although for 8% rate of growth (See Chart 13). However, as neither the full social cost of supply has been considered to internalise the costs of environmental externalities nor the issues of energy poverty and energy security have any weight in the formulation of the model and generation of scenarios, as described in the report , they cannot be characterised as the social welfare maximising solution. However, they all provide good basis for evaluation of alternative policies for environmental control.

It is important to notice that the dependence of India on coal in 2031-32 will remain 51% in electricity generation and have a share of over 41% in the total primary energy mix even as per the best environmental scenario among the options , as indicated in Table 30. The gas resource is to be used only for peaking power even when it is forced as an option. The capacity utilisation of hydro power is found to be low because of the low availability of water resources. However, the total energy need as per the best option economises the requirement of the total primary energy resources by 21%, demand for primary commercial energy by 19% and that of coal and oil by 38% and 28% respectively in 2031-32 vis-à-vis the coal dominant option. The CO2 emission is correspondingly expected to go down by 35% in the terminal year. The CO2 emission is projected to grow from the current level of 1 billion tonne per year to 5.5 billion tonne as per the high coal development scenario and 3.9 billion tonne as per the most environmentally conserving scenario. Even with all these energy sector developments, India’s per capita carbon emission would be in the range of 2.6 to 3.6 tonnes of CO2 while the same for the US and the World on the average has been 20 tonnes and 4.5 tonnes respectively in 2004.

Among the various policy options for environmental sustainability, various studies have shown that the demand side management for efficiency improvements are economically the most attractive option (Garg et al 2003a). The fuel switching for the changes of energy mix pose greater challenges. The hydropower development would require the resolution of problems relating to water rights, resettlement and rehabilitation of the people affected by the project and environmental degradation of the kind discussed in an earlier section. Similarly nuclear energy maximisation requiring thorium requires the success of materialisation of import like LWRs as the plutonium recovered from the process can be used in the fast breeder reactor along with the plutonium of PHWR reactors using indigenous uranium. This success depends on the removal of the political constraint of sanction on India by the Nuclear Suppliers’ Group for the supply of uranium and nuclear power plant. The competitiveness of gas for justifying 16% share depends again on the price of gas being less than U$ 2.27 per MMBtu (i.e. equivalent to $ 45 per tonne of competing imported coal). The high cost option of the non-conventional renewables would not provide more than 5.6% of the total primary energy requirement even with the maximum mobilisation of these resources with an appropriate policy support. This is of course in tune with the worldwide projections of the share. For any gap in meeting any of these challenges posed by resource switching, the shortfall of the consequent energy supply will have to be met by coal for ensuring the high growth. (Planning Commission 2006a)

17. Future Projection of the Energy Requirement of the Household sector

So far as the household sector is concerned the Expert Committee of the Planning Commission projected the requirements of the sectors with fuel-wise break up – commercial and noncommercial- for the growing household expenditure in the future upto 2031-32 horizon. It made these projections using the proportion of spending on the total energy and the individual fuels as obtained from the data of the NSS 55th round of 1999-2000 (NSSO 2001) and assuming a log normal distribution of monthly consumption expenditure for the rural and the urban sector which would be consistent with the mean household expenditure for 8% and 9% GDP growth rate and the targets of reduction of poverty and of the rural- urban gap. In view of the independent target of providing electricity to all by 2009-10, as a part of inclusive growth, the impact of the Rajeev Gandhi Viduytikaran Yojana (RGGVY) for the purpose was taken into account in demand assessment for the years beyond 2010, by using the energy consumption pattern of only those households which had connectivity with electric power in the NSSO 55th round sample, for all in the respective income classes. The projection presumes that the released kerosene for lighting due to electrification of homes will be used for cooking by the household in order to climb upwards along the energy ladder. Table 31 shows the projected demand for energy items by the households assuming the provision of electricity to all by 2009-10.

Table 31 clearly shows a decline in the share of biomass fuel source to decline from 81.24 % in 2000 to estimated figures of 61.64% in 2011-12, 52.07% in 2021-22 and 47.7% in 2031-32. What is thus important to notice is that the relatively lower income-earning households will have to depend in a significant way on biomass for their energy need in spite of 9% growth and thrust on inclusiveness. This implies that the energy poverty cannot be fully removed even over the time horizon 2031-32 and there will be considerable continued pressure on Indian forests since the absolute quantity of fuel wood required is projected to increase at the annual rate of 0.8% per annum.

In order to reduce the degradation of forests due to the growth of absolute requirement of biomass for the households , and to protect the health of women and children, special policy initiatives are required for the further improvement of the cooking appliances including *chullahs*, solar cooker, pressure cooker, etc and biomass based modern energy development for higher efficiency of fuel use and abatement of pollution. There is also the requirement of further commercialization and market development for fuel wood subject to the environmental regulation in order to reduce the collection time. Even on the basis of such optimistic scenario of growth and electrification, the climbing along the energy ladder for a majority of rural population would be slow in India. As a result a more proactive policy thrust than the BAU trend in policies is imperative to ensure that electricity can meet the lighting need and the adverse externalities and user’s cost of biomass fuel are at least further reduced than what the projections of the Expert Committee would imply.

18. Energy Transition and the Role of Decentralised Development of New Energy Technologies

In this context of removal of energy poverty in rural India, one may also consider an alternative strategy of decentralised energy development which combines the attack on income poverty and low quality of life of the rural people with the development of energy supply like biogas plants which produce power and slurry for fertilizers together . Any decentralized development of energy like biogas based power can in fact empower the local people by providing access to electricity which can augment the water supply for irrigation as well as for the household, and at the same time supply organic fertiliser for agriculture (Reddy et al 1991b for Case analysis of Pura Village triumphing over the tragedy of commons). Besides, the decentralized power development can reduce the overall T&D loss and T&D investment. Such decentralized energy and power development using non conventional resources is of very high order of significance in the villages – particularly those located in remote areas for removing the energy poverty and the income poverty at the same time.

One may refer here to the Development Focussed –End Use oriented Service Directed (DEFENDUS, Reddy et al 1991a) paradigm of energy planning which focuses on combining the objectives of removing income poverty with that of energy poverty by appropriate combination of the improvement of demand side efficiency and the choice of such supply side options, particularly the ones like biogas plant which can generate important dynamic externalities of an income and employment generation in the local rural economy through its livestock-biomass-power-water linkages. Some policy support may however be required for such decentralised energy development in order to internalise these dynamic externalities.

19. Energy Security and Macro Economic Feedback of the Energy development

There are a few other concerns relating to energy security and feedback of the energy sector development on the macro economy that deserve mention here. As India's oil reserve accretion has slowed down and the crude oil production has stagnated, the demand supply gap has already been widening for oil over the last decade. For high growth at 8%, India will have to import in the range of 315 to 451 million tonnes of oil which would be in the range of 90-93% of oil requirement in 2031-32 as per the Expert Committee Report (Planning Commission 2006a). In view of the low quality of coal and rigidities in mining capacity expansion for various environmental and technological difficulties arising from the location and geological complexity of the resource deposits, there is likely to be an import dependence ranging from 11 to 45% of its requirement in 2031-32 for the various policy options considered for the energy sector development as mentioned.

Will the high dependence on the import of oil affect the economic sustainability of 8-9% of GDP growth of India in the longrun time frame particularly in view of the sustained global oil price increase since 2002? It is a fact that the recent growth of the incremental global energy use in China and India accounts for a substantial part of (40% to 50%) of incremental global energy use, but their level of oil use still accounts for only 9-12% of global oil use. The growth of the aggregate oil use has not been too dramatic in these years because the increased energy use of China and India has been partly offset by the deceleration in the use of oil in the traditionally oil dependent industrialised countries (Shalizi 2007). The steady sustained rise in oil prices is explained by the net growth of demand as combined with the inelasticity of global supply due to the declining spare capacity of the OPEC production, geopolitical uncertainties associated with the supplies from Iraq, Nigeria, and Venezuela and the under-investment all along the supply chain including refinery etc. However, it is also to be noted that the recent hike in oil price has not affected the growth of either India or China, as the energy sector and the energy cost constitute a small fraction, although critical, of the aggregate economy and of the value of the gross national output respectively. Since energy is a complementary input with capital and material, what matters about GDP growth is the elasticity of availability in response to demand in the global market rather than the price unless it is a case of spike of oil price, resulting in a sharp rise in the ratio of energy cost to the value of output. It is therefore more a challenge of energy security that such high growth of oil price poses for India. This requires the adoption of appropriate strategies for the enhancement of exploration activities in hydrocarbons within the country and for equity investment in oil abroad through joint venture.

So far as coal is concerned , the failure to improve the efficiency of coal thermal plants , DSM and carbon free technology may substantially raise the import dependence for coal raising the share of India’s import in the world trade of coal to as high as 75%. This may have serious effect on international coal prices (Planning Commission 2006a).

However, the various policy options for environmental sustainability of India’s high growth would not only result in higher total long run energy cost of growth, but would also require higher investment. The energy policy document projects a requirement of Rs.60 trillion for the electricity sub-sector, and Rs100-110 trillion for the entire energy sector in 2005 prices over the time horizon upto 2031-32 (Planning Commission 2006a). It is however possible to finance such capital investment over the time horizon with appropriate private –public partnership in a situation of high economic growth which should by itself be able to generate sufficient savings and financial resources. However, this requires that the energy prices are rationalised and energy market reforms create conditions which provide adequate incentive for investors to invest in energy conserving and energy supplying technologies in a competitive environment while at the same time protect the interest of the consumers –particularly the households of this basic necessity.

There still remains one macro level concern regarding the feedback effect of the growth of energy sector on the macro economy. Of the different policy options for reducing environmental stress, the cheapest ones in terms of cost and capital intensity have been found in several studies to be the measures of demand side efficiency in energy use followed by the supply side efficiency improvement and the up-gradation of electricity transmission and distribution in the order of marginal cost per unit of energy capacity saved or conserved and per unit of carbon emission mitigated for the same GDP growth profile. The introduction of renewable technology or fuel switching from coal to renewables or to gas obtained from in- situ gasification etc. would be the highest cost option. The potentials in terms of quantum of mitigation of emission are also higher for the reduction of carbon or other types of pollution intensity of energy for the cheaper options (Garg et al 2003a). However, the environmental sustainability of high GDP growth may require a range of measures on both the demand side and the supply side to be combined to take care of the absolute burden of environmental stress on the concerned ecosystem. This may make the order of investment requirement large enough to crowd out some investment in other sectors if there is no additional capital inflow from the rest of the world to the Indian financial market causing a rise in interest rate. Such crowding out of investment may result in an adverse impact on GDP at least in the medium run transition period of technological restructuring of the energy sector due to the rise in the value of the marginal capital -output ratio. The macroeconomic feedback effect is thus sensitive to the share of the high cost options like fuel switching in the total mitigation of emissions.

There arises the question here whether a developing country like India with high substantive burden of poverty should delay the introduction of high cost alternatives to fossil fuel technology till the additional technological innovations through R&D reduce such costs. However, delaying such implementation of new technologies would save money now but would end up with a larger energy sector requiring larger investment for fuel switch in future due to the scale effect of requirement. The simulations of IMACLIM- R (Shalizi 2007) addressing this issue give the result that the net benefit /cost ratio would be lower for delayed implementation of new technologies as the loss of environmental benefits of earlier implementation is not compensated by the cost economy of delayed implementation at later period for a growing energy system supporting the high growth trajectory . This justifies the early adoption of new technologies by the developing economies like India as the short run losses would be more than compensated in the long-run in a growing economic system.

20. Energy Pricing and Institutions

The challenge of high growth with environmental sustainability would require appropriate institutional arrangement so that investible resources of the economy are rationally allocated for the purpose. The creation of appropriate incentives for investment for energy capacity expansion, energy conservation and fuel substitution for cleaner energy would require both rationalisation of energy prices and institutional reforms. Although the real price indices for electricity and petroleum products have been rising since mid-nineties after the introduction of economic reforms, such rise has been lower than the increase in real global oil prices in terms of India’s purchasing power (See Table 8 and 32 together). India being a net importer of energy, mainly in the form of oil, this has resulted in inadequate cost recovery in energy industry. This problem would be pressing for the urgency of price and institutional reform in the interest of growth of the energy industry to meet the challenge of inclusive growth and energy poverty removal.

20(a). Petroleum Products.

For the petroleum products, the Government of India has already dismantled the administered pricing arrangement. The prices of all petroleum products as of today are fixed in principle on import-parity basis and therefore driven by the global market forces excepting for kerosene and LPG. For these two products the subsidies are also supposed to be phased out over time. While the share of government taxes and duties in the final price paid by the consumers in India is about 50% in the case of petrol, and 32% in the case of diesel, the major part of the total subsidy given to the consumers of kerosene and LPG is being borne by the oil companies in the form of under recoveries. This raises an issue of financial sustainability of such uncovered subsidies, which would constrain the internal resource generation for the expansion of the oil sector. Given the pattern of energy consumption of the different income classes, the removal of LPG subsidy has been shown not to affect adversely the people of the lower income classes, while the same for the kerosene would have some adverse effect on the poor (Gangopadhyay, Ramaswamy and Wadhwa 2004).

20(b). Electricity

While the power sector faces the big challenge of growth of about 8.5% per annum over the eleventh plan, the sector faces serious problem of financial viability due to the subsidized prices for the agricultural and domestic sector resulting in substantial overall under-recoveries of costs to the extent of 30-38% by the state utilities (Sengupta et al 2007). Table 33 shows the sector-wise subsidisation through prices indicative of the distortion in the Indian energy market. However the electricity reforms process, which was initiated during the Eighth Plan period, is yet to be complete to produce satisfactory results. The reforms process consisted of unbundling the earlier vertically integrated state utilities, establishing independent regulatory regimes at the state level as well as at the centre, introducing financial discipline by restructuring the prices, increased private participation and competition in generation and distribution of power. As power is a subject in the concurrent list of the Indian constitution for jurisdiction, the progress of pricing and institutional reforms is widely varying across the states.

As there is an absurdly high rate of subsidization of agricultural consumers to the extent of 89% as per the latest available data, such low prices have mainly resulted in the wasteful use of ground water, which is a critical and scarce resource in many states of India and in the wasteful use of chemical fertilizers causing water pollution as well. The chemical fertilizers are substantively washed away along with run off water, the latter being treated as free good due to low energy prices. While the accelerated growth of agriculture would require more of water, fertilizer and electrical energy on a macro scale, there is substantive scope of economizing their use at micro scale per unit of gross crapped area for any given crop. Besides, the benefit of energy and fertilizer subsidies is mostly appropriated by the well-offs of the rural sector who are already included and not excluded in the development process.

So far as the electricity tariff for the domestic sector is concerned, the problem can be resolved by charging life line rates for the basic lighting need of the poor households and the progressive tariffs for consumption levels in excess of the basic needs (Barnes and Toman 2006). It is a problem of political will in India to enforce such rationalization in pricing which is needed to resolve the highly solvable problem.

In the context of rationalization of prices , an IEA study (International Energy Agency 2001) attempted to quantify the size of electricity subsidy in terms of price – cost gap analysis and the potential impact of the removal of such subsidy on electricity consumption and CO2 emissions. The IEA used a price elasticity of demand of -0.75 for all the power consuming sectors and obtained the result that the total electricity demand and CO2 emission would fall by 40% assuming the constancy of the heat rate of all coal thermal plant even at lower scale of operation. The rationalisation of prices is thus important not only for attracting investment but also for immediately reducing the environmental pressure.

21. Summary and Conclusion

The sustainable energy planning for high inclusive growth has thus to address the following challenges:

(a) To meet the substantially growing requirement of end use needs of energy services of all the producing sectors, by both conserving energy use and supplying additional energy through creation of new capacity at least cost.

(b) To remove energy poverty of all households by supplying modern clean energy services within a time horizon.

(c) To combine energy security with environmental sustainability of the economy in its choice of mix of primary energy resources to mitigate the adverse macroeconomic impact of the rise of world oil prices of the recent years.

(d) To reduce the local and global externalities due to pollution and environmental degradation arising from the use of the energy resource in its entire life cycle.

The energy security issue arises essentially from the imbalance of resource flow between the nature and the economy because of the use of exhaustible energy resources exceeding the rate of human discovery of more deposits of the same or of an alternative renewable energy resource, the monopoly control of ownership of energy reserves and geopolitics. The problem of environmental pollution arises from the waste flow due to the material balance principle and the Entropy Law. Environmental sustainability of energy use and supply is crucial for taking care of the local as well as the global externalities from such pollution arising. The local externalities have their main impact in the form of adverse health effect, while the regional and the global externalities which are mostly reciprocal in nature have their effects in the form of destruction of primary productivity of the ecosystem and climate change. As the health attainment is a crucial determinant of human capability and as the modern electric lighting service is a crucial facilitator for education and learning, clean supply of modern energy service is a major factor behind the growth of human capital which is the key driver of high economic growth as well as human development. Climate change is also of considerable importance for India because of the factors of uncertainty over its long run economic effects and asset losses due to the possible sea level rise. It is important to explore the policy linkages between the control of GHG emissions and those of local emissions , as developing countries may give higher priority to the current equity issues connected with energy use in the form of freedom of the people to breathe clean air, use clean energy and achieve high health attainment compared to those issues relating to climate change in future for quite understandable reasons.

So far as the methodology of energy planning for the development of future energy system and energy policy is concerned, use of both top down and bottom up approach of modelling has been found useful for getting answers to different sets of questions regarding sustainable energy development. The top down models of general equilibrium are useful to get answers of macro-level questions relating to inter-dependence between macro-economic growth and energy use , while the bottom up partial equilibrium model approach is useful for the analysis of the choice of device or technology of energy use of the various sectors including energy appliances, fuel etc. and of the choice of fuel mix and technology of energy supply. Energy planning and policies are often based on the comparison of results of various scenarios simulated by different assumptions of policy initiatives giving alternative environmental impacts.

In most of such studies, the environmental effect modules are soft linked, the impacts are assessed often partly or mostly in physical units and partly in monetised unit to the extent possible. As the reliable estimation of fully integrated social cost internalising the monetised values of all kinds of pollution externalities is difficult, it is advisable to use the hybrid results of physical and monetary values of impact as a basis of sustainable energy planning and policy.

The use of least cost optimisation (mostly linear programming) model for energy use and energy supply provided simulation results for different future energy-environment scenarios for India as carried out by various scholars, international agencies like the World Bank, and the Planning Commission of the Government of India. As per the results the official studies of the Planning Commission for a high annual GDP growth rate of 8 to 9% India would require its consumption of the primary commercial energy resources to grow at the annual rate of 6-6.4% with an implicit GDP elasticity in the range of 0.7 to 0.75, the elasticity declining with higher growth. This has presumed the maximum use of potential of hydro, nuclear and gas resources. However, coal remains the cheapest option for the long run requirement of growth of energy by augmenting energy capacity in the supply side without any such policy forcing of fuel option. There is a CO2 mitigation potential of 35% in 2031-32 of vis-à-vis coal dominated least cost option by the combination of efficiency improvement on demand side and supply side and by change in fuel mix and energy supply technologies.

Several studies have the convergent finding that for reducing the energy requirement and mitigation of CO2 , demand side management is the cheapest option in India , followed by supply side efficiency improvement in coal thermal plants , strengthening T& D system to reduce losses and lastly changing fuel mix by non conventional technologies of new renewables and /or in –situ coal gasification or liquefaction in the order of marginal cost. India has in fact already achieved substantive reduction in energy intensity of GDP over time particularly after the introduction of economic reform in 1991. The reduction in carbon intensity of energy has also taken place at macro level but of much smaller order. The higher cost of reduction of carbon intensity of energy than the energy intensity of GDP rationalises the relative extent of variation.

While the investment requirement for the maximum reduction of pollution using the various options is considerable, it would be affordable with appropriate private – public partnership and additionally by an inflow of foreign savings in case the energy sector development tends to crowd out investment without such flow. As the rate of return in energy development with renewables and non-hydrocarbons would be lower, their enforcement through policy support may crowd out other relatively profitable investments resulting in net GDP loss.

However, with rise in the savings rate , high receipt of foreign remittance, and increased earning from export of IT services, India’s savings-investment account and the Rest of the World Account in the national accounting have improved, enhancing her affordability of investment for sustainable energy development. Besides, such strengthening of the macroeconomic fundamentals of India has imparted to India much greater resilience to oil price rise and volatility. It has also been observed in some of the studies that delaying investment in high cost renewables to replace fossil fuel may worsen long run benefit cost ratio. The improving macro-economic drivers of growth should in fact enable India to be more pro-active and take role of leadership in exploiting the potential of non-conventional renewables.

Coming to sectoral issues, the infrastructural sectors of electricity and transport are the ones deserving maximum attention. While electricity is transformation of one form of energy into another for final end use, transport makes only use of energy for providing the service of mobility. Electric plant is the one of the largest single point source of emission and urban transport is the single largest source of urban pollution in India. The former admits choice of fuel and technology for the conversion of primary energy into final electrical energy while the transport admits a range of modal choice of device of transport implying different rates of emission for the use of petroleum fuels. The energy intensive industries of India, particularly the industrial boilers are also one of the major areas offering opportunities of energy conservation. Transport and Industry in India provide major opportunities of improvement of demand side efficiency, while the electricity sub- sector provides the major scope for improving supply side efficiency.

The removal of energy poverty requires the provision to electrical power to all and replace the traditional biomass fuel by hydrocarbons (particularly LPG) for cooking. In spite of the enforcement of the programme of electrification of all homes to provide the lifeline requirement of electrical energy to all by 2010-2011, the Indian households will have to depend on traditional biomass fuel for 47.7% of the total household energy requirement. It becomes important therefore to innovate devices and cooking appliances and invest in R&D and technology development for bio-gas for wide scale implementation. The latter can provide a decentralised model of sustainable development of rural energy using livestock-energy-agriculture nexus in clean modern forms of both gas for cooking and small scale power generation for the local consumption of electricity. Since some of the other non-conventional renewable energy resources would also be suitable for decentralised development of energy at smaller scale, they may play an important role in the removal of energy poverty and in ensuring the regional inclusiveness of development.

In order to attract adequate investment for such energy sector development, the existence of a proper institutional framework to provide adequate incentives for investment should be in place and energy prices need to be rationalised for the optimum allocation of resources for the development of the energy sector of India. The pricing reforms and institutional restructuring are yet to be complete to yield any impressive result. The pricing of energy is more a matter of politics than economics in India. The demand for additional financial resources for making the energy development environmentally sustainable requires serious commitment of India’s political economy to make the energy industry financially viable and at the same time to ensure the access of all households to clean modern energy service by appropriate affordable price–subsidy arrangement.

India is now poised for a sustained high growth as its macroeconomic basic conditions fulfil the necessary conditions for such growth. She can derive a demographic dividend from the growing share of population in the working age group in the coming decades since such working population with appropriate education and skill development would contribute to the formation of the most important asset of human capital for the explosion of India’s productivity and growth.

Clean energy is a fundamental requirement for driving the growth as well as human capital formation as it directly contributes to the higher educational and health attainment of households. Pollution from unclean commercial energy is a cause of serious inequity in Indian society. The rich mostly benefit from the clean output of electricity though generated often in an unclean manner, while the poor suffer more from the emissions of power plants as they are more vulnerable to diseases than the rich. The real challenge is how to produce modern commercial energy services with little pollution and making them affordable for all.

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Abbreviations for all the Tables and Charts that follow.

TPES: Total Primary Energy Supplies
CMBRN: Combustible Renewal and Wastes
TPCES: Total Primary Commercial Energy Supplies
FNLEN: Final Energy
ELG: Electrical Energy Generation (Gross)
FNLELC: Final Electrical Energy
PENEL: Primary Energy for Electricity
CO2MT: Carbon Dioxide Mill.tonne
CONV.-LS: Conversion Loss % of Primary energy input
Aux-Loss: Auxiliary Loss as % share in Gross Generation
TLS-%ENG: Total Losses as % share of Primary Energy Input
Mtoe: Million tonnes of oil equivalent

Tables

Table 1: Comparative Energy Use and CO2 Emission

	India	China	Japan	USA	World
Population (million-2005)	1094.6	1304.5	127.8	296.4	6437.7
GDP per capita (2000 US$ PPP)	3072	6012	27817	37267	8477
Primary Energy Use per capita (t.o.e) in 2004	0.531	1.241	4.173	7.92	1.793
Share of Biomass Wastes (%) 2004	37.4	13.7	1.17	3.04	10.26
Electric Power Consumption per capita - 2004 (KWH)	457	1585	8072	13351	2606
CO2 Emission per capita (tonne) 2003	1.196	3.216	9.641	19.904	4.3
Share of CO2 emission in World Total (%) 2003	4.76	15.5	4.6	21.64	100
Energy Intensity of GDP (kg 2000 ppp$) 2004	183	229	155	217	211

Source: World Bank, World Development Indicators Data Base, 2007.

Table 2: Major Economy-Energy Indicators of India

Year-Calendar	Population (mill)	GDP-const.price -RsBill)	Trade as % GDP	Real Pr. Engy Index (1993 base)	Real Global oil price Index (1993 base)	TPES (mtoe)	CO2MT
1971	550.75	2985.21	8.36	64.86	21.88	157.00	204.20
1980	675.25	3944.19	15.74	95.24	172.17	243.04	347.20
1985	751.00	5085.12	13.20	101.97	135.42	292.28	488.16
1990	834.75	6837.36	15.71	91.67	106.55	359.13	677.71
1995	923.50	8841.80	23.21	97.81	90.23	430.05	907.28
2000	1014.50	11860.36	28.36	125.78	152.62	501.89	1158.74
2005	1100.62	16457.96	44.72	158.73	235.82	537.31	1355.68

Source: IEA: Energy Balances of Non-OECD Countries Different Volumes; CSO 2006; CSO 2004; GOI, 2007.

Table 3: Some Socio-economic Indicators of India

	Around 1990	Recent Year	Best State Recent Year	Worst Sate Recent Year
Net National income per capita (Rs. At 1993-94 prices)	7321	11799	16679	3557
Consumption Poverty Head Count Ratio	36.0	27.8	5.2	46.5
Literacy (age 7+)				
Male	64.1	75.3	94.2	59.7
Female	39.3	53.7	87.7	33.1
Enrolment Ratio Elementary School (6-14 years of age)	55.3	71.1	103.1	55.8
Infant Mortality Rate (per 1000 live births) 2003	80	60	11	83

Source: Planning Commission, 2006b.

Table 4: Growth Rates and GDP-elasticities of Energy Use in India.

Variable	**Period**	**Growth Rate**	**GDP-elasticity**
GDP at Factor Cost	1971-1990	4.4	-
	1991-2005	6.0	-
Real Price of Energy	1971-1990	2.2	-
	1991-2005	4.0	-
Real Price of Global Crude Oil	1971-1990	6.1	-
	1991-2005	5.1	-
CO2	1971-1990	6.5	1.47
	1991-2005	4.4	0.75
Total Primary Energy	1971-1990	4.1	0.86
	1991-2005	2.8	0.52
Total Primary Commercial Energy	1971-1990	5.7	1.28
	1991-2005	4.8	0.79
Final Energy	1971-1990	4.7	1.09
	1991-2005	3.4	0.56
Gross Generation of Electricity	1971-1990	7.8	1.77
	1991-2005	5.7	0.98
Final Use of Electricity	1971-1990	7.5	1.71
	1991-2005	4.5	0.75

Source: Author’s own estimation using IEA Data on Energy balances of Non-OECD countries, different volumes.

Table 5: Fossil Fuel Reserves of India as on 2005
(Unit: Million tonnes of Oil equivalent)

Resources	Proved	Production (2004-05)	Net Imports (2004-05)	Proved Reserve to Production
Extracted Coal	13489	157	16	86
Extractable Lignite	1220	9		136
Oil	786*	34	87	23
Natural Gas	1101*	29	3(LNG)	38
Coal Bed Methane	765			

* indicates Balance of recoverable Reserves
Source: Planning Commission, 2006a.

Table 6: Renewable Energy Resources of India

(Unit: mtoe per year)

	Resources	Present	Potential
1	Hydro Power Capacity (in MW)	32	1,50,000
2	Biomass		
	(a) Fuelwood	140	620
	(b) Biogas*	0.1	15
3	Bio-Fuels @		
	(a) Biodiesel	-	20
	(b) Ethanol	<1	10
4	Solar @		
	(a) Photovoltaic		1200
	(b) Thermal		1200
5	Wind Energy	<1	10
6	Small Hydro-power	<1	5

Based on the assumption of Community Plants.

@ Based on assumptions regarding land availability (for details see the source)

Source: Planning Commission, 2006a.

Table 7: Potential Availability of Nuclear Energy of India

	Resource Base	Metal resource (tonnes)	Electricity Energy (GWe-Yr)	Electricity Capacity (MWe)
1	Uranium Metal	61,000		
	(a) In PWHR	-	330	10,000
	(b) in Breeder	-	42,200	5,00,000
2	Thorium Metal	2,25,000		
	In Breeder	-	1,50,000	Very large

Source: Planning Commission, 2006a.

Table 8: Energy Import of India and Global Oil Price Movement.

Year	Share in Net import in Total Primary Commercial Energy Supplies (%)	Share of Oil in total net import of energy (%)	Global Oil Price Index 1993=100	Real Global Oil Price Index for India 1993=100
1971	24.32	100.0	3.24	21.88
1980	24.85	98.6	56.11	172.17
1985	12.07	100.0	66.34	135.42
1990	17.24	86.6	78.38	106.55
1995	22.10	84.1	107.97	90.23
2000	30.43	84.5	246.82	152.62
2005	32.07	75.22	461.34	235.82

Source: Estimated by the author on the basis of the crude oil price data from the source of British Petroleum and the Energy balances of Non OECD countries of the International Energy Agency, for the different years, published by OECD.

Table 9: Adjustment of Savings Rate for Energy Related resource Depletion and Environmental Degradation

(Unit: % of Gross National Income)

Year	Gross Saving Rate	Consumption of Fixed Capital	Energy Depletion	Co2 Damage	Damage due to Particulate Emission	Forest Depletion	Total energy related Depreciation
1971	15.71	6.79	0.74	0.54	-	8.93	-
1990	22.27	9.75	3.31	1.05	0.82	1.35	6.53
1995	26.90	10.36	2.68	1.41	0.91	1.33	6.32
2000	26.01	9.71	2.22	1.51	0.81	0.88	5.41
2003	29.99	9.11	2.62	1.34	0.80	0.76	5.59
2005	32.23	9.19	4.83	1.30	0.74	0.57	7.44

Source: World Bank; World Development Indicators Data Base 2007.

Table 10: Primary Energy Supply and Electricity

Year-Calendar	TPES (mtoe)	CMBRN (mtoe)	TPCES (mtoe)	FNLEN (mtoe)	ELG- Twh	FNLELC-Twh
1971	157.00	95.78	61.22	47.84	66.38	51.74
1975	208.52	132.21	76.36	56.56	85.93	65.58
1980	243.04	148.13	94.91	63.61	119.26	89.53
1985	292.28	162.33	129.95	87.59	188.48	138.14
1990	359.13	175.82	183.31	118.99	289.44	211.74
1995	430.05	188.65	241.40	146.92	417.62	309.19
2000	501.89	201.58	300.31	171.14	562.19	368.72
2005	537.31	158.12	379.19	199.05	699.04	477.91

Source: IEA : Energy Balances of Non-OECD Countries, Different Volumes.

Table 11: Primary Commercial Resources Supplies and Resource Mix

Unit %

Year-Calendar	TPCES (mtoe)	Coal	Oil	N.Gas	Nuclear Energy	Hydro	Non-Conv. Energy
1971	61.22	58.05	36.57	0.93	0.51	3.94	0.00
1975	76.36	62.65	31.40	1.24	0.77	3.97	0.00
1980	94.91	54.97	35.87	1.25	0.82	4.21	0.00
1985	129.95	58.66	33.94	3.16	0.86	3.48	0.00
1990	183.31	57.86	32.04	5.36	0.87	3.36	0.00
1995	241.40	57.45	30.73	6.74	0.86	2.58	0.02
2000	300.31	54.96	38.08	7.30	1.47	2.13	0.05
2005	379.19	54.85	33.91	7.61	1.19	2.27	0.14

Source: IEA : Energy Balances of Non-OECD Countries, Different Volumes.

Table 12: Final Energy Supply and Shares of Fuels

Unit %

Year	FNLEN (mtoe)	Coal	Oil	Gas	Electricity
1971	47.84	51.67	38.44	0.59	9.30
1975	56.56	52.88	36.17	0.97	9.97
1980	63.61	48.94	43.66	1.07	12.11
1985	87.59	40.66	43.77	2.71	13.56
1990	118.99	34.71	45.25	4.74	15.30
1995	146.92	25.70	50.48	5.72	18.10
2000	171.14	18.91	56.90	5.66	18.53
2005	199.05	18.96	53.38	7.01	20.65

Source: IEA : Energy Balances of Non-OECD Countries, Different Volumes.

Table 13: Gross Electricity Generation and Fuel based Generation Mix

Unit: % share

Year	ELG- Twh	Coal	Oil	Gas	Nuclear	Hydro
1971	66.38	49.09	6.32	0.57	1.79	42.22
1975	85.93	49.16	8.42	0.60	3.06	38.77
1980	119.26	51.54	6.39	0.52	2.52	39.04
1985	188.48	61.92	6.35	1.18	2.72	27.83
1990	289.44	66.20	3.47	3.44	2.12	24.76
1995	417.62	75.31	1.47	3.82	1.91	17.38
2000	562.19	70.69	4.86	7.65	3.01	13.25
2005	699.04	68.66	4.47	8.94	2.48	14.31

Source: IEA: Energy Balances of Non-OECD Countries, Different Volumes.

Table 14: Electrical Energy Balances of India

year	PENEL-mtoe	CONV.-LS %	Aux-Loss-%Gen	T&D-Loss-%BB	TLS-%ENG	FNLELC-mtoe
1971	18.66	69.40	5.69	16.36	76.15	4.45
1975	24.25	69.53	23.66	0.02	76.74	5.64
1980	33.32	69.22	24.89	0.03	76.89	7.70
1985	50.97	68.20	23.96	2.75	76.69	11.88
1990	70.10	64.49	7.79	19.05	74.02	18.21
1995	108.74	66.97	7.42	18.54	75.55	26.59
2000	152.76	68.35	7.06	27.35	79.24	31.71
2005	191.28	68.57	6.87	24.76	78.51	41.10

Source: IEA: Energy Balances of Non-OECD Countries, Different Volumes.

Table 15: Distribution of Primary Fossil Fuels between Direct Final Use and Use in the Energy Industry in India

Unit:% Share of a Sectoral Use

Fossil Fuel	Period	Direct Final Use	Electricity Generation	Others in Energy Sector, including losses
Coal	1971	71.6	0.29	-
	1990	42.9	53.4	3.7
	2005	18.1	74.8	7.1
Oil	1971	81.6	6.9	11.5
	1990	87.8	5.0	7.2
	2005	82.6	6.4	11.0
Natural Gas	1971	50.9	46.3	2.8
	1990	61.1	30.2	8.7
	2005	48.4	44.4	7.2

Source: Author's own estimation using IEA Data on Energy balances of Non-OECD Countries, Different Volumes.

Table 16: Fuel Composition in Power Industry in India

Unit: % in total energy input.

	1971	**1990**	**2005**
Coal	55.3	81.2	81.3
Oil	8.3	4.2	4.3
Natural Gas	1.4	4.3	6.7
Hydro/Nuclear Non-Conventional Energy	35.0	10.4	7.1
Combustible Renewables & Wastes	-	-	0.6

Source: Author's own estimation using IEA Data on Energy balances of Non-OECD Countries, Different Volumes.

Table 17: Fuelwise Sectoral Distribution of Final Commercial Energy Use in India.
Unit: % Sectoral share

Year	Fuels	Industry	Transport	Agriculture	Commercial & Public Services	Residential Households
1971	Coal	61.7	31.3	-	-	7.0
	Oil	24.5	37.4	4.3	0.8	21.6
	Natural Gas	94.5	-	5.5	-	-
	Electricity	70.0	3.2	9.8	9.1	8.0
	Total Final Energy	48.7	30.9	2.5	1.2	12.6
1990	Coal	93.0	5.5	-	-	1.5
	Oil	22.9	45.1	0.4	3.1	23.8
	Natural Gas	98.1	-	1.2	-	0.7
	Electricity	52.0	2.2	22.0	10.1	13.7
	Total Final Energy	57.3	21.6	3.5	2.8	12.8
2005	Coal	78.1	-	-	14.6	7.3
	Oil	17.9	33.3	5.6	0.4	19.7
	Natural Gas	36.6	4.7	0.9	-	4.5
	Electricity	43.9	2.2	20.0	12.2	21.6
	Total Final Energy	52.10	18.5	7.2	5.5	16.7

Note: The shortfall of the row sum from 100 is to be imputed to Non-energy use of energy resources or use by other sectors.
Source: Author's own estimation using IEA: Energy Balances of Non-OECD Countries, Different Volumes.

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Table 18: Sector-wise Fuel Composition of Final Commercial Energy Use in India.
Unit: % share of a fuel.

Year	Fuels	Industry	Transport	Agriculture	Commercial & Public Services	Residential Households	Total Final Use
1971	Coal	66.5	53.3	-	-	29.4	
	Oil	19.3	45.8	63.6	27.8	64.8	
	Natural Gas	1.2	-	1.3	-	-	
	Electricity	13.1	0.9	35.1	72.2	5.8	
	Total Final Energy	100	100	100	100	100	
1990	Coal	61.1	9.6	-	-	4.3	
	Oil	17.0	88.9	4.7	47.2	79.6	
	Natural Gas	8.5	-	1.7	-	0.3	
	Electricity	13.3	1.5	93.6	52.8	15.8	
	Total Final Energy	100	100	100	100	100	
2005	Coal	41.1	-	-	49.5	8.3	19.0
	Oil	26.6	95.8	41.5	-	63.0	53.4
	Natural Gas	7.1	1.8	0.9	-	1.9	7.0
	Electricity	25.2	2.4	57.6	50.4	26.8	20.7
	Total Final Energy	100	100	100	100	100	100

Source: Author's own estimation using IEA: Energy Balances of Non-OECD Countries, Different Volumes.

Table 19: Sectoral Distribution of Total Direct and Indirect Use of Primary Energy (including Traditional Fuel) in 2005, India.

Unit: % share.

Item	Industry	Transport	Agriculture	Commercial & Public Services	Residential Households	Non-Energy Use
Share of indirect use through power of the total direct & indirect sectoral use of primary energy	50.9	10.4	86.3	66.2	21.9	-
Sectoral share of total direct & indirect primary energy use	30.7	7.5	8.3	6.6	35.2	11.7

Source: Author's own estimation using IEA: Energy Balances of Non-OECD Countries, Different Volumes.

Table 20: Decomposition Analysis of Growth of Primary Energy Intensity of GDP in India.

Unit: % change over the period

Period	Total Effect	Structural Effect	Technological Effect	Residual
1971-1990	20.2	16.4	3.5	-0.1
1990-2005	-28.8	0.6	-29.0	-0.3

Source: Author's own estimation using the Conventional Divisia Method and IEA data on Energy balances of Non-OECD countries, different volumes.

Table 21: Decomposition Analysis of Growth of Final Energy & Fuel-wise Intensity of GDP in India.

Unit: % change over the period

Fuel	Period	Total Effect	Structural Effect	Technological Effect	Residual Effect
Final Energy	1971-1990	11.57	18.52	-5.87	negligible
	1990-2005	-32.57	4.83	-35.10	-0.89
Electricity	1971-1990	64.88	11.12	49.67	-0.86
	1990-2005	-12.77	-5.64	-7.54	-0.03
Coal	1971-1990	-17.15	20.68	-35.93	7.14
	1990-2005	-67.62	2.72	-79.21	51.67
Oil	1971-1990	30.59	14.41	7.95	2.36
	1990-2005	-31.5	17.78	-34.78	-4.75

Source: Author's own estimation using the Conventional Divisia Method and IEA data on Energy balances of Non-OECD countries, different volumes.

Table 22: Share of final compositional effect in the total change in Carbon Intensity of Energy in India

Unit: % increase over the period

Period	Sector	Total Effect	Compositional Effect
1971-1990	Aggregate Economy	11.38	-0.26
1990-2005	Aggregate Economy	-1.05	-1.34
1971-1990	Electricity	58.68	40.07
1990-2005	Electricity	5.00	1.52

Source: Author's own estimation using the Conventional Divisia Method and IEA data on Energy balances of Non-OECD countries, different volumes.

Table 23: Distribution of households per 1000 by primary source of energy used for cooking for each major State. **Rural India**

State	Poverty ratio	61st Round (July 2004-June 2005)				
		No cooking arrangement	Firewood and chips	Dung cake	LPG	Others including coke & coal
Andhra Pradesh	11.2	36	803	1	144	16
Assam	22.3	-	924	0	69	7
Bihar	42.1	2	498	334	17	149
Chhattisgarh	40.8	13	923	24	15	25
Gujarat	19.1	43	734	8	105	110
Haryana	13.6	9	564	192	191	44
Jharkhand	46.3	10	828	10	14	138
Karnataka	20.8	17	897	-	65	21
Kerala	13.2	19	791	0	182	8
Madhya Pradesh	36.9	5	907	38	38	12
Maharashtra	29.6	17	749	3	149	82
Orissa	46.8	15	797	58	29	101
Punjab	9.1	4	314	333	242	107
Rajasthan	18.7	0	941	3	51	5
Tamil Nadu	22.8	29	809	-	134	28
Uttar Pradesh	33.4	3	667	265	48	17
West Bengal	28.6	9	733	36	43	179
All India	28.3	13	750	91	86	60

Source: NSSO 2007

Table 24: Distribution of households per 1000 by primary source of energy used for cooking for each major State. **Urban India**

State	Poverty ratio	61st Round (July 2004-June 2005)				
		No cooking arrangement	Firewood and chips	Kerosene	LPG	Others including coke & coal
Andhra Pradesh	28.0	55	300	70	566	6
Assam	3.3	64	272	47	606	12
Bihar	34.6	21	189	27	539	224
Chhattisgarh	41.2	26	375	30	495	74
Gujarat	13.0	39	144	138	623	56
Haryana	15.1	15	142	69	729	46
Jharkhand	20.2	71	123	13	427	366
Karnataka	32.6	88	237	136	529	10
Kerala	20.2	70	484	8	437	2
Madhya Pradesh	42.1	13	381	32	545	28
Maharashtra	32.2	58	138	159	633	11
Orissa	44.3	64	372	65	358	141
Punjab	7.1	38	80	132	703	47
Rajasthan	32.9	29	386	43	513	29
Tamil Nadu	22.2	72	219	175	533	1
Uttar Pradesh	30.6	18	263	45	561	112
West Bengal	14.8	59	125	112	461	242
All India	25.7	49	217	102	571	61

Source: NSSO 2007

Table 25: Distribution of households per 1000 by primary source of energy used for lighting for each major State. **Rural India**

State	Poverty ratio	61st Round (July 2004-June 2005)		
		kerosene	electricity	others
Andhra Pradesh	11.2	157	840	3
Assam	22.3	695	303	2
Bihar	42.1	894	101	5
Chhattisgarh	40.8	366	619	15
Gujarat	19.1	196	802	2
Haryana	13.6	91	897	12
Jharkhand	46.3	736	260	4
Karnataka	20.8	137	862	1
Kerala	13.2	201	794	5
Madhya Pradesh	36.9	300	692	8
Maharashtra	29.6	234	762	4
Orissa	46.8	681	315	4
Punjab	9.1	20	955	25
Rajasthan	18.7	519	472	9
Tamil Nadu	22.8	153	846	1
Uttar Pradesh	33.4	749	240	11
West Bengal	28.6	654	342	4
All India	28.3	444	549	7

Source: NSSO 2007

Table 26: Distribution of households per 1000 by primary source of energy used for lighting for each major State. **Urban India**

State	Poverty ratio	61st Round (July 2004-June 2005)		
		kerosene	electricity	others
Andhra Pradesh	28.0	48	949	3
Assam	3.3	137	862	1
Bihar	34.6	259	738	3
Chhattisgarh	41.2	67	932	1
Gujarat	13.0	27	958	15
Haryana	15.1	33	955	12
Jharkhand	20.2	127	871	2
Karnataka	32.6	41	959	0
Kerala	20.2	65	930	5
Madhya Pradesh	42.1	34	964	2
Maharashtra	32.2	39	957	4
Orissa	44.3	186	813	1
Punjab	7.1	2	978	20
Rajasthan	32.9	103	895	2
Tamil Nadu	22.2	54	946	0
Uttar Pradesh	30.6	142	844	14
West Bengal	14.8	125	873	2
All India	25.7	71	923	6

Source: NSSO 2007

Table 27: Projected Primary Commercial Energy Requirement for Maximum Hydro-Nuclear Potential Use and for GDP Growth Rate of 9% in India by the Expert Committee for Integrated Energy Policy.

Year	Total Primary Commercial Energy (mtoe)	% share of				
		Coal	Oil	Natural Gas	Hydro	Nuclear & Non-Conventional
2005	379.19	54.9	34.0	7.6	2.3	1.2
2011-12	546	51.8	34.1	8.8	2.2	3.1
2021-22	1011	51.5	30.8	11.0	2.3	4.4
2031-32	1858	50.4	29.5	12.9	1.9	5.3
Compound Annual Growth Rate (%) of Total Use of Fuels	6.4	6.3	5.6	8.0	5.9	11.2
GDP elasticity of fuel use	0.71	0.7	0.62	0.88	0.65	1.24
Rate of Growth of Energy Intensity of GDP(%)	-2.6	-2.7	-3.4	-1.0	-3.1	2.2
Per Capita Consumption of Commercial Energy in 2032 (kgoe)	1266	638	373	163	24	67

Source: Planning Commission 2006a.

Table 28: Projected Total Primary Energy Requirement with GDP Growth Rate of 9% in India.

Year	Total Primary Energy (mtoe)	Share of Primary Commercial Energy (%)	Share of Non-Commercial Energy (%)
2006-07	550	72.2	27.8
2011-12	715	76.4	23.6
2021-22	1192	84.8	15.2
2031-32	2043	90.9	9.1
Compound Annual Growth Rate of Fuel Consumption (%)	5.4	6.37	0.76

Source: Planning Commission 2006a.

Table 29: Projected Share of Requirement of Energy Resources for Maximum Use of Hydro-Nuclear Potential and GDP Growth Rate of 9% in India.

Year	Electricity Generation at Bus-bar (TWh)	Shares in Generation of			
		Fossil Fuels	Hydro	Nuclear	Other Renewables
2005	699	82.0	14.31	2.48	0.88
2006-07	724	81.5	12.00	5.40	1.10
2011-12	1091	80.4	12.70	5.90	1.00
2021-22	2280	79.8	11.80	7.50	0.79
2031-32	4493	82.2	8.90	8.30	0.53

Source: Planning Commission 2006a.

Table 30: Energy Resource Mix for 8% GDP Growth in 2031-32, India.

Items	Coal Dominant Case	Max. Use of Potential of Hydro, Nuclear & Gas	Simultaneous Use of all Optima for Sustainable Energy Development
Total Energy requirement (mtoe)	1702	1652	1351
Shares of			
(a) Coal	54.1	45.5	41.1
(b) Crude Oil	25.7	26.4	22.8
(c.) Natural Gas	5.5	10.7	9.8
(d) Hydro	0.7	1.9	2.2
(e) Nuclear	4.0	5.3	6.4
(f) Renewables	0.1	0.1	5.6
(g) Non-Commercial	9.8	10.1	12.0

Source: Planning Commission 2006a.

Table 31: Projected Demand for Fuels by the Households for 9% GDP Growth Rate in India (mtoe)

Year	Fuel Wood & Chips	Dungcake	Kerosene	LPG	Electricity	Total
2000	79.62	29.61	10.07	6.42	8.43	134.45
2011	88.00	31.16	13.16	27.36	33.63	193.31
2021	97.67	30.28	13.71	44.72	59.35	245.73
2031	102.41	28.78	13.59	53.05	76.95	274.78

Source: Planning Commission 2006a.

Table 32: Real Prices of Fuels in India.

Year-Calendar	Real Pr. Engy	Real Pr.Coal	Real Pr.El	Real Pr.Petro	Kerosene	LPG
1981	104.761	79.356	88.227	132.045	181.18	128.51
1985	101.970	96.259	92.238	118.406	165.13	113.72
1990	91.670	94.207	89.246	97.007	130.40	86.83
1995	97.811	91.499	109.826	89.563	83.57	94.59
2000	125.778	101.105	125.709	128.969	141.06	147.10
2005	158.726	124.713	140.996	188.246	182.83	174.40

Source: CSO 2004; CSO 2006; GOI, 2007.

Table 33: Average Tariff, Cost and Subsidy of Electrical Energy in India

Unit: Rs./KWh

Items & Sectors	1996-1997	1999-2000*	2000-2001 **
1. Average Tariffs			
(a) Residential Household	1.05	1.50	1.83
(b) Agriculture	0.21	0.25	0.35
(c.) Industry	2.76	3.50	3.67
(d) Overall	1.65	-	2.26
2. Average Cost of Supply	2.15	-	3.27
3. Rate of Subsidy (%)†			
(a) Household	51.0	57.9	44.0
(b) Agriculture	90.0	93.0	89.0
(c.) Overall (%)	24.0	38.0	31.0

Notes:

† Subsidy is to be taken as the under-recovery of cost of supply for 1996-97 and 2000-01. For 1999-2000 the estimates are taken from IEA 2002.

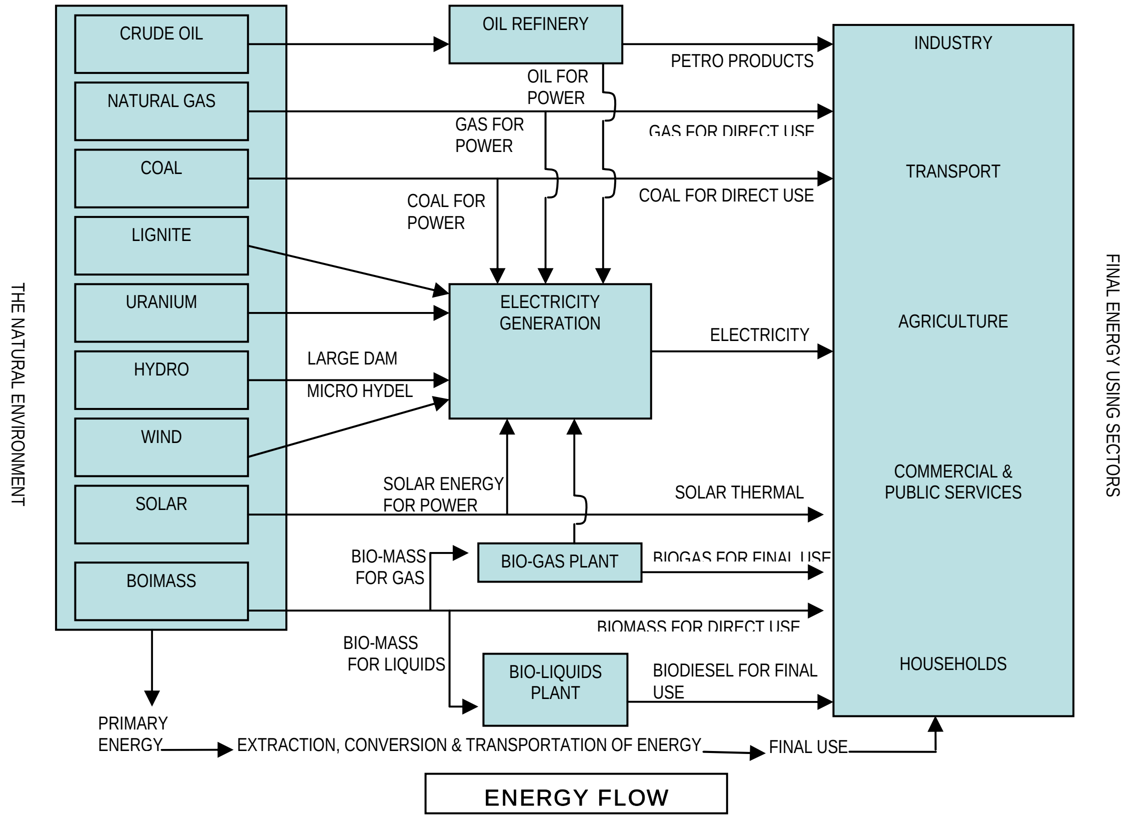
* For 1999-2000 the estimates are taken from IEA 2002.

** The data are as per Revised Budgetary Estimates of the Electricity Board.

Source: Planning Commission, 2002; IEA 2002.

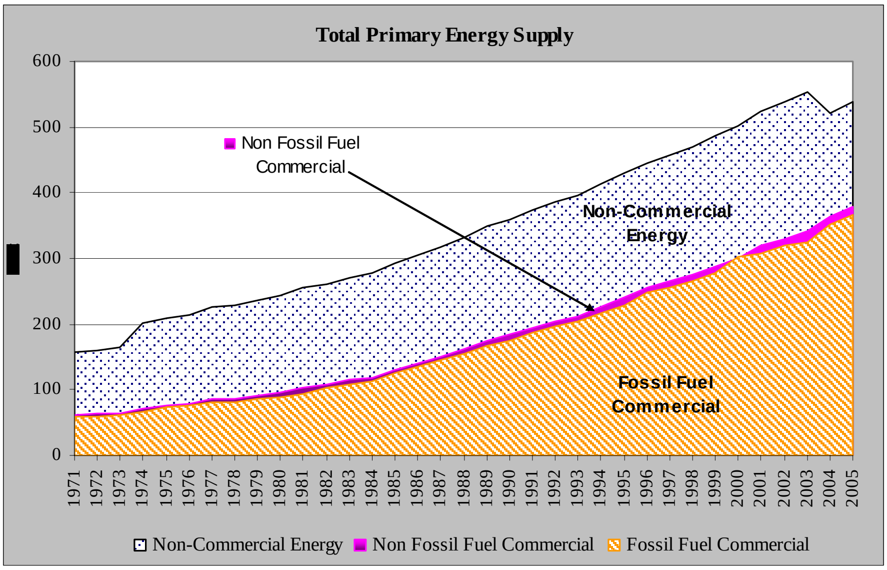
Charts

Chart1:
Energy Flow Chart



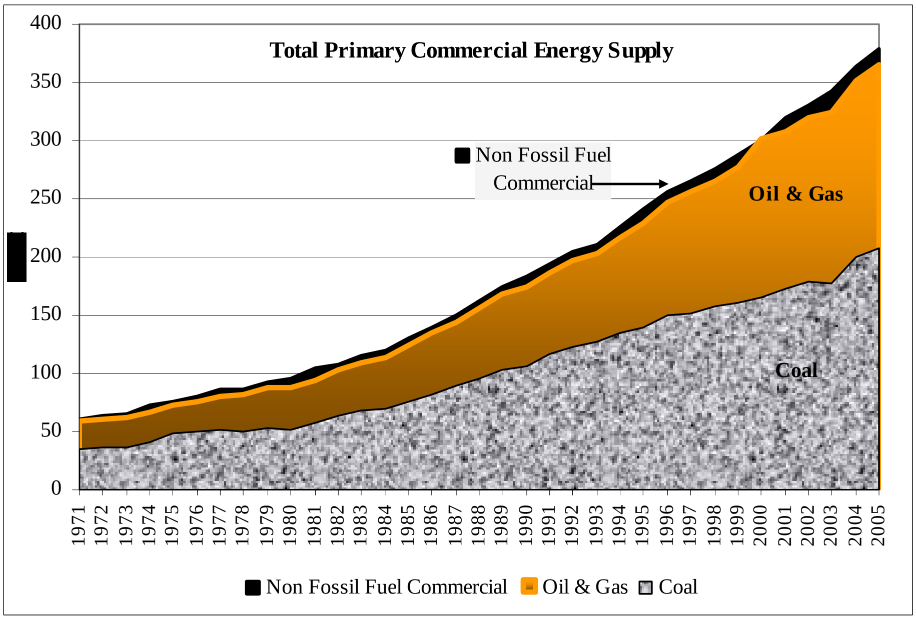
Source: Author

Chart 2:



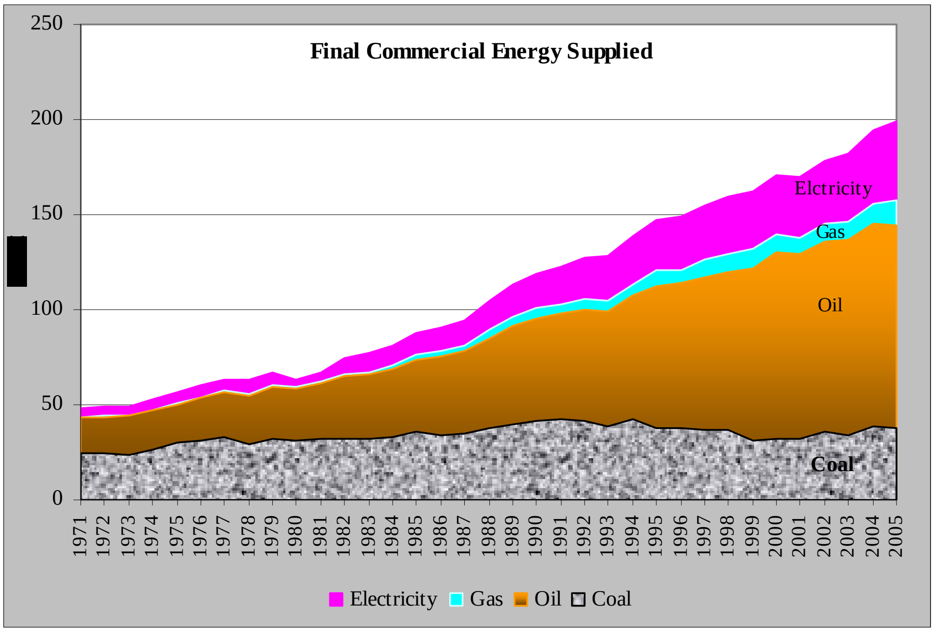
Source: Based on IEA Data on Energy balances of Non-OECD countries, different volumes.

Chart 3:



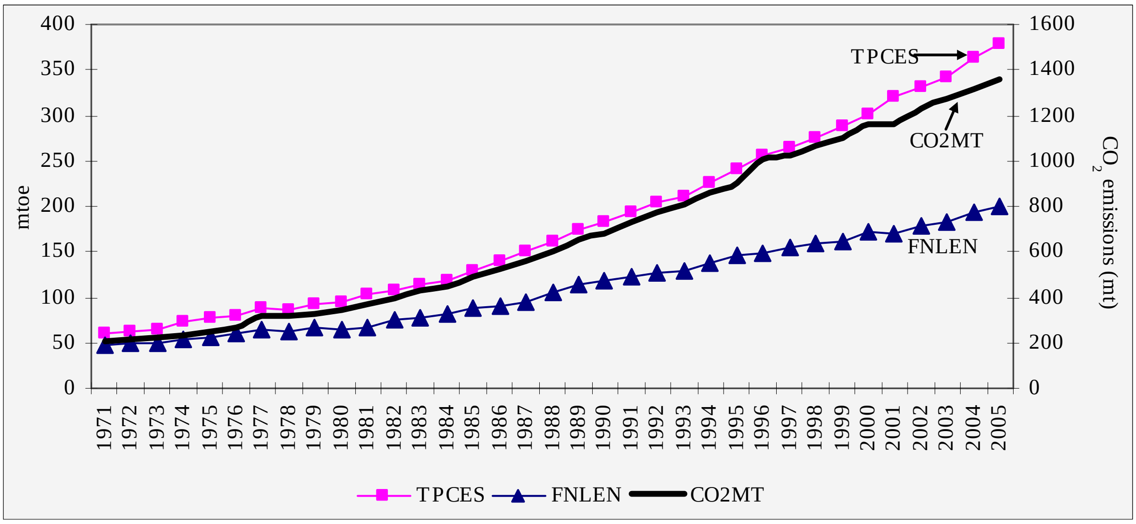
Source: Based on IEA Data on Energy balances of Non-OECD countries, different volumes.

Chart 4:



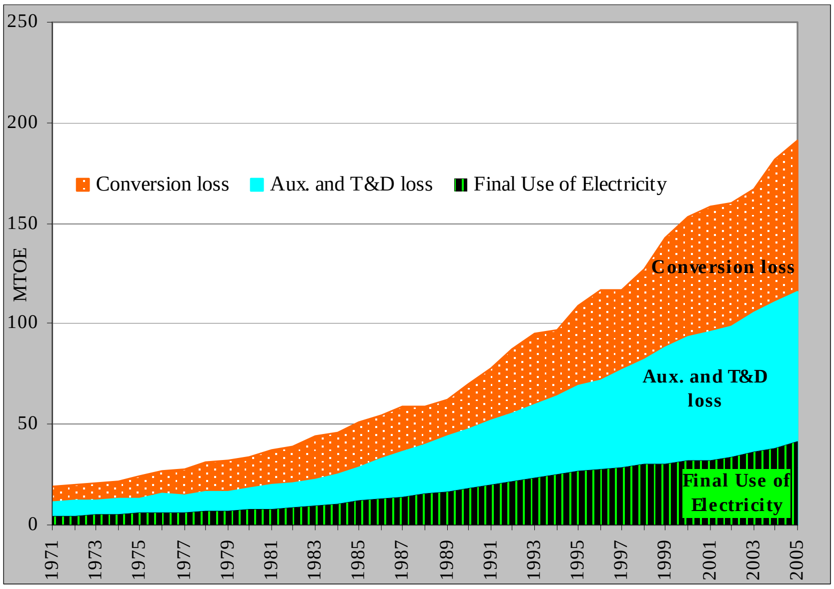
Source: Based on IEA Data on Energy balances of Non-OECD countries, different volumes.

Chart 5:
Supplies of Total Primary and Final Commercial Energy and CO_2 Emissions.



Source: Based on IEA Data on Energy balances of Non-OECD countries, different volumes.

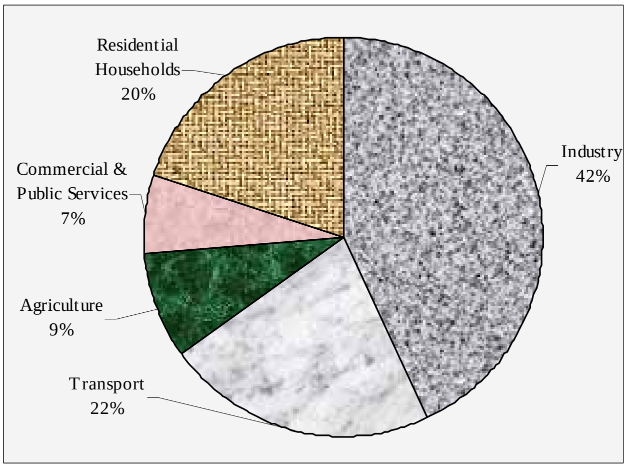
Chart 6:
Total Energy Input, Losses and Final Use of Electricity.



Source: Based on IEA Data on Energy balances of Non-OECD countries, different volumes.

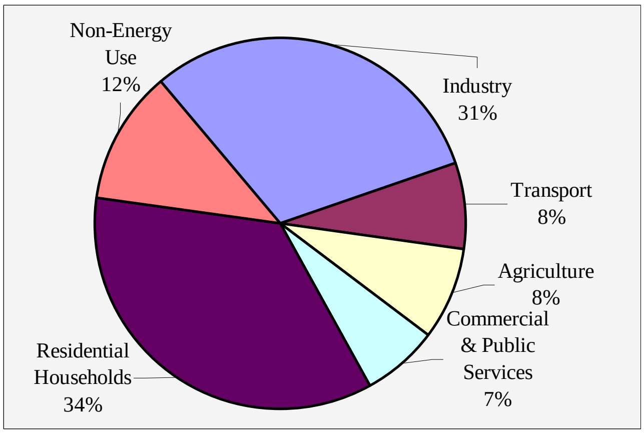
Chart 7:
Sectoral Distribution of Final Commercial Energy Use.

Unit: % Sectoral share



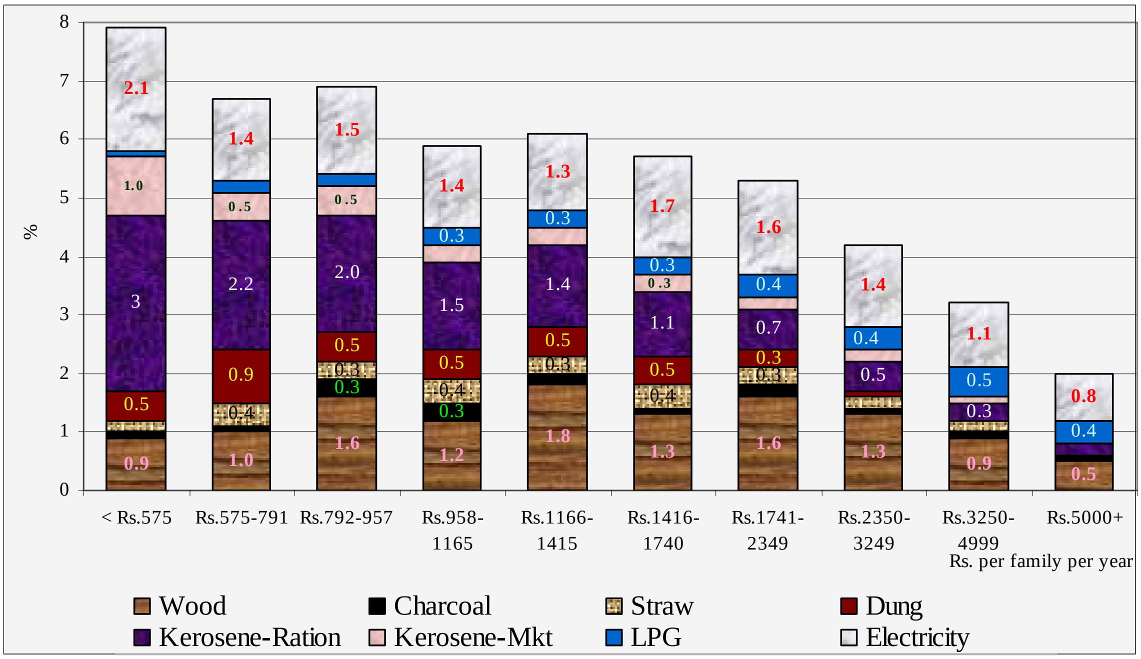
Source: Based on IEA Data on Energy balances of Non-OECD countries, different volumes.

Chart 8:
Sectoral Distribution of Total Direct and Indirect Primary Energy (including Traditional Fuels) in 2005



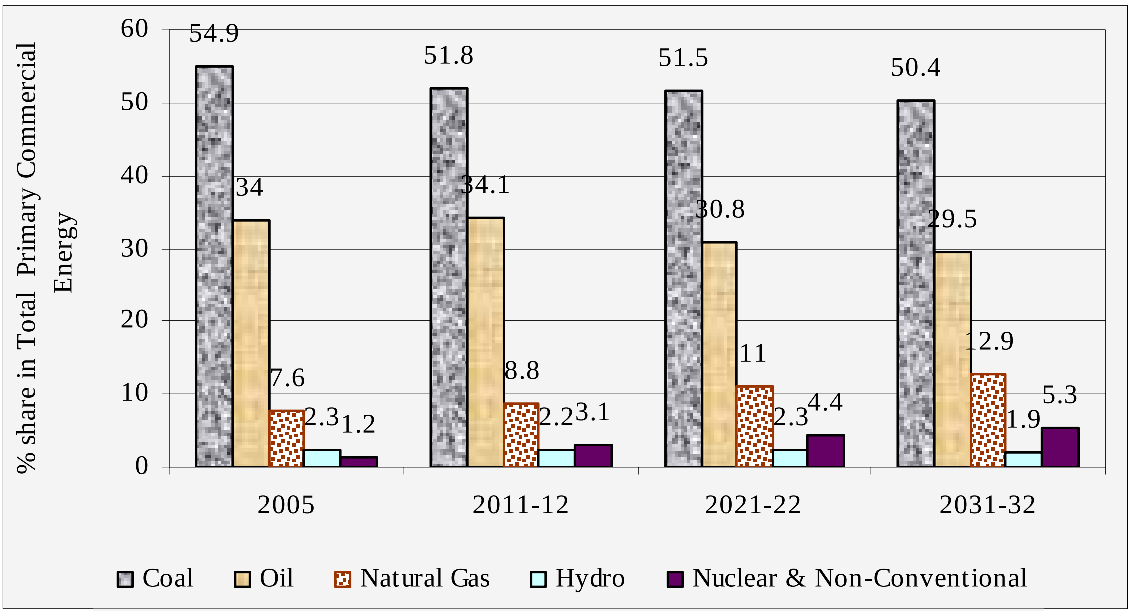
Source: Based on Author's own estimation as derived from IEA Data on Energy balances of Non-OECD countries, different volumes.

Chart 9:
Share of Income Spent on Different Fuels in Rural India for Different Income Classes, 1996 (Unit: %)



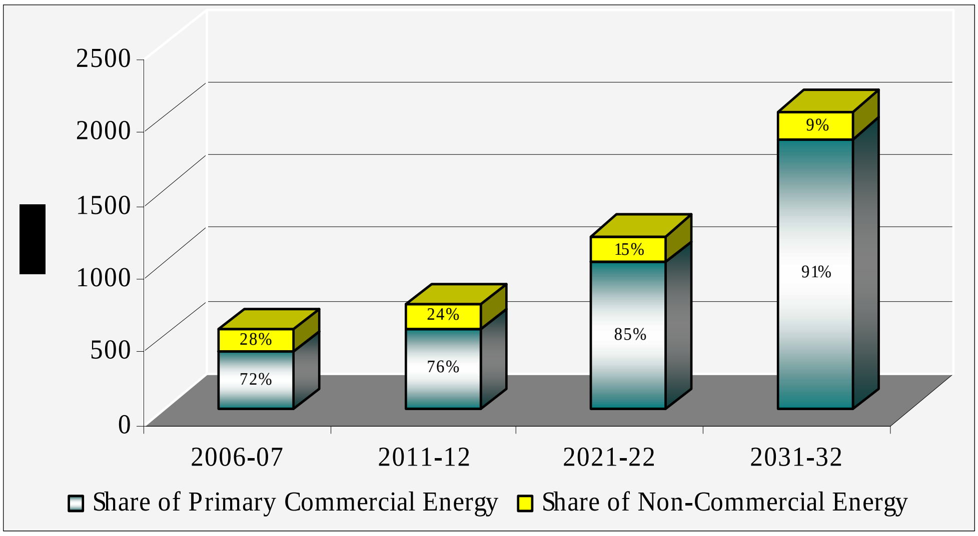
Source: World Bank 2002; Barnes and Toman, 2006.

Chart 10:
Projected Primary Commercial Energy Requirement for Maximum Hydro-Nuclear Potential Use and for GDP Growth Rate of 9%



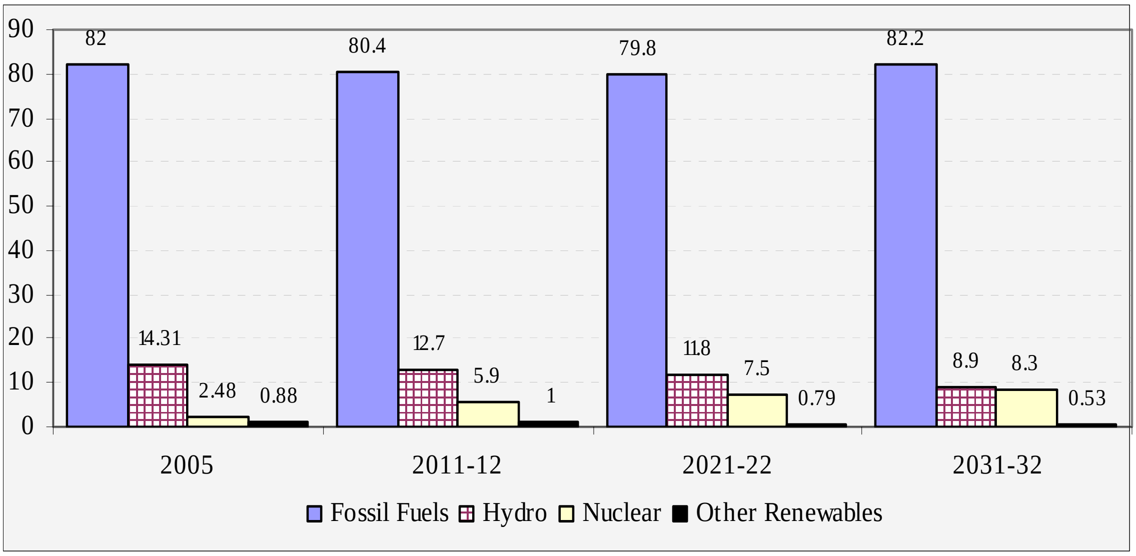
Source: Based on Planning Commission, 2006a.

Chart 11:
Projected Total Primary Energy Requirement with GDP Growth Rate of 9%.



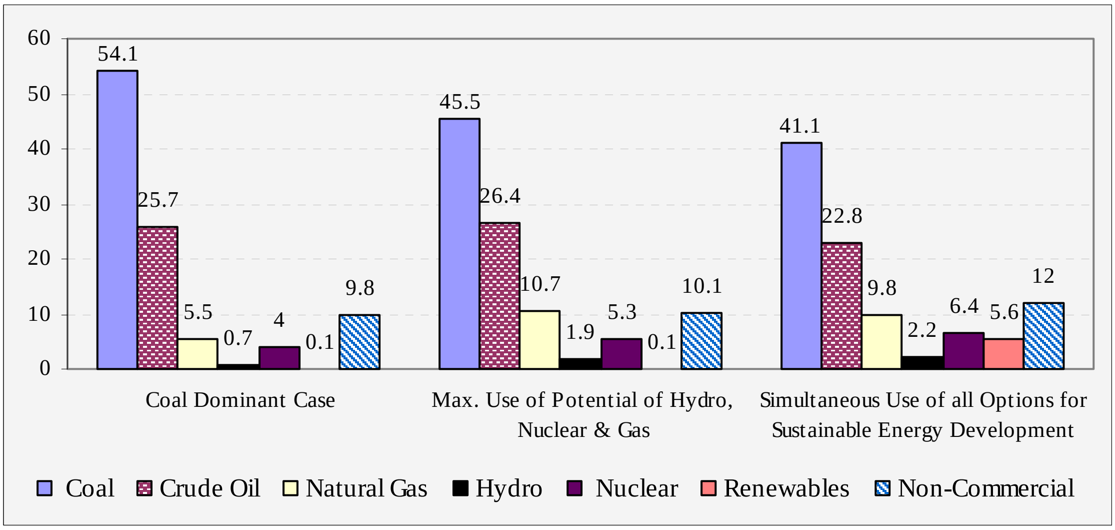
Source: Based on Planning Commission, 2006a.

Chart 12:
Projected Share (%) of Energy Resources in Electricity Generation for Maximum Use of Hydro-Nuclear Potential and GDP Growth Rate of 9%.



Source: Based on Planning Commission, 2006a.

Chart 13:
Energy Resource Mix for 8% GDP Growth in 2031-32 for different Policy Scenarios.



Source: Based on Planning Commission, 2006a.