IMPACT OF RENEWABLE ENERGY SOURCES IN POWER SUPPLY OF INDIA– A SYSTEM DYNAMICS APPROACH

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Abstract - In this paper, an attempt is made to answer the question: Can renewable energy sources eventually supply India's electricity needs in the future? In particular, we examine the total potential of renewable energy sources in India and extent to which they can supply these needs. The estimates made here indicate that even with a frugal per capita electricity need of 2000 kWh/annum and a stabilized population of 1500 million by 2025, India would need to generate approximately 3000 TWh/yr. As opposed to this, a systematic analysis of the information available on all the renewable energy sources indicates that the total potential is only around 1000 TWh/yr. It is concluded that in the future as fossil fuels are exhausted, renewable sources alone will not suffice for meeting India's needs.

Keywords *- Electricity, future needs, per capita basis, population estimates, renewable energ.*

I. INTRODUCTION

India's economy is growing at the rate of 8% or 9% every year for the past few years, and a high growth rate is projected for the years ahead. This implies a high growth rate in the consumption of commercial energy, which includes electrical energy. The focus in this paper is on the future needs of electricity in India. In particular, we examine the total potential of renewable energy sources in India and the extent to which they can supply these needs.

Renewable energy sources thus represent important pillars for the long-term development of the electricity sector in the given context. A wide gap can be observed between the supply and demand in the present scenario which can further increase if we rely mainly on depleting non-renewable resources.

A. The Present Scenario

We begin by studying the electrical energy scene today. Data on the installed capacity of commercial energy units and the electricity produced are presented in Table 11. It can be seen from Table 1 that the total installed capacity on 31 December 2010 was 171,644 MW and the total amount of electricity produced in 2009–2010 was 801,828 GWh. Using a population estimate of 1200 million, the amount available on a per capita basis comes to 597 KWh/yr. The contribution of various energy sources is also given in Table 1. It can be seen that fossil fuels – coal, lignite, oil and natural gas – were the principal contributors. Together, they supplied 640,538 GWh (79.9%) of the electricity produced, with coal and natural gas dominating. Renewable sources – large and small hydro-electric power units, wind energy and biomass power – contributed 142,654 GWh (17.8%) to the total. The largest contribution (13.6%) came from large hydro-electric power units. Nuclear energy contributed only 18,636 GWh (2.3%).

	Installed capacity (as on 31 December 2010)		*Electricity produced in 2009–2010*	
Energy Source	MW	%	GWh	%
Coal + lignite	*92378*	*53.8*	*539,501*	*67.9*
Oil	*1200*	*0.7*	*7,878*	*1.0*
Natural gas	*17456*	*10.2*	*93,159*	*11.6*
Hydroelectric (large)	*37367*	*21.8*	*109,255*	*13.6*
Nuclear power	*4560*	*2.7*	*18,636*	*2.3*
Wind power	*13065*	*7.6*	*18,187*	*2.3*
Biomass power	*2664*	*1.6*	*7,001*	*0.9*
Hydroelectric (small)	*2953*	*1.7*	*8,211*	*1.0*
Total	**171644**	**100.0**	**801,828**	**100.0**

Table 1. Source-wise break-up of installed capacity on 31 December 2010 and electricity produced in 2009–2010 (captive power not included)

B. Benchmarking Future's Needs

We will first obtain an estimate of India's needs for electricity in the future. A rational way of planning and projecting the future is to consider the electrical energy required on a per capita basis to satisfy basic human needs and to multiply this number by the population of the country.

II. LITERATURE REVIEW

A. Energy Planning – Per Capita Needs

Goldemberg.5,6 carried out a seminal study on per capita energy needs. They performed their calculations by considering various activities grouped under the broad headings of residential, commercial, transportation, manufacturing, agriculture, mining and construction, and evaluating the energy inputs under each activity. Adding all these inputs, they arrived at the result that in a country like India, the average requirement of power on a per capita basis would be

210 W of electricity, which corresponds to an annual electricity requirement of 1840 kWh.

An essential feature of the calculation done by Goldemberg5,6 was that it was based on the adoption of high-quality energy carriers and energy-efficient technologies in every activity, even if the use required higher initial investments. Since the study was conducted many years ago, it is likely that the energy requirements generated by it would have decreased by 10% or 20% because the efficiencies of most devices and systems have increased over the year.

Before we can make predictions for the future needs for electrical energy, it will be necessary to answer the following question: What is the per capita value for electrical energy which India should aim for in the long run?

Should we try to increase the availability from the present value of about 600 kWh and eventually match the large per capita values (greater than 10,000 kWh) which exist today in most Western countries, or should we be satisfied with values which are not very different from those obtained by Goldemberg5,6?

Although it would be nice to imagine a future in which the people of India would have at their disposal plentiful supplies of electricity, such is not likely to be the case. Given the size of our population, the limitations of our energy resources and the environmental issues involved, it would be wise for the nation as a whole to plan for a simple lifestyle. Our most viable option would be to provide annual per capita electricity availability around 2000 kWh and no more. Such frugal use of energy may be the only way to ensure sustainable development in the future. Studies indicate that with the present economic growth rate, a per capita value of 2000 kWh would probably be reached in about 20 years 7,8.

Support for the suggestion that a per capita electricity production around 2000 KWh should be adequate also comes from the notion of the human development index (HDI). HDI is an empirical parameter dependent on the life expectancy, educational level and per capita income in a country. Its value ranges between 0 and 1. When HDI values for various countries are plotted against per capita electricity generation and an average curve is drawn, it is seen that the HDI values increase significantly from about 0.6 to 0.8 as the per capita electricity generation increases from about 600 to 2000 kWh. Thereafter, the value increases slowly from about 0.8 to 0.9, even though the generation increases three times from 2000 to 6000 KWh.

B. Population Estimate

Next, we predict India's future population. Table 2 presents data on the population at 10-year intervals, starting in 1951. The percentage growth over the intervals is also given. Data for 1951–2001 are actual values, while those for 2011 are preliminary values based on the on-going census2. It is seen that the population has grown from 361.1 million in 1951 to 1210 million in 2011.

Year	Population (in million)	Percentage change in 10 years
1951	361.1	–
1961	439.2	21.6
1971	548.2	24.8
1981	683.3	24.6
1991	846.6	23.9
2001	1027.0	21.4
2011	1210.0	17.8
2021	1381.7	14.2
2031	1514.3	9.6
2041	1605.2	6.0
2051	1659.7	3.4
2061	1686.3	1.6
2071	1693.0	0.4
2081	1693.0	0.0

Table 2. Population of India – past data and future predictions

It is also seen that the percentage increase in the six decades from 1951 to 2011 has gone up from 21.6 to 24.8, where it has peaked. Subsequently, the percentage growth has decreased slowly to 24.6 and 23.9 and then more rapidly to 21.4 and 17.8. This is along expected lines. The Population Foundation of India (PFI) has made projections of India's future population3. Utilizing the growth values of 14.2% and 9.6% for the next two decades used by PFI, we predict values of 1382 million and 1514 million for 2021 and 2031 respectively.

In Table 2, population for 1951–2001 is based on actual data. Population for 2011 is a provisional number based on on-going census. Population for 2021 and 2031 is predicted on the basis of 10-year growth rates obtained by the Population Foundation of India. Population for 2041 onwards is predicted on the basis of a 10-year growth rate gradually declining to zero.

C. *Present Electricity Supply*

As per the surveys conducted by International Energy Agency4 the following data regarding the electricity supply of India for the year 2009 is tabulated below.

	Electricity (in GWh)
Production from:	
coal and peat	616584
oil	26099
gas	111206
biofuels	1995
nuclear	18636

hydro	106909
solar (PV + thermal)	27
wind	17933
Total Production	**899389**
Import	10533
Export	519
Domestic Supply	909403
Losses	219866
Energy industry own use	57663
Final Consumption	**702144**

Table 3. Electricity in India in 2009

III. METHODOLOGY

A. Identify the various variables

The various variables identified within the scope of the project are – population, births, deaths, total electricity requirement, non-renewable energy supply, total energy supply and the difference between the demand and the supply.

B. Develop inter-relationship between variables

The following inter-relationships have been developed amongst the identified variables.

- Population = births – deaths
- Total Electricity requirement = per capita electricity requirement * population
- Renewable Energy supply = solar + hydro + biofuel + wind + gas + nuclear
- Non-renewable Energy supply = compound indicator * population
- Total Power generated = Renewable energy supply + Non-renewable Energy supply
- Total power available = Renewable supply + Non-renewable supply + imports – exports – losses
- Difference between demand and supply = Total electricity requirement – Total power available

C. Create Causal loop diagrams

A causal loop diagram is a simple map of a system with all its constituent components and their interactions. By capturing interactions and consequently the feedback loops (see figure below), a causal loop diagram reveals the structure of a system. By understanding the structure of a system, it becomes possible to ascertain a system's behavior over a certain time period. The following shows an example of the causal loop diagram used in the modeling describing the dependency of the variable population on birth rate and death rate.

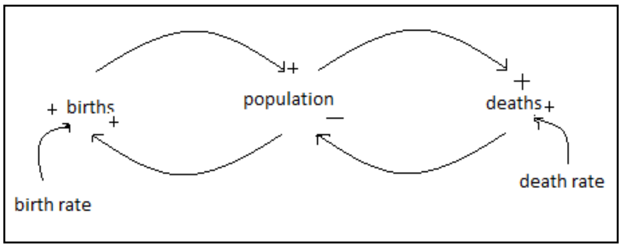

Fig.1 : Causal loop diagram for population changes

D. 3.4 Model using Stock and Flow diagrams

Causal loop diagrams aid in visualizing a system's structure and behavior, and analyzing the system qualitatively. To perform a more detailed quantitative analysis, a causal loop diagram is transformed to a stock and flow diagram. A Stock and flow model helps in studying and analyzing the system in a quantitative way, such models are usually built and simulated using computer software.

A stock is the term for any entity that accumulates or depletes over time. A flow is the rate of change in a stock.

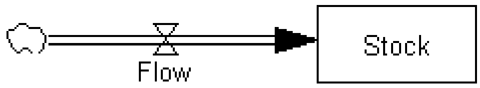

Fig. 2 : A flow is a rate of accumulation of stock

The following shows the stock and flow model of the causal diagram shown in Figure 1.

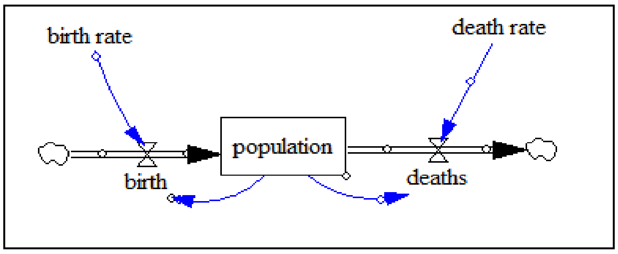

Fig. 3: Stock and Flow diagram for the population changes

The following stock and flow diagram is constructed and simulated in Vensim PLE to carry out a quantitative study of the various variables under consideration.

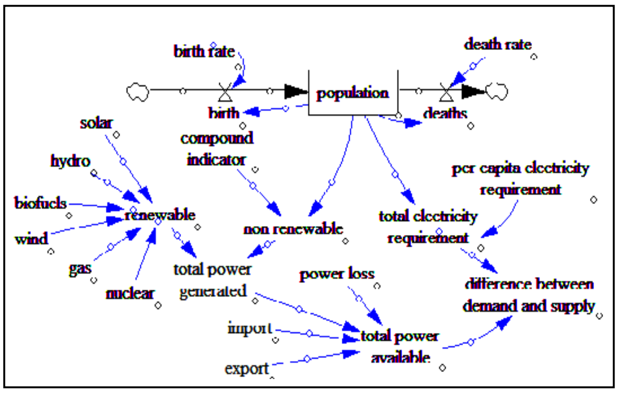

Fig. 4 : Stock and flow diagram to study the contribution of various power supply source to meet the electricity demand

IV. RESULTS ANALYSIS

A forecast is made from the simulated model for different variables from 2009 to 2025. The change in these variables is observed over this period and is represented graphically below.

Figure 5 shows the population variation in the period under consideration. We can observe that the population of India is increasing at a good rate and is expected to cross 1.5 billion somewhere in the year 2022. This again validates the projection made by The Population Foundation of India (PFI) as mentioned in section 3.2 (population estimation).

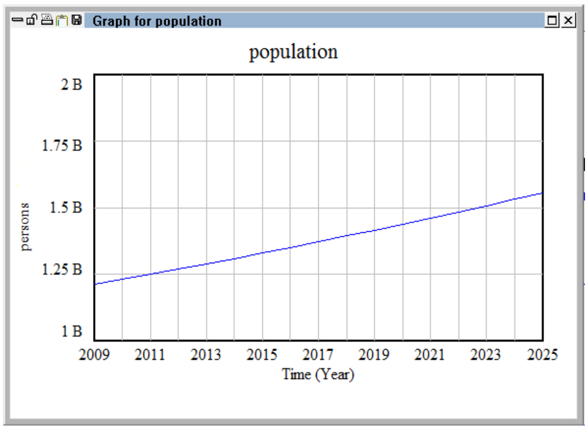

Fig. 5: A forecast of the population of India till 2025

In 2009, the potential of renewable sources of energy was approximately 250 TWh. In the future the use of non-renewable sources is expected to rise with the rise in population in order to meet the demand. Figure 6 shows the expected rise in the use non-renewable sources during the period of consideration along with the variation of population in the same time period.

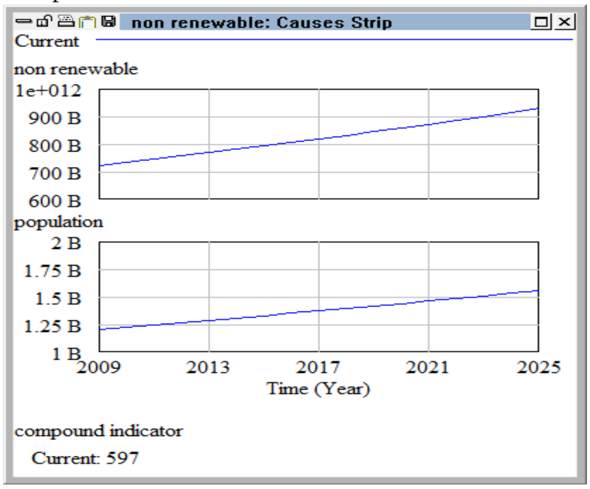

Fig. 6 : Forecast of utilization of non-renewable sources in future

The figure 7 shows the comparison of the electricity supply, demand and their difference over a period of 16 years from 2009 to 2025. The observations from the figure are tabulated below in Table 4.

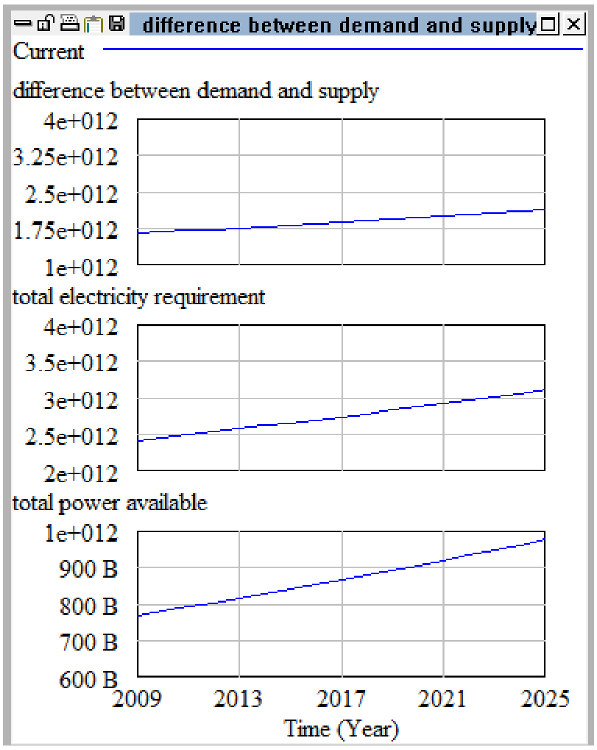

Fig. 7 : Comparison between the supply and the demand for electricity and their difference

Year	Supply (in TWh)	Demand (in TWh)	Difference (in TWh)
2009	780	2400	1620
2013	810	2600	1790
2017	860	2700	1840
2021	910	2900	1990
2025	990	3100	2110

Table 4. Observations

We can observe a great gap between the demand and the supply of electricity presently. This gap is expected to further increase in the future if we rely only on non-renewable sources of energy for our electricity supply without any increase in the production from renewable sources.

V. SUMMARY

The major finding emerging from this study is by the year 2025; India will need to produce 3100 TWh of electricity annually. This is approximately four times of its present generation. This amount will be needed despite of setting a low benchmark of 2000KWh per capita annual electricity requirement.

Presently, a large gap is there between the demand and the supply. Since, fossil fuels will extinguish in future, the renewable sources of energy have to play a significant role in order to achieve sustainability. Hence, the potential of renewable energy sources is the key to meet the demand.

REFERENCES

[1] Monthly Report (December 2010) and Annual Report 2009–2010. Central Electricity Authority, Ministry of Power; www.cea.nic.in/sitemap.html (accessed in June 2011).

[2] Population of India, 1951–2011; exim.indiamart.com/economicsurvey/pdfs/tab97.pdf and www.censusindia.gov.in (accessed on 5 July 2011).

[3] Srinivasan, K. and Shastri, V. D., A set of population projections of India and the larger states based on 2001 census results. Population Foundation of India,2001; planningcommission.nic.in/reports/genrep/bkpap2020/25_bg2020.pdf (accessed in June 2011).

[4] International Energy Agency;

http://www.iea.org/stats/electricitydata.asp?COUNTRY_CODE=IN

[5] Goldemberg, J., Johansson, T. B., Reddy, A. K. N. and Williams, R. H., Basic needs and much more with one kilowatt per capita. Ambio, 1985, 14, 190–200

[6] Goldemberg, J., Johansson, T. B., Reddy, A. K. N. and Williams, R. H., Energy for a Sustainable World, Wiley Eastern Ltd, New Delhi, 1988.

[7] Grover, R. B. and Chandra, S., Scenario for growth of electricity in India. Energy Policy, 2006, 34, 2834–2846.

[8] National energy map for India. The Energy and Resources Institute, New Delhi, 2006.

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