

Energy Supply, Demand and Environmental Analysis – A Case Study of Indian Energy Scenario

I.V. Saradhi, G.G. Pandit and V.D. Puranik

Abstract—Increasing concerns over climate change have limited the liberal usage of available energy technology options. India faces a formidable challenge to meet its energy needs and provide adequate energy of desired quality in various forms to users in sustainable manner at reasonable costs. In this paper, work carried out with an objective to study the role of various energy technology options under different scenarios namely base line scenario, high nuclear scenario, high renewable scenario, low growth and high growth rate scenario. The study has been carried out using Model for Energy Supply Strategy Alternatives and their General Environmental Impacts (MESSAGE) model which evaluates the alternative energy supply strategies with user defined constraints on fuel availability, environmental regulations etc. The projected electricity demand, at the end of study period i.e. 2035 is 500490 MWYr. The model predicted the share of the demand by Thermal: 428170 MWYr, Hydro: 40320 MWYr, Nuclear: 14000 MWYr, Wind: 18000 MWYr in the base line scenario. Coal remains the dominant fuel for production of electricity during the study period. However, the import dependency of coal increased during the study period. In baseline scenario the cumulative carbon dioxide emissions upto 2035 are about 11,000 million tones of CO₂. In the scenario of high nuclear capacity the carbon dioxide emissions reduced by 10 % when nuclear energy share increased to 9 % compared to 3 % in baseline scenario. Similarly aggressive use of renewables reduces 4 % of carbon dioxide emissions.

Keywords—Carbon dioxide, energy, electricity, message.

I. INTRODUCTION

INDIA is the largest democracy with an estimated population of about 1.05 billion, is on a road to rapid growth in economy. Policy initiatives of the Government of India during the past decade have resulted in a faster growth of GDP and forecasts by several agencies point towards continued growth of the Indian economy over next 30 to 40 years. Energy is a vital input into production and if India is to move with higher growth rate that is now feasible, reliable supply of energy, particularly electric power and petroleum products, at internationally competitive prices is needed. The broad vision behind the energy policy should reliably meet the demand for energy in all sectors. It is a matter of concern that the annual per capita consumption of electricity in India, at about 750 kWh (including captive power generation) [1] is among the lowest in the world. Further, people in a large number of villages have no access to electricity. Environmental concerns are associated with all forms of energy, including fossil fuels,

nuclear energy, renewable throughout the chain from their exploration/mining, transportation and generation to the end-use. Studies on global climate change carried out under Inter-governmental Panel on Climate Change, indicate that global warming due to increase in carbon dioxide levels as a result of human activities is a fact of life. With regard to energy supplies, India has to plan its energy infrastructure based on its resource profile, technology base and human resource. For oil and gas India will become ever more dependent on imports from a few distant, often politically unstable part of the world. Thus it is necessary to review energy situation for short term as well as long term planning.

The present power supply position prevailing in the country is characterized by persistent shortages and unreliability and also high prices for industrial consumer despite impressive growth. There is also concern about the position regarding petroleum products. India depends to the extent of 70 percent on imported oil, which raises issued about energy security. Electricity is domestically produced but its supply depends upon availability of coal, exploitation of hydro power sources and the scope for expanding nuclear power, and there are constraints affecting each source. For efficient utilization of energy, electricity in particular, need long time for developing new technologies and therefore, scenario building is desirable to identify the key areas and initiate research and development. There is also a need for clarity in the direction in which we wish to move in aspects like energy security, research and development, addressing environmental concerns, energy conservation, etc.

To address these issues in an integrated manner, a study has been carried out wherein India's energy demand growth rates, electricity in particular, are reviewed and strategies to meet the projected demand have been chalked out under different scenarios with an objective to i) to study the present and projected energy demand in India, in particular electricity sector and ii) to perform analysis of various scenarios in the electricity sector.

II. INDIAN ENERGY SCENARIO

India is steadily gaining importance in the world energy scene. It is already fifth largest economy and a major energy importer. Even imports of coal the mainstay of the nation's energy resource, is expected to rise. High economic growth in the Asia Pacific region, including India, is spurring a rapid increase in energy consumption. India has seen an expansion in the total energy use for the past five decades, with a shift from non commercial energy to commercial energy sources. The trends in production of primary commercial energy in the past five decades indicate coal as the most abundant among all

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commercial energy sources [1]. Petroleum and natural gas sector has significant growth in the domestic production and supply. Despite increasing dependency on commercial fuels, a sizeable quantum of energy requirements especially in rural household sector, is met by non-commercial energy sources, which include fuelwood, crop residue, animal waste. However, other forms of commercial energy of a much higher quality and efficiency are steadily replacing the traditional energy resources being consumed in the rural sector. Resources augmentation and growth in energy supply has not kept pace with increasing demand and, therefore, India continues to face serious energy shortages. This has led to increased reliance on imports to meet the energy demand. A brief review of commercial energy sources and power generation is presented below.

A. Coal

India is the third largest producer of coal in the world. Major portion of coal produced is consumed by the power sector. In addition other industries like steel, cement, fertilizers, chemicals, paper and other medium and small-scale industries also depend on coal.

The majority of coal reserves are concentrated in states of Bihar, Madhya Pradesh and West Bengal. The total coal reserves of the country upto a depth of 1200 m, as per exploration carried out by Geological Survey of India, estimated 247.85 BT as on January, 2005 [1]. Of this 92.96 BT is in the proven, 117.1 BT in the indicated and 32.97 BT in inferred category. Lignite reserves in the country have been estimated at 35.95 BT as on January, 2005. These reserves are purely based on geological studies.

During 2004-05 domestic production of coal is about 382 million tonnes and net imports are 25.3 million tonnes. Production of lignite was about 24.8 million tonnes. Since some of the major consumption sites in India are located away from the resource locations, and enormous burden is placed on transport infrastructure. Therefore it is important to design comprehensive energy security plan for India as coal is the major contributor to the Indian energy scenario.

B. Oil and Gas

The demand for hydrocarbons is increasing rapidly with the growth in Indian economy. During the year 2004/05 the crude oil and gas production aggregated to 33.98 Million Tonnes and 31.77 Billion Cubic Meter respectively. Also to meet the increasing demand India imported 95.86 Million Tonnes of crude oil in 2004/05 contributing to 75 % of the total supply [1]. To meet the increasing demands government has permitted private sector participation in this field and private entrepreneurs have made significant contribution in discovery of new oil and gas fields. High import dependency is associated with the risks of disruption in supplies on account of such large crude oil imports that can have serious repercussions on the economy.

C. Power Generation

Electricity is one of the most vital infrastructure input for the economic development of a country. In March 2005, India had an installed generating capacity of more than 118419 MW [1]. This includes thermal (80902 MW), hydro (30936 MW), nuclear (3850 MW), Wind (2980) and other renewables (831

MW). The contribution of nuclear power generation is increased to 4070 as on October, 2007 [2]. It can be seen that thermal power plants contribute to around 68 % followed by hydro 26 %, nuclear 3 %, wind 2 % and other renewables 1%. The annual electricity generation in the utilities is presently about 587 BU. Additionally there is also captive power generation of 71.58 BU. Coal is the dominant fuel used in the power sector. The per capita consumption of electricity in India increased from 191 kWh in 1986/87 to 592 kWh in 2003/04 [1]. However there are large inter regional variations in per capita electricity consumption ranging from 192.33 kWh to 837.2 kWh. Industrial sector is one of the largest consumers of electricity in most of the states in India. Besides purchasing power from utilities, a number of industries such as aluminium, cement, iron and steel, paper, fertilizer, textiles and sugar have established their own captive power plants. These captive plants are intended not only to supplement the electricity purchased, but also for emergency use in case of power cuts and failures.

D. Hydro Energy

The hydro electric potential in India has been estimated to be 150,000 MW [3]. The hydroelectric potential is not evenly located with 83 % in the North and North-East region. As on March 2005, only about 31 GWe has either been developed or is being developed. In the last decade the development of hydroelectric power, which was expected to represent 40 % of generation capacity, actually slowed down. The reasons include high capital investment, time lag between feasibility studies and commissioning, environmental requirements and public opinion etc. Recently Ministry of Power has initiated several steps to accelerate the capacity addition of hydroelectric projects to utilize hydroelectric potential of the country. Hydroelectric initiative for development of 162 new hydroelectric plants spread across 16 states in the country with aggregate 47,930 MW has been launched.

E. Non-conventional Renewable Energy

The estimated potential of non-conventional renewable energy resources in our country is about 100 GWe [4]. Wind, small hydro and biomass Power have greater potential with solar PV, solar thermal and waste-to-energy being the other important components. All these resources will be increasingly used in future especially in remote areas. The medium term goal is to ensure atleast 10 GWe from renewable sources by 2012 [5]. Good progress has been made in the field of wind power and installed capacity additions in the recent years have been quite impressive. However wind mills have, so far, reported very poor capacity factors [4].

F. Nuclear Energy

In India at present indigenously built nuclear power plants are of Pressurized Heavy Water Reactor (PHWR). Based on such reactors nearly 330 GWe-yr of electricity can be produced for domestic uranium resource, which is equivalent to about 10 GWe installed capacity of PHWRs running at a lifetime capacity factor of 80 % for 40 years. This uranium on multiple recycling through the route of Fast Breeder Reactors (FBR) has the potential to provide about 42,200 GWe-yr assuming utilization of 60 % of heavy metal, percentage utilization being an indicative number [4]. FBR generation

potential indicated above is equivalent to an installed capacity of about 530 GWe operating for 100 years at a lifetime capacity factor of 80 %. The thorium reserves, on multiple recycling through appropriate reactor systems, have the potential of about 150,000 GWe-yr, which can satisfy India's energy needs for a long time.

To utilize the resources appropriately a three-stage nuclear power programme has been chalked out by the Department of Atomic Energy. It is planned to install nuclear power capacity of about 20 GWe by the year 2020. The second stage of the nuclear power programme involves building a chain of fast breeder reactors multiplying fissile material inventory along with the power production. Subsequently building FBRs will be the mainstay of the nuclear power programme in India. The third stage consists of exploiting country's vast resources of thorium through the route of fast or thermal critical reactors or the accelerator driven sub-critical reactors (ADS).

III. RESOURCES AND DEMAND

In recent years, India's energy consumption has been increasing at one of the fastest rates in the world due to population growth and economic development. Primary commercial energy demand grew at the rate of six percent between 1981 and 2001. Despite the overall increase in energy demand, power capital energy consumption is still very low compared to other developing countries.

India is well endowed with both exhaustible and renewable energy resources. Coal, oil and natural gas are the three primary commercial energy sources. India's energy policy till the end of 1980s was mainly based on availability of indigenous resources. Coal was by far the largest source of energy utilized. The different energy resources available in the country are given in Table I [6]. The maximum indigenous coal availability can at best be increased by a factor of 2 to 3 from the current production levels. The estimated hydrocarbon reserves (about 12 BT) together may provide about 1200 EJ of energy. Uranium and thorium resources are much higher than the fossil fuel resources clearly makes a case

TABLE I
INDIA'S ENERGY RESOURCE BASE

	Amount	Thermal Energy			Electricity Potential GWe-Yr
		EJ	TWh	GW-Yr	
Fossil					
Coal	38 BT	667	185279	21151	7614
Hydrocarbon	12 BT	511	141946	16204	5833
Non-Fossil					
Nuclear					
Uranium-Metal	61000 T				
In PHWR		28.9	7992	913	328
In Fast Breeders		3699	1207616	117308	42231
Thorium-Metal	225000 T				
In Breeders		13622	3783886	431950	155502
Renewable					
Hydro	150 GWe	6.0	1679	192	69
Non-Conventional Renewables	100 GWe	2.9	803	92	33

Source: Sudhinder Thakur and Sekar, 2005

for deployment of nuclear technologies for power generation to ensure long term energy security.

To meet the increasing demand one has to tap all the resource base including exploration of additional fossil fuel resource base, competitive import of energy, harnessing full hydro potential for generation of electricity and increasing use of non-fossil resources including nuclear and non-conventional energies. Nuclear fuel resources have the potential of significantly reducing the gap in the demand and supply of energy particularly in the situations of GHG restrictions if any.

In a study carried out by Government of India to formulate an Integrated Energy Policy has made projected energy requirements as well as electricity requirements based on growth of economy, population growth, the pace at which non-commercial energy is replaced by commercial energy, progress of energy conservation, increase in energy efficiency as well as societal and lifestyle changes. Table II presents the projected electricity requirements [7]. With this background on energy and electricity it is proposed to study the future scenario under different options of available technologies to meet the required demand.

IV. STUDY OF INDIAN ELECTRICITY SECTOR

To study the various technology option available for meeting the electricity demand in future upto 2035 an optimised energy system is developed for the given supplies and utilization requirements using the package MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impacts) [8]. In MESSAGE, the whole electricity supply system is represented as an oriented network of technologies and activities, starting from extraction or supply of primary energy, passing through energy conversion processes (e.g. electricity generation), to transmission and distribution to meet the given demand for final energy in the industry, transportation, household and service sectors. In this oriented energy network the links represent technologies of electricity whilst the nodes represent

TABLE II
PROJECTIONS FOR ELECTRICITY REQUIREMENTS

Year	Billion kWh				Projected Peak Demand (GW)		Installed Capacity Required (GW)	
	Total Energy Requirement		Energy Required at Bus Bar		@ GDP Growth rate		@ GDP Growth rate	
	@ GDP Growth rate		@ GDP Growth rate		8 %	9 %	8 %	9 %
	8 %	9 %	8 %	9 %	8 %	9 %	8 %	9 %
2003-04	633	633	592	592	89	89	131	131
2006-07	761	774	712	724	107	109	153	155
2011-12	1097	1167	1026	1091	158	168	220	233
2016-17	1524	1687	1425	1577	226	250	306	337
2021-22	2118	2438	1980	2280	323	372	425	488
2026-27	2866	3423	2680	3201	437	522	575	685
2031-32	3880	4806	3628	4493	592	733	778	960

Source: Integrated Energy Policy, 2006

energy forms (e.g. electricity). Both existing technologies and candidate technologies for future system expansion are included in the network. Technologies are represented by set of parameters such as investment costs, fixed and variable costs, energy conversion efficiencies, historical capacities, availability factors, emission factors and others.

The mathematical method used in the MESSAGE model is linear programming, which means that all technical and economic relations describing the energy system are expressed in terms of linear functions. The optimisation criterion of the MESSAGE model is the minimization of the present value of the cumulated costs of the energy system throughout the planning period. The planning period is user-defined. In this study, a medium term time scope of 30 years is chosen. The period of the study is from 2005 to 2035. Discount rate of 5 % is used for all the investments. Four seasons are considered for each year. A typical model is constructed for Indian electricity network by specifying characteristics of a set of technologies and defining a reference electricity system, which include all the possible technologies. The model will then determine how much of the available technologies and resources are actually used to satisfy a particular end-use demand, subject to various constraints, while minimizing total discounted costs.

The decision variables in the model optimisation are energy flows and capacities of technologies. The model variables are determined subject to a system of constraints, representing structural and technological properties of the energy system, existing stock of equipment, projected energy demand, energy policies and environmental protection policies etc.

As a result of the optimisation of using the MESSAGE model a least-cost intertemporal mix of energy supply technologies can be found. Strategies for future energy supply structure can be formulated, and different emission control strategies can be compared with respect to their emission reduction efficiencies and their impact on structure and economic performance of the energy system.

After analysis the final electricity demand is divided into five categories for the study. The categories include industrial electricity, residential electricity, electricity for transport, commercial electricity, and electricity for agriculture. The projected future demands of the final electricity consumption by different categories are studied under various scenarios. The growth rates of electricity considered for the present study is 1.063 per annum, upto 2025 and 1.049 from 2025 to 2035 [4] for 8 % growth of GDP for business-as-usual scenario. The various technologies utilized for conversion of the resources available into end use demand are represented in electricity flow network for business-as-usual scenario.

A. Scenario Development

Scenarios provide framework for exploring future energy perspectives, including various combinations of technology options and their implications. Scenarios are useful tools for investigating alternative future developments and their implications for learning about behaviour of complex systems, and for policy making. Five alternative development scenarios discussed below are studied in the present analysis

1) Business-as-usual Scenario

This scenario is characterized by most likely path of development in the absence of any major intervention. This

scenario incorporates existing government plans and policies. In this scenario 8 % growth rate of GDP is considered over entire modeling framework. In this scenario deployment of clean technologies and penetration of technologies are assumed as per the existing trends and proposed projects for nuclear and renewables. The nuclear energy based power generations capacity is assumed to the extent of 20 GW and renewables upto 45 GW.

2) Low Growth Scenario

The scenario assumes a low growth of GDP at the rate of 6 % per annum. All other assumptions with respect to technologies and other parameters are similar to those in business-as-usual scenario.

3) High Growth Scenario

The scenario assumes a high growth of GDP at the rate of 10 % per annum. All other assumptions with respect to technologies and other parameters are similar to those in business-as-usual scenario.

4) High Nuclear Scenario

In this study nuclear-based power generation is expected to increase to 6.8 GW by 2012 and further to 14 GW by 2017, 55 GW by 2027 and 63 GW by 2032. The high nuclear energy based power generation has been assumed in view of the latest development in the nuclear sector due to enhanced international cooperation and Government of India's initiative in this direction. This scenario considers aggressive pursuit of nuclear energy based power generation driven by the assumption that the country is able to import fuel. This scenario assumes a projected GDP growth rate of 8 % similar to business-as-usual scenario.

5) Aggressive Renewables Scenario

In this scenario, high penetration of renewable energy is considered. The lower bound of installed capacities considered by 2035 for 45 GW, 10 GW, 8 GW and 8 GW for wind, small hydro, solar and biomass respectively. The maximum capacities considered in the study are the expected potentials of these technologies. This scenario also assumes a projected GDP growth rate of 8 % similar to business-as-usual scenario.

V. RESULTS AND DISCUSSION

A. Business-as-usual Scenario

The results of the study carried out using MESSAGE model for business-as-usual scenario of Indian electricity system are discussed in this section. Fig.1 gives the share of power technologies in future from 2005 to 2030 for the business-as-usual scenario. The total electricity consumption increased by 6.2 times during the study period. Coal remains the dominant fuel during the entire study period. The contribution from nuclear is becoming increasingly significant towards the end of the study period without any special intervention. The nuclear capacity is limited to 20GW in business-as-usual scenario. The contribution of hydropower steadily decreased during the study period. The contribution of wind power technology also significantly increased during the study period in this scenario up to maximum potential of 45 GW as it is available at competitive price. Although coal remains dominant fuel during the study period, with limited domestic production capacity, the import dependence of coal found to

be about 70 % by 2035. The contributions from oil is forcibly limited during the initial study period as the same will be utilized in other commercial energy sectors like transport industry. Fig.2 shows the variation in percentage share of commercial fuels over the modeling time frame. At the end of the study period the percentage share of coal, gas, oil, hydro, nuclear and wind are 81, <1, 4, 8, 3 and 4 respectively. The model indicates that hydro power is also utilized to the potential of 84 GW but the percentage share of hydro power in the total power generation is reduced to 8 %

If the new installed capacities of various electricity generation technologies during the study period for business-as-usual scenario are observed the new coal based power plants are coming up during entire study period. Nuclear power plants are coming up from 2015 to 2030. The wind and hydro power plants are coming up uniformly during the entire study period.

B. Inter-scenario Comparison

The comparative analysis of the key results across all the scenarios is presented in this section. It also provides a deeper insight into the variations in the final electricity consumption under alternative sets of assumptions. In the business-as-usual scenario the electricity consumption increased by 6.2 times over the study period where as in low growth scenario and high growth scenario the electricity consumption increased by 4.4 and 9 times respectively.

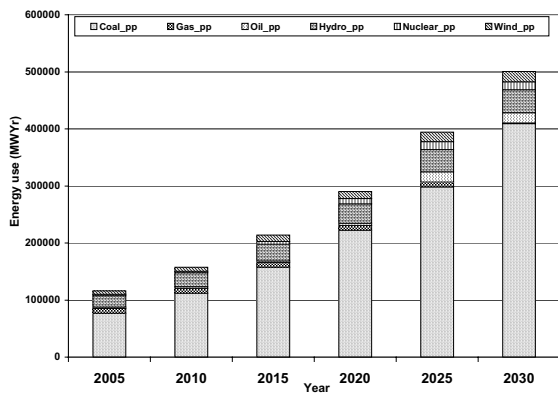


Fig.1 Commercial energy use in the business-as-usual scenario (MESSAGE model output)

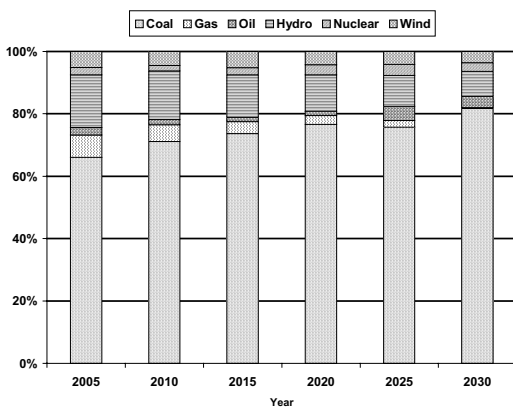


Fig.2 Percentage share of fuel mix (Business-as-usual scenario)

Fig.3 presents the electricity consumption (MWYr) during 2010, 2020 and 2030 for business-as-usual, low growth and high growth scenarios. The total electricity generation capacity at the end of the study period across various scenarios found to be about 650 GW, 420 GW and 850 GW for business-as-usual, low growth and high growth respectively. The coal based capacity for the business-as-usual scenario is about 500 GW at the end of study period.

In high nuclear scenario the percentage share of electricity consumption from nuclear increased to 9 % compared to that of 3 % in the business-as-usual scenario. Similarly in aggressive renewable scenario the percentage share of electricity consumption from renewables increased to 6.2 % compared to that of 4 % in the business-as-usual scenario.

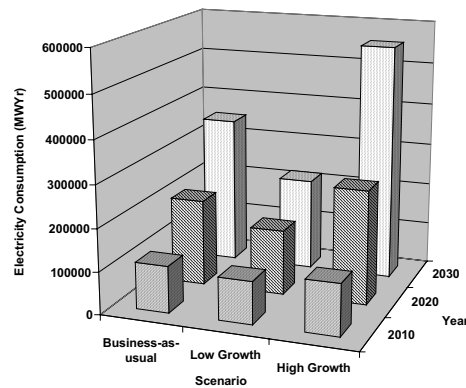


Fig.3 Comparison of electricity consumption across various scenarios

C. Carbon dioxide Emissions

The cumulative carbon dioxide emissions for the study period from 2005 to 2035 in each of the scenarios are presented in Table III. These emissions are significantly lower (33 % approximately) in low growth scenario. The high nuclear scenario also reduced 10 % carbon dioxide emissions compared to business-as-usual scenario. Similarly aggressive renewables scenario reduced 4 % carbon dioxide emissions compare to business-as-usual scenario.

TABLE III
CUMULATIVE CARBON DIOXIDE EMISSIONS FOR DIFFERENT SCENARIOS (2005-2035)

Scenario	Cumulative CO ₂ emissions (million tones)
Business-as-usual	11151
Low growth	7473
High Growth	16409
High Nuclear	10135
Aggressive Renewables	10755

VI. CONCLUSIONS

Coal remains the dominant fuel for production of electricity during the study period. Introduction of high nuclear capacity replaces coal to some extent and also contributes to 10 % reduction in carbon dioxide emissions. Introduction of renewables also replaces coal to some extent and contributes to 4 % reduction in carbon dioxide emissions. Further scenarios can be designed in the form of hybrid scenario

where both nuclear and renewables capacity can be increased along with full utilization of hydropower to reduce the dependency of coal. Scenarios can also be designed by introducing limitations of carbon dioxide emission restrictions in the form of constraints (inline with the possible restrictions to India during Post-Kyoto period) and the trends can be studied.

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