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Modeling of Integrated Energy System for Power Generation in India

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ABSTRACT

Energy is supplied in the form of electricity, heat or fuels and an energy supply system must guarantee sustainable energy supplies, production and distribution of energy. A system which can be utilized as integrated energy system which can satisfy the electricity needs of the country in appropriate and sustainable manner is developed in this paper. Integrated Energy System for electricity generation is modeled and optimized using LINGO 10.0 software. The objective function targets at minimizing the cost and the constraints take care of various other factors such as demand, potential, reliability and emission. The production and demand for various energy sources in India is estimated with the help of data from various government departments. The electricity optimization model is prepared for the base year i.e. 2004. This model is a top-down optimization which requires energy requirements as a prerequisite. This model can be used to forecast the future energy mix for electricity generation in India. It is found that for the base year, 56.76% of the total demand is met by coal indicating that the country is mostly dependent on coal which is the primary energy resource. Gas meets about 8.21% of the total electricity demand while from nuclear energy only 0.875% of demand is being met. Whereas amongst the renewable energy sources hydro meets 10.61% of the total demand while wind meets 17.33% and biomass 6.2% of the total demand. Oil and Solar PV does not contribute to meeting the energy demand, as the unit cost of electricity generation from these sources is comparatively higher.

Key words: *Integrated energy system, optimization model, LINGO 10.0, forecast*.

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1. INTRODUCTION

The energy requirement in India is steadily increasing and this requirement is being met by both commercial and renewable energy sources. India faces formidable challenges in meeting its energy needs and providing adequate energy of desired quality in various forms to users in a sustainable manner and at reasonable costs. Due to the non-availability of sufficient resources and a considerable amount of emission of pollutants from commercial energy, it is now being felt that renewable energy has to be utilized to a greater extent. India needs to sustain a high economic growth to eradicate poverty and meet its economic & human development goals. Such economic growth would call for increased demand for energy and ensuring access to clean, convenient and reliable energy for all to address human development. To deliver a sustained growth of 8% through 2031, India would, in the very least, need to grow its primary energy supply by 3 to 4 times and electricity supply by 5 to 7 times of today's consumption. A top down optimization model has been developed to determine the optimum allocation of different energy sources, conventional and non-conventional for electricity generation. The aim is to provide energy security by proper utilization of available energy resources and long term sustainability and security.

2. LITERATURE REVIEW

A number of optimization models have been developed for renewable energy allocation at both the macro and micro level of energy planning. Optimization and simulation models have been applied to renewable energy systems modeling. Samarakao *et al.* (1988) demonstrated the use of optimization and embedded simulation to establish the least cost configuration of an isolated wind/PV/diesel system with battery backup [1]. The model was implemented using two different non-linear optimization packages. Hernandez (1997) presented a thermo-economic optimization and cost-benefit balance to sanction the substitution of fossil fuel fed energy systems by renewable energy sources [2]. The model was analysed on economic-environment criteria.

Mourelatos *et al.* examined the impact of CO_2 reduction policy on the strategic planning of the energy sector [3]. The conflicts between economic and environment goals influencing the penetration of renewable energy sources (RES) were studied. In the linear programming model, energy flows were optimized with respect to the system's economic efficiency. Chedid *et al.* (1999) provided a methodology for the optimization of an electrical distribution network when upgraded by renewable energy technologies. A multi-objective linear programming model was used in conjunction with fuzzy logic [4].

Optimization models had been applied by researchers to Indian conditions for modeling renewable energy systems. Sinha and Kandpal (1991) had developed a linear programming model for determining an optimal mix of technologies for domestic cooking in the rural areas of India [5]. A mathematical model involving common sources (including biomass, commercial and solar) and commercially available technologies is formulated along with the detailed technoeconomics of the different energy conversion routes. Similar exercise has been done for irrigation and lighting. Minimizing cost was chosen as the objective in all cases.

Joshi *et al.* had developed a linear programming model for decentralized energy planning for three Nepalese villages. The model sought to optimize energy sources as a function of energy conversion efficiencies for different end-uses [6].

A linear programming model had been developed for India by Srinivasan and Balachandra, taking into account different energy sources that can provide different end-use services through different end-use devices [7]. This micro-level energy planning model was developed for Bangalore North Taluk.

Suganthi and Samuel had developed a macro level energy planning model which maximized the GNP-energy ratio [8]. It determined the optimum allocation of commercial energy and renewables for emission reduction from commercial energy utilization.

Iniyan and Jagadeesan (1999) had developed a renewable energy optimization model for India. The model considered the allocation of renewable energy sources in different end-uses. It optimized the cost and efficiency of the system [9].

The literature review reveals that the electricity model taken up in this paper which includes allocation of conventional as well as renewable energy sources has not been taken by others till date.

3. THE ENERGY SCENE IN INDIA

India, the seventh largest energy consumer in the world plans for major infrastructure investments to keep pace with the growing demand particularly for the electric power and for the imports of LNG to supply power projects. Oil accounts for about 30% of the total energy consumption. Coal satisfies most of India's energy requirement. India is the third largest coal producer in the world after China and USA. An exponential growth in natural gas utilization is expected. The domestic gas supply is unlikely to keep pace with domestic gas demand. To meet this constantly growing commercial energy demand, India has to depend to a large extent on imports. On the renewable energy front, after the creation of a separate Ministry

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in 1992, special emphasis was given in the Eighth Plan to the generation of grid quality power from renewable energy sources.

3.1. COAL

Coal is the most important & abundant fossil fuel in India and accounts for 55% of India's energy need. India's industrial heritage was built upon indigenous coal, largely mined in the eastern and the central regions of the country. India is, however, poorly endowed with oil assets and has to depend on crude imports to meet a major share of its needs (around 70 percent). A large population of India in the rural areas depends on traditional sources of energy such as firewood, animal dung and biomass. The usage of such sources of energy is estimated at around 155 mtoe per annum or approximately 47 percent of total primary energy use.

Coal has been recognized as the most important source of energy for electricity generation in India. About 75% of the coal in India is consumed in the power sector. In addition, other industries like steel, cement, fertilizers, chemicals, paper and thousands of medium and small-scale industries are also dependent on coal for their process and energy requirements. In the transport sector, though direct consumption of coal by the Railways is almost negligible on account of phasing out of steam locomotives, the energy requirement for electric traction is still dependent on coal converted into electric power.

The coal reserves of India up to the depth of 1200 m have been estimated by the Geological Survey of India at 247.85 billion tonnes as on January 1, 2005 of which 92 billion tonnes are proven. Hard coal deposits spread over 27 major coalfields are mainly confined to eastern and south central parts of India.

The lignite reserves in India are estimated at around 36 billion tonnes, of which 90% occur in the southern State of Tamil Nadu. 4150 million tonnes (mt) spread over 480 sq km is in the Neyveli Lignite fields in Cuddalore District of which around 2360 Mt have been proved. Geological reserves of about 1168 mof lignite have been identified in Jayamkondacholapuram of Trichy District of Tamilnadu. In Mannargudi and East of Veeranam, geological reserves of around 22661.62 Mt and 1342.45 mt of lignite have been estimated respectively. Other states where lignite deposits have been located are Rajasthan, Gujarat, Kerala, Jammu and Kashmir and Union Territory of Pondicherry.

Inspite of various policy initiatives to diversify the fuel mix but considering the limited reserve potentiality of petroleum & natural gas, eco-conservation restriction on hydel project and geo-political perception of nuclear power, it is becoming increasingly evident that coal will continue to occupy centre-stage of India's energy scenario. Indian coal offers a fuel source to domestic energy market for the next

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century & beyond. Based on estimates, the consumption of coal is projected to rise by nearly 40 percent over the next five years and almost to double by 2020.

3.2. OIL

The Indian Petroleum industry is one of the oldest in the world, with oil being struck at Makum near Margherita in Assam in 1867 nine years after Col. Drake's discovery in Titusville. The industry has come a long way since then. For nearly fifty years after independence, the oil sector in India, has seen the growth of giant national oil companies in a sheltered environment. A process of transition of the sector has begun since the mid nineties, from a state of complete protection to the phase of open competition. The move was inevitable if India had to attract funds and technology from abroad into our petroleum sector.

The sector in recent years has been characterized by rising consumption of oil products, declining crude production and low reserve accretion. India remains one of the least-explored countries in the world, with a well density among the lowest in the world. With demand for 100 million tonne, India is the fourth largest oil consumption zone in Asia, even though on a per capita basis the consumption is a mere 0.1 tonne, the lowest in the region- This makes the prospects of the Indian Oil industry even more exciting.

The years since independence have, however, seen the rapid growth of the upstream and downstream oil sectors. There has been optimal use of resources for exploration activities and increasing refining capacity as well as the creation of a vast marketing infrastructure and a pool of highly trained and skilled manpower. Indigeneous crude production has risen to 35 million tonnes per year, an addition of fourteen refineries, an installed capacity of 69 million tonnes per year and a network of 5000 km of pipelines.

But with the consumption of hydrocarbons said to increase manifold in the coming decades (155mmtpa by the end of the 10th plan) the liberalisation, deregulation and reforms in the petroleum sector is essential for the health and overall growth of our economy.

India remains one of the least explored regions in the world with a well density of 20 per 10000km^2. Of the 26 sedimentary basins, only 6 have been explored so far. The Oil and Natural Gas Corporation (ONGC) and the Oil India Limited (OIL) - the two upstream public sector oil companies- in 1981/82 had taken their search to previously unexplored areas. Number of wells drilled as well as the meterage increased. However current reserve accretion continues to be low.

3.3. GAS

Natural Gas currently accounts for 8% of the energy consumption in the country. The current demand is 89 mcmd with domestic availability lagging behind at 63mcmd. The total gas consumption in 1996/97 was 19bcm with power and fertilizer sectors accounting for more than 80% of the consumption.

The gap between demand and supply is set to widen unless major gas discoveries are made. India is also looking at pipeline gas and LNG imports from neighbouring countries as well as countries from Iran, Oman, Central and South East Asia.

The growth of the gas/ LNG imports are very closely intertwined with the power sector, and the competition, and perhaps to an extent the replacement of coal as the preferred fuel. The setting up of Natural Gas import infrastructure would depend to a large extent on the ability of the power sector to pay for gas as against the cheaper coal, or an alternative fuel.

The aggregate consumption of petroleum products during 1997/98 was 90mt. In the period 1992-98, LPG and HSD registered the largest demand growth rate of 9.2% and 8.6% respectively. The Transport (38%), residential (26%)and industrial(24%) sectors are the largest consumers of petroleum products. The total production of petroleum products during 1997/98 was 61mt (MoPNG 1998). India's self sufficiency in petroleum products has declined to 34% in 1997/98 from 60% in 1985/86 resulting in a substantial growth in the import bill.

3.4. NUCLEAR ENERGY

India has consciously proceeded to explore the possibility of tapping nuclear energy for the purpose of power generation and the Atomic Energy Act was framed and implemented with the set objectives of using two naturally occurring elements Uranium and Thorium having good potential to be utilized as nuclear fuel in Indian Nuclear Power Reactors. The estimated natural deposits of these elements in India are:

- Natural Uranium deposits - ~70,000 tonnes
- Thorium deposits - ~ 3,60,000 tonnes

India has at present 14 operating nuclear reactors – 2 Boiling Water Reactors (BWR) and 12 Pressurized Heavy Water Reactors – with a total installed capacity of 2770 MWe. Nuclear Power Corporation of India Ltd. (NPCIL), a wholly owned enterprise of Government of India under the administrative control of Department of Atomic Energy (DAE) operates these plants.

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3.5. RENEWABLES

The oil shocks of 1970s led to spiraling crude oil prices in the world market which prompted planners to view energy security as an issue of national strategic importance. Energy security has an important bearing on achieving national economic development goals and improving the quality of life of the people. India's dependence on crude oil will continue for most part of the 21st century but the continued dependence on crude oil is loaded against it with inherent price volatility linked to finite global reserves. In addition, global warming, caused largely by greenhouse gas emissions from fossil fuel energy generating systems, is also a major concern. India needs to develop alternate fuels considering the aforesaid two concerns.

The search for alternative fuels that would ensure sustainable development on the one hand and energy security on the other began in the 1970s itself. Consequently, new and renewable sources of energy have emerged as an option.

Ministry of Non- Conventional Energy Sources (MNES) supports the implementation of a large broad-spectrum of programmes covering the entire range of new and renewable energies. The programme broadly seeks to, inter-alia, supplement conventional fossil fuel- based power; reach renewable energy, including electricity to remote rural areas for a variety of applications like water pumping for irrigation and drinking water purposes, drying farm produce, improved chulhas and biogas plants, energy recovery from the urban, municipal and industrial wastes. In addition, exploitation of hydrogen energy, geothermal energy, tidal energy and bio-fuels for power generation and automotive applications is also envisaged.

The Electricity Act 2003 contains several provisions to promote the accelerated development of power generation from non- conventional sources. The Electricity Act 2003 provides that co-generation and generation of electricity for renewable sources would be promoted by the SERCs by providing suitable measures for connectivity with grid and sale of electricity to any person and also by specifying, for purchase of electricity for such sources, a %age of the total consumption of electricity in the area of a distribution licensee.

Efforts are being made to reduce the capital cost of projects based on non- conventional and renewable sources of energy, reduce cost of energy by promoting competition within such projects and at the same time, taking adequate promotional measures for development of technologies and a sustained growth of these sources.

The efforts to increase the share of renewables in the total power generation capacity of the country have yielded results. The share has been continually rising. Renewables presently contribute about 4800 MW, which represents over 4.5% of the total installed capacity. The power generation capacity established so far has largely come about through private investments. Wind power contributes about 2483 MW, while biomass power and cogeneration account for 613 MW and the share of small hydro power is 1603 MW.

4. INDIA'S ENERGY SECURITY

India's energy security, at its broadest level, has to do with the continuous availability of primary commercial energy at an affordable price. Reducing energy requirement and increasing energy use efficiency and augmenting the domestic energy resource base are the most important measures to increase energy security. However, it is still necessary to recognize that India's growing dependence on energy imports increases uncertainty regarding availability of energy at affordable prices.

Long-term projections for energy requirements depend on assumptions of growth of the economy, growth of population, the pace at which "non-commercial energy" is replaced by "commercial energy", the progress of energy conservation, increase in energy efficiency as well as societal and lifestyle changes. No wonder the various available projections differ widely.

The strategies to meet the energy requirement are constrained by country's energy resources and import possibilities. Unfortunately, India is not well-endowed with them. Reserves of oil, gas and uranium are meager though we have large reserves of thorium. While coal is abundant, it is with low calorie and high ash content, though with low sulphur content and regionally concentrated. The extractable reserves, based on current extraction technology remain limited. Hydro potential is significant, but small compared to our needs and its contribution in terms of energy is likely to remain small. Further, the need to mitigate hydro environmental and social impact, often delays its development.

5. METHODOLOGY OF MODELING

The challenge in designing a reliable energy system is to find a combination of technologies where the pros of some types balanced out the cons of the others. A reserve capacity is necessary as a backup for fluctuating sources, especially in the electrical system [17]. Designing a combination of technologies where fluctuations in production match a varying demand, such that any fluctuations in supply never lead to electrical production shortage. The model requires the assessment of the energy share of each of the supply inputs with the objective of achieving a minimum cost of power generation.

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An Integrated Energy System for Power Generation (IESPG) has been developed for achieving minimum cost of electricity generation, energy security and environment protection. The model is formulated on the basis of Linear Programming (LP) as:

Objective function:

Minimize $$\sum_{i=1}^{8} (C_i / \eta_i)\ X_i$$

Constraints:

Demand $$\sum_{i=1}^{8} Xi \geq D$$ ………………… 1 constraint

Supply $$\sum_{j=1}^{8} \left[\sum_{i=1}^{1} Xi \leq Pi - Ei \right]$$ ……….. 8 constraints

Reliability $$\sum_{j=1}^{8} \left[(1/Rj) \sum_{i=1}^{1} Xi \leq Pi - Ei \right]$$ …8 constraints

Emission $$\sum_{j=1}^{8} \left[Єj \sum_{i=1}^{1} Xi \leq Pi - Ei \right]$$ ……8 constraints

where

η denotes the efficiency of different energy systems.

i denotes the different energy systems,

j denotes the number of energy systems,

C is the cost of the system,

X the quantity of energy,

D the energy demand in a particular year,

P the production or potential in that particular year,

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E the direct use of the energy source for that year,

R is the reliability factor,

Є is the emission factor.

P – E: Net energy for power generation.

Note: E=0 for the nuclear energy and renewable energy sources (hydro, wind, biomass, solar) as they are meant only for producing electricity.

The data for direct use of energy sources are taken from Integrated Energy Policy [10] and Reliance Review of Energy Markets [18].

6. ASSESSMENT OF ENERGY PRODUCTION, DEMAND, DIRECT USE AND ELECTRICITY UNIT COST

The demand of electricity for different years starting from 2004 and up to 2054 is shown in Table 1. The values are considered by referring to Integrated Energy Policy [10]. Table 2 shows the production and direct use of different energy sources for various years and Table 3 shows potential of biomass, wind and solar PV. The data for production are taken from IEA's website [11] for the base year and is projected for future years considering a uniform growth rate. The unit cost values for the base year for conventional energy sources are obtained from Central Electricity Authority [12] and for renewable energy sources from [13]. The forecasting of cost per unit energy is done by considering growth rate, inflation index, capital cost, O&M costs, life of plants, etc. used for calculation for each resource [14]. Fig. 1 and Fig. 2 show the variation of unit cost of energy sources for different years. Reliability factor [15] and emission factor [16] are also considered on a relative basis. The energy quality factor is also considered as the programme contains both high and low grade energies.

Table 1: Annual electricity demand prediction

Year	Total electricity demand (GWh)
2004	667782
2009	847083
2019	1312376
2029	2103272
2039	3672834

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2049	5986719
2054	7603133

Table 2: Forecasting year wise production potential of energy sources

Year	Production potential (GWh)					Direct Use (GWh)		
	Coal	Oil	Gas	Nuclear	Hydro	Coal	Oil	Gas
2004	927652	333360	302802	9972	111366	136600	90099	111131
2009	1128874	306691	368405	16060	141435	152992	94604	128911
2019	1671009	260688	545329	41595	230530	189710	104064	167585
2029	2003502	221584	807221	107732	375760	227652	114471	217860
2039	3661387	188347	1194884	279026	612480	277736	1259179	283218
2049	5419747	160095	1768720	722678	998340	338837	1385096	368184
2054	6593950	147287	2151918	1163511	1267892	379498	1454351	427093

Table 3: New renewable energy sources potential

Renewable Energy Potential (GWh)	
Biomass	70200
Wind	162000
Solar PV	754290.4

Table 4: Year wise projected unit cost of electricity from different energy sources

Year	Coal	Oil	Gas	Nuclear	Wind	Hydro	Biomass	Solar PV
1999	3.48	6.14	4.8	4.275	3.675	2.25	3.25	16.8
2004	4.13	6.5	5.75	4.5	3.5	2.5	3.1	15.27
2009	4.87	8.775	6.9	5	3.465	2.76	3.06	13.7
2019	6.9	12.74	9.66	5.94	3.36	3.03	3	10.96
2029	9.6	24.97	13.5	7.13	3.28	3.34	2.95	8.8
2039	13.59	48.94	18.9	7.84	3.2	3.67	2.91	7.9
2049	19.2	95.93	26.46	9	3.06	4.04	2.86	6.4

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2054	22.65	134.3	31.75	9.92	2.95	4.4	2.7	5.05

Source: Central Electricity Authority, New Delhi.

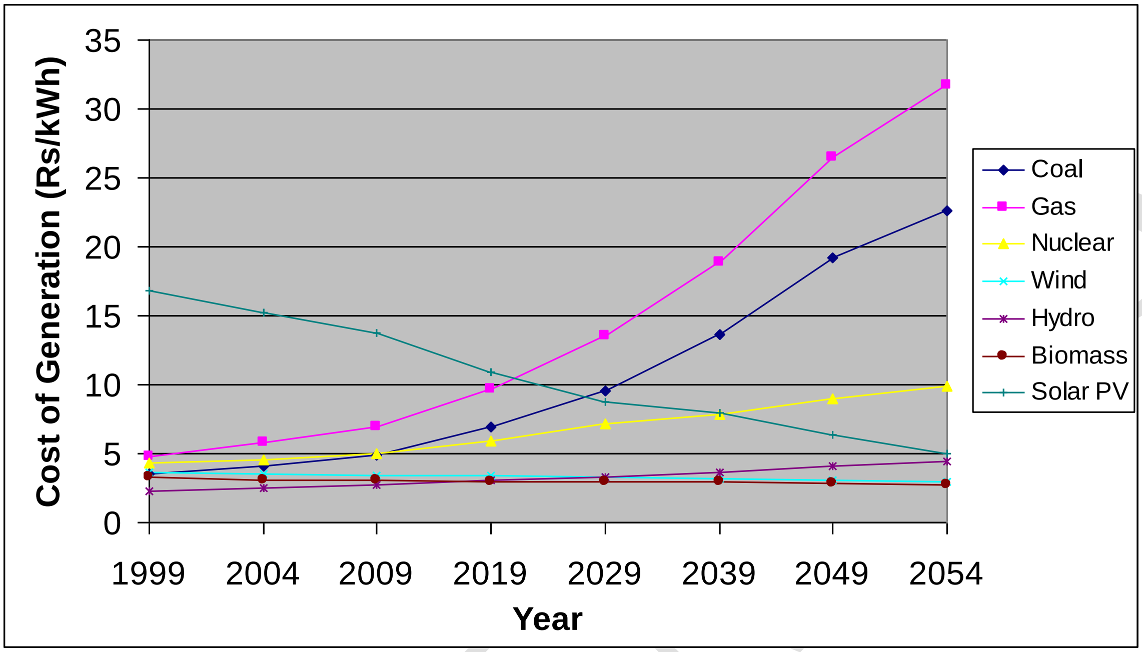

Fig. 1: Projected cost of electricity generation from various sources

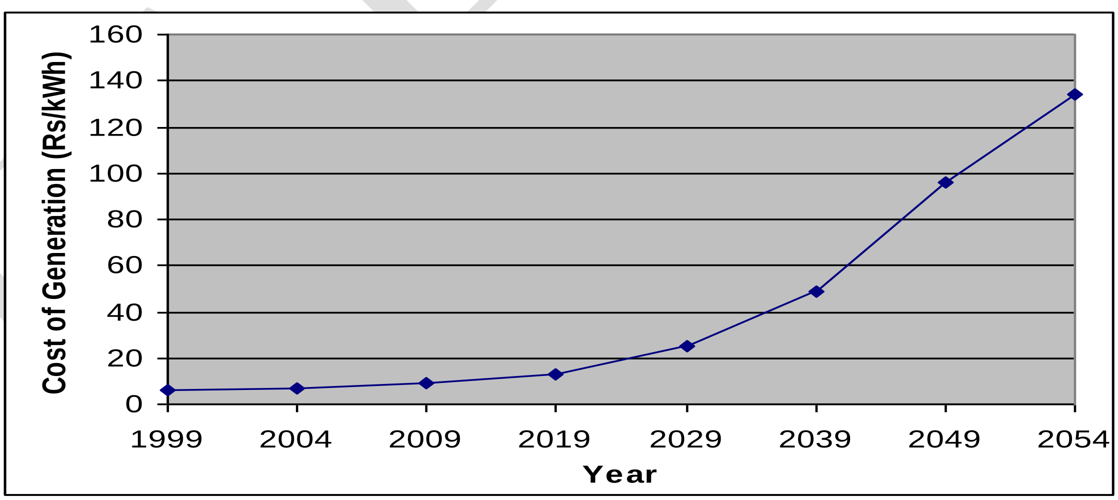

Fig. 2: Projected cost of electricity generation from oil

7. MODEL ANALYSIS

Various optimization techniques for Integrated Energy Systems have been reported in the literature like: (i) linear programming (LP) [19]; (ii) geometric programming (GMP); (iii) integer programming (IP) [20]; (iv) dynamic programming (DP); (v) stochastic programming (St P) (Dantzig and Charnes and Cooper (1955, 1959)]; (vi) quadratic programming (QP); (vii) separable programming (Se P); (viii) multi objective programming (MOP); (ix) goal programming (GP); (x) HOMER; (xi) VIPOR; and (xii) Hybrid 2, etc.

Presently, the softwares available for optimization are LINDO, LINDO API, LINGO, HOMER, VIPOR, TORA, etc., out of which LINGO 10.0 version [21] has been reported to be the most traditional package for solving linear, integer and quadratic optimization models. The software offers the most comprehensive tools for studying the inner workings of the revised Simplex Method used to solve linear optimization models [22]. Its unique features are its goal programming, parametric analysis and efficient solution of quadratic programs.

8. RESULTS DISCUSSION

The LINGO 10.0 software is being run for the year 2004 to 2054. Table 5 gives the results obtained from the software for different years. In the initial years solar PV does not contribute in the fulfillment of demand as the unit cost of electricity generation from it is very high. With the decrease in cost of generation of solar PV, its contribution to the total demand increases. The contribution to total demand in case of oil decreases and becomes zero in 2019 when its unit cost is the highest of all. A study of results reveals that the reliance on renewable energy sources increases as the time passes by. The software optimizes the cost with considering the factors like reliability and emission. The optimum cost for all the years as calculated by the software is shown in Table 6.

Table 5: Year wise programme results for power generation

Year	Coal	Oil	Gas	Nuclear	Hydro	Wind	Biomass	Solar PV
2004	336316	47979	65887	5390	70869	103091	38250	0
2009	438270	46489	86093	11575	90004	127059	47593	0
2019	665254	0	135791	24357	146701	127059	51887	161327
2029	797537	0	230577	82498	273280	127059	53542	538779
2039	1804614	0	401294	213669	445440	139765	57436	610616
2049	2903377	0	798359	602231	816824	142941	57436	665550

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2054	3551116	0	1125683	969593	1046883	142941	57436	709481

The IESPG thus formulated can also be used for calculating the actual cost of electricity generation. A comparison of the optimum cost and the actual cost is made in Table 6. It shows that there is a considerable saving in the cost of electricity generation when the IESPG is implemented. Fig.3 & 4 shows the flow chart and percentage distribution of energy sources for different years in the form of pie charts respectively.

Table 6: Year wise model and actual costs

Year	Model Cost		Actual Cost	
	Rs	Rs/kWh	Rs	Rs/kWh
2004	2.72E+12	04.07	3.45E+12	05.16
2009	4.03E+12	04.76	5.18E+12	06.11
2019	8.84E+12	06.74	9.43E+12	07.20
2029	1.76E+13	08.37	1.90E+13	09.10
2039	4.09E+13	11.12	4.51E+13	12.28
2049	9.05E+13	15.10	9.45E+13	15.81
2054	1.35E+14	17.70	1.40E+14	18.46

Fig. 3 shows flow chart for the IESPG model.

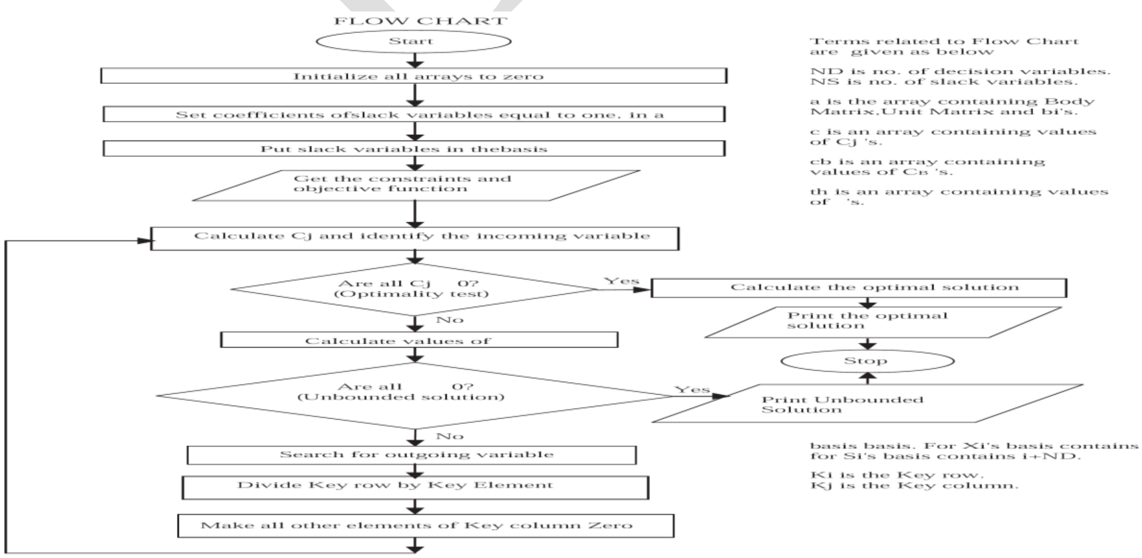

Fig. 4: Year wise percentage allocation of energy sources

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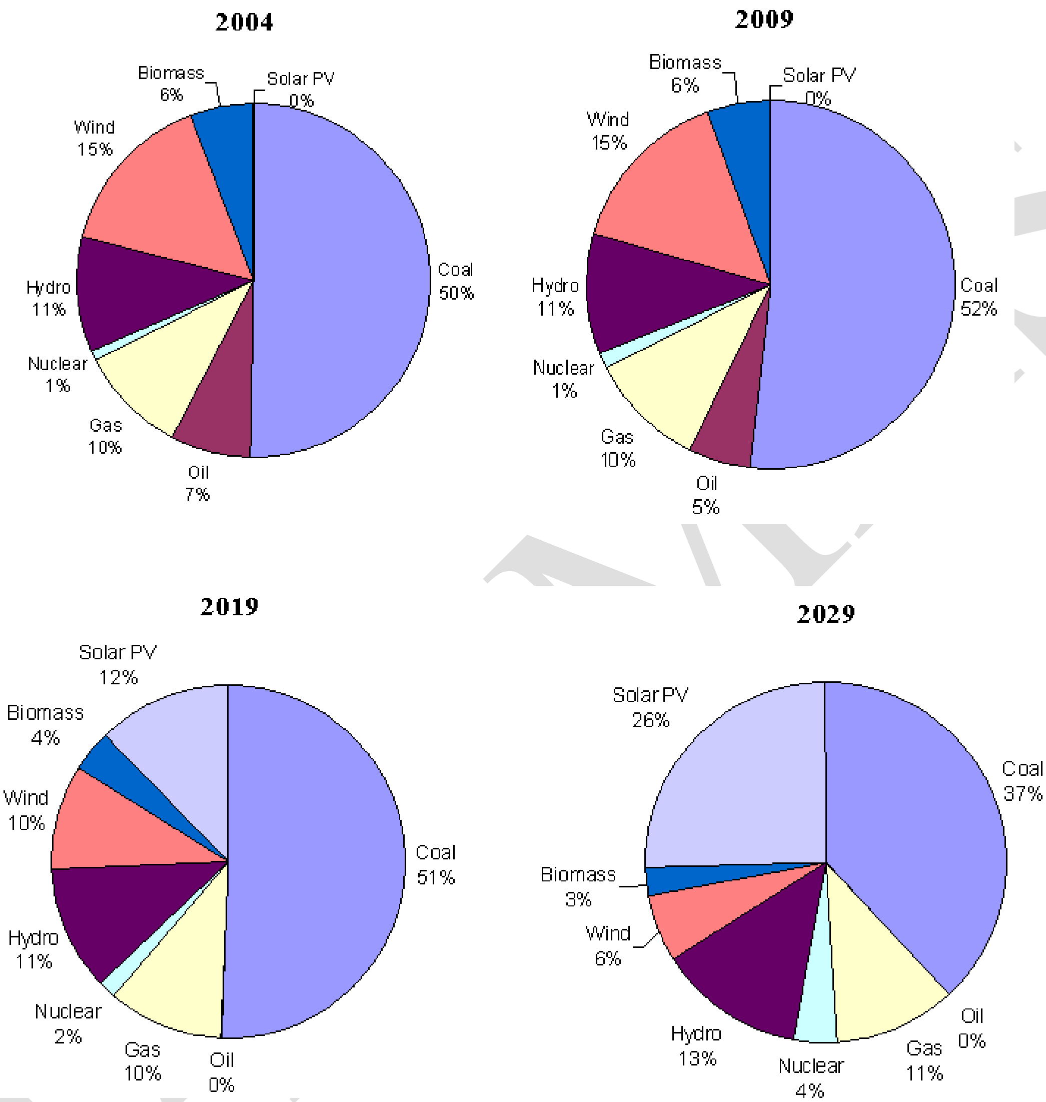

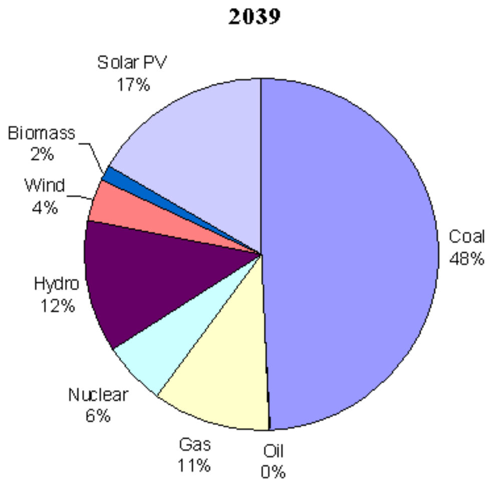

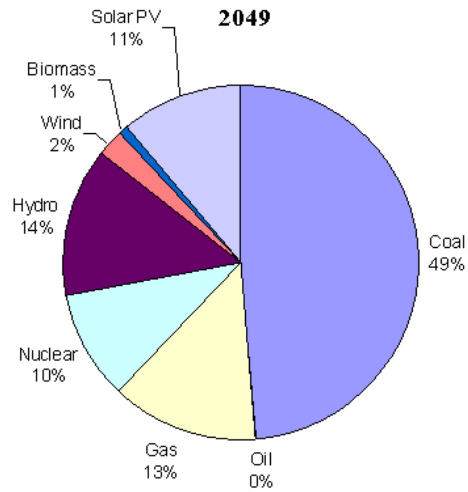

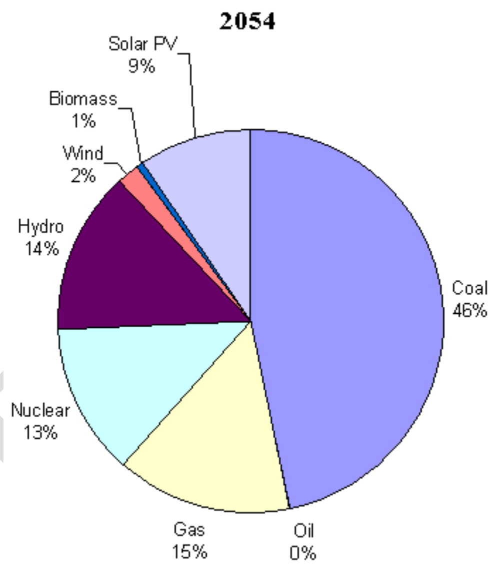

9. CONCLUSION

The result obtained from the modeling of IESPG for 50 years gives an optimum mix of energy sources to fulfill electricity demand. The cost of electricity generation corresponding to demand is minimized. Along with the cost, preference is given to the energy source having more efficiency, reliability and less emission. If the reliability and efficiency of the sources are improved it is found that the renewable energy utilization will be more. The model also suggests that for ensuring long term energy sustainability and security, the proper mixing of commercial and renewable energy would be a key player. IESPG can be used for any year thereafter if the data to be input is available for obtaining energy mix for optimum cost.

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The study would also aid energy planners and policy makers in visualizing the future energy scenario for power generation.

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