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Abstract: India is one of the fastest growing economies of the world. The most important factor which affects the economic growth is energy security. In this paper, it has been tried to analyze different energy security scenarios of India up to year 2047 under various demand and supply conditions. The paper is designed to compare the framework and projections of energy consumption and supply of various sectors till the year 2047. A tool, IESS 2047, developed by NITI Aayog, Government of India has been used for the analysis purpose in this paper. It is observed that there will be a huge coal dependence for India if heroic efforts are not employed for the energy security. A significant difference in the energy supply sectors has been observed while following the different pathways.

Keywords: Energy Scenario; Energy Security; Energy Demand; Energy Supply

1. Introduction

The need for increased energy efficiency and lower harmful emissions is much emphasized due to the current energy crisis, environmental problems, and strict emission limits. Advancements in the energy systems are being continuously explored for maximum useful effect with minimum input [1]. The increased rate of population growth in the last century, urbanization, globalization and motorization throughout the world has contributed to this imbalance in energy and environment. United Nations has estimated the world's population to be increased by 2 billion more to reach a very high number of 9.7 billion in the next 30 years i.e. by the year 2050[2]. Altogether, the level of physical facilities, infrastructure and comfort which is being planned for the upcoming population will give a steep rise in the energy demand at even higher rates as shown in Fig.1. Every country is putting hard efforts to make itself energy sustainable and energy independent because it is the elementary requirement for human to survive in present time[3),4)]. Substantial long-term economic development of any country needs a significant amount of energy resources and self-reliance[5]. Economic development depends on energy policies which ensures equitable access to modern energy services, all of which are essential for eradicating poverty and reducing inequalities among the individuals. With respect to Paris Agreement, India has already made a plan for INDC (Intended Nationally Determined Contribution) to UNFCCC. With a vision and effective policies, India has marching towards the accomplishment of set targets within stipulated times. After Paris agreement, the NDC statistics of India shows its commitment towards sustainable economic development with minimal environmental risks. India is targeting to lessen the emissions intensity by 33–35% of its GDP from 2005 levels by the year 2030. Many technological advancements are being approached for the attainment of this ambitious goal[6].

1.1 Energy – Indian Perspective

It is expected that India would be one of the fastest growing economies of the world by the year 2025. India holds 18% share of the world's population yet it utilizes only 6% of the world primary energy. The energy demands by such a large population could only be fulfilled by moving on to the renewable energy with fast pace. The present governments have shown great interest in this field.

Dependency on coal has been reduced by allowing biomass pellets in the boilers for co-firing in power plants. High quality biomass pallets has been produced for giving high efficiency by various researchers[7]. During a period of only one year (2014) an amount of 7.40 billion dollars

was invested for stimulating the renewable energy sector across the country[8]. Energy demand of this country has become almost two times since the year 2000 and it is anticipated to be 11% by 2040 which would still be below its 18% share in the anticipated global population as shown in Fig.1. As the technologies and market conditions improve the demand will also go on rise and the expected rise could be more than the anticipated. Various researchers are working for the continuous improvement in the technological advancements of solar PV module system[9]. Till June 2016, renewable energy based capacity of the country became 43,727 MW as compared to the total installed capacity of 303,100 MW which has shown a good sign[10].

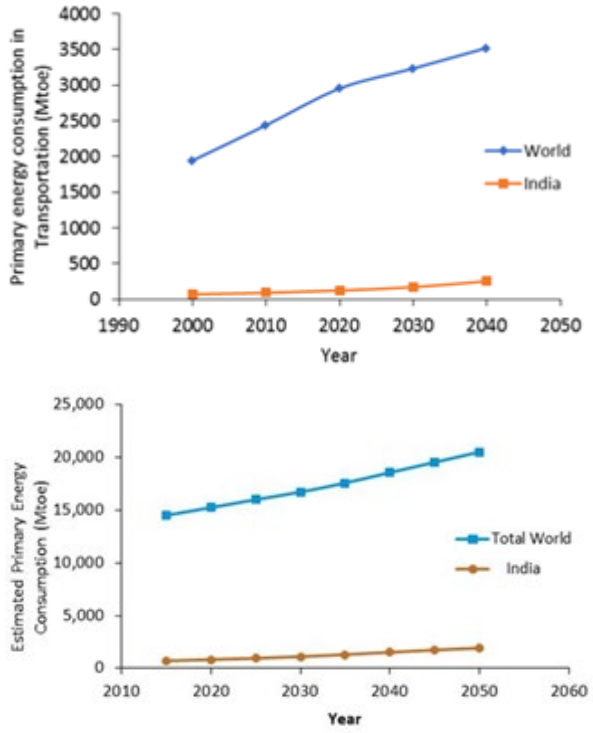

Fig.1 Relative energy consumption of India[11]

In the near future, India is set to be a giant partner of the global energy need. Rapid growth in urbanization would be a serious factor behind this trend as an expected 315 million population to shift in urban areas by 2040. It will elevate the energy demand from energy intensive sectors. In spite of newly discovered and high estimated overall energy reserves, it would not be sufficient to cater the future needs of India. As a fact, reserves of fossil fuel are limited and could not be recycled[12),13)]. Moreover, due to over and unplanned exploitation of conventional energy sources it led to increase in hazardous pollutants also. Energy obtained out of the fossil fuels was declared to be non-sustaining from the times of energy crisis of 1970.

On the basis of the estimated reserves and energy consumption rate, International Energy Agency has estimated that most fossil sources, i.e. crude oil, natural gas and coal, would get deplete very fast and to be exhausted[14]. State wise data of India for reserves of crude oil and natural gas which are prime source of transportation fuel are given in tabulated form in Table 1.

All the factors discussed above would really be going into a dreadful situation of energy insufficiency. High population burst without any proper planning will lead to deadly problems. A number of cities in India are not capable enough even in the present condition to maintain the air and water quality for healthy living[15].

It has been seen that various energy based sectors have made a good shift from conventional fossil fuels to non-conventional sources, yet transportation like segments are still at a very initial stage in using renewable sources (Figure 2). Due to the high power density of I.C. Engines, they are extensively used in transportation and as a stationary power source [16]. The switching of the transport sector from IC engines to electric drives has shown a good sign but still the increased harmful exhaust emissions is a big challenge[17]. Fig. 2 shows statistics of primary energy demand to be catered by different sources. It could be seen here that the energy consuming sectors are changing fast from the fossil fuel based systems to renewables. Change in the lifestyles and increased opulence has grown the global energy demand. The figure shows the way demand would be catered in the upcoming decades via diverse range of supplies including renewables with oil, gas and coal.

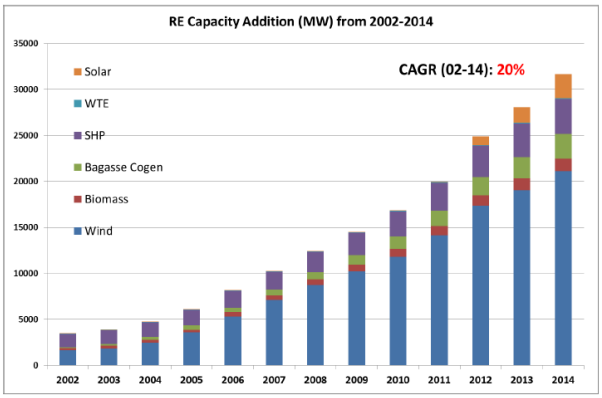

Fig.2 Energy share of different sources

Various cities in India like New Delhi are suffering from high level of air pollution which is a big threat not only to the human health but the entire eco-system[18), 19)]. Out of the 10 most polluted cities across the planet 7 lies in India. If we see only the amount of PM2.5, an average 113.5g/m^3 is measured in the capital of India i.e. Delhi[20)]. To address all this is a great concern, measures are being taken. It is a good sign that the renewable energy share in India's primary energy consumption is increasing at a quicker speed as compare to other source (Figure 2). It will lead to decrease in net carbon footprints.

Table 1. Approximated Reserves of Natural Gas and Crude Oil in India as per state (dated 31.03.2016 and 31.03.2017)[28,29)]

States/ UTs/ Region	Crude Petroleum (million tonnes)				Natural Gas (billion cubic metres)			
	31.03.2016		31.03.2017		31.03.2016		31.03.2017	
	Estimated Reserves	Distribution (%)	Estimated Reserves	Distribution (%)	Estimated Reserves	Distribution (%)	Estimated Reserves	Distribution (%)
Arunachal Pradesh	1.73	0.28	1.52	0.25	0.95	0.08	0.93	0.07
Andhra Pradesh	10.90	1.75	8.15	1.35	42.03	3.42	48.31	3.75
Assam	160.78	25.88	159.96	26.48	153.76	12.53	158.57	12.29
Cold Bed Methane (CBM)	0.00	0.00	0.00	0.00	126.48	10.31	106.58	8.26
Eastern Offshore[1]	36.39	5.86	40.67	6.73	451.46	36.78	507.76	39.37
Gujarat	121.16	19.50	118.61	19.63	63.06	5.14	62.28	4.83
Nagaland	2.38	0.38	2.38	0.39	0.09	0.01	0.09	0.01
Rajasthan	31.72	5.11	24.55	4.06	35.66	2.91	34.86	2.70
Tamil Nadu	8.99	1.45	9.00	1.49	31.68	2.58	31.98	2.48
Tripura	0.07	0.01	0.07	0.01	28.28	2.30	36.10	2.80
Western Offshore[2]	247.13	39.78	239.20	39.60	293.96	23.95	302.35	23.44
Total	621.28	100.00	604.10	100.00	1227.40	100.00	1289.81	100.00

Note:

1. Proved and indicated Balance Recoverable Reserves.
2. Western offshore includes Gujarat offshore.

Source: Ministry of Petroleum & Natural Gas.

Since renewable energy has several merits over conventional, Governments have taken various steps to increase the portion of non-conventional sources in the power generation of the country. Out of the total installed electric generation capacity in India (368.98 GW up to 29th February, 2020), a substantial share of renewable energy marks 23.39%. Alone Solar capacity has shown a drastic increase in the last 5-6 years i.e. from 2.6 GW to more than 34 GW.

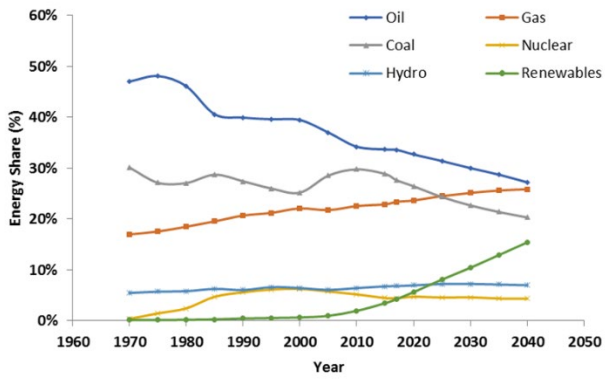

Fig.3 Energy share of different sources globally[11)]

The government of India is targeting ambitiously to install 175GW capacity of renewable energy (other than large hydro power plant) by 2022 and 450GW by 2030.

2. India - Way towards energy sustainability

The attainment of these ambitious targets in energy generation capacity will depend on the type of efforts made by the respective governments. NITI Aayog, GoI has developed a tool for analyzing energy security scenarios. This tool has been utilized in this paper to analyze the different scenarios developed by following the different paths of energy generation and efforts made. The recent trends show that access of electricity and clean cooking fuel to the citizens is kept at the top of the country's development agenda.

In a period of last 10 years, a large number of households got access to electricity which reflects good policy and its implementation. The government of India has made commendable progress in the reduction of using cow-dung or wooden fuel in cooking which was the main reason of indoor air pollution. E-vehicles are being promoted to curb down the urban pollution. It will also reduce the dependency on coal imports. At the same time scientists are working to find alternative fuels for higher energy efficiency of the existing engines[21–23)].

Table 2 Primary energy demand of fuel (in Mtoe)[11)]

Million toe	1970	1980	1990	2000	2010	2020	2030	2040
Oil	2292	3053	3237	3691	4145	4675	4829	4860
Gas	827	1224	1676	2065	2731	3382	4041	4617
Coal	1467	1793	2222	2356	3606	3779	3647	3625
Nuclear	18	161	453	584	626	673	739	770
Hydro	266	384	489	601	778	993	1165	1245
Renewables	6	11	35	59	234	802	1674	2748

The government of India has also achieved an ambitious goal of blending alcohols in diesel production. Similar is the field of biodiesel where lot of research is being going to make India energy independent[24]. The IEA commends for the efforts made by India for offering market-based attractive solutions by providing ambitious reforms in the energy sector. India has now developed an institutional framework system to attract substantial funds for its demanding energy requirements e.g. the government has allowed private-sector to invest in coal mining, and has also opened up the retail market of country's oil and gas. The development of effective energy markets would preserve the coal, gas, and power industries' economic viability, which is essential for ensuring energy security and advancing the nation's economic growth. Future energy demand and investment requirements will be driven up by India's economic growth, making this issue more and more important.

India still has a financial health challenge with its power sector due to excess capacity, less utilization of coal and natural gas plants, and growing shares of renewable energy[25]. It has been trying continuously by the government to improve financial viability of power sector. It has taken steps to address certain "stressed properties" in coal and gas-fired production. Indian energy security has significantly improved as a result of the establishment of a national power grid project and significant investments in thermal and renewable energy capability. India is also promoting inexpensive battery storage.

Coal supply with increasing demands have met the requirements after the year 2000, and coal continues to be the dominant source of electricity production. Due to stringent air pollution standards, newer coal power plants are made emission efficient and cleaner. Moreover, government is promoting renewable power plants and discouraging the setup of new coal power plants. India's oil consumption growth rate is about to surpass that of the China which makes India a striking market for refinery business. To keep a leading position in refinery industry, the government of India is tracking on a long-term planning by expanding its refining capacity aligning with the country's expected demand by 2040. Import dependency of India on crude oil is going to be increased as the found oil reserves are lesser than the domestic needs in the coming decades. India is working on to promote domestic production and developing of dedicated emergency oil stocks under India's strategic petroleum reserve project. India is continuously increasing its strategic oil reserve capacity which can cover over 100 days of domestic oil needs. The government is planning to increase natural gas share in the country's energy mix from 6% to 15% by the year 2030 along with conforming its target of environmental sustainability.

The current policy pattern is likely to increase the India's energy demand in 2040 by twice, with triple demand in the electricity due to increased use of electrical appliances and cooling requirements. It is expected that India will need around 1 billion air-conditioning units in the country by 2050 for which addition of large power generation capacity is required to meet this demand if no significant improvement in the energy efficiency is observed. IEA reports show that India is investing more in solar photovoltaic as compared to that of all fossil fuel sources together for electricity generation. Newer energy policies have promoted renewables energy costs at steep decreasing rates.

Furthermore, the tool developed by NITI aayog i.e. IESS 2047 gives freedom to analyze the future energy demand and supply scenarios under various conditions[26]. The following sections discusses these scenarios which might be expected under the specified conditions.

3. Energy Security Scenarios

On analyzing with the IESS 2047 energy tool, it was observed that the energy demand of the country will increase to 12656 TWh/year in the year 2047 as compare to 4920 TWh/year provided that the heroic efforts are employed for the energy sustainability. In similar conditions the primary energy supply will increase to 21533 TWh/year from 7075 TWh/year. It is shown graphically in Fig.4.

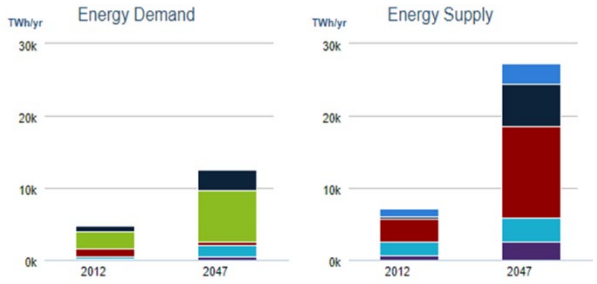

Fig.4 Comparison of energy demand and supply in 2012 and 2047 (Heroic Effort scenario)

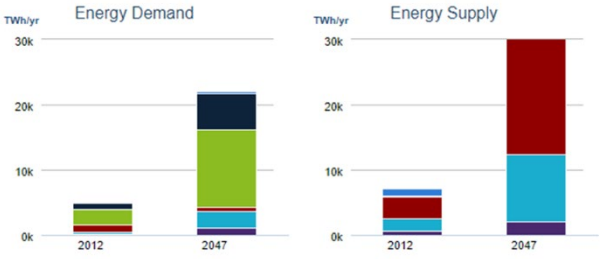

Fig.5 Comparison of energy demand and supply in 2012 and 2047 (Least effort pathway)

If least effort pathway is followed by different agencies and government, the conditions will be different. In this case, the energy demand of the country will increase to 22089 TWh/year in the year 2047 as compare to 4920 TWh/year. In similar conditions the primary energy supply will increase to 33930 TWh/year from 7075 TWh/year and maximum share of coal will be dominated in it with 19789

TWh/year which is also shown graphically in Figure 5.

Overall import dependence will increase from 31 percent to 84% in 2047 under the option of least effort. It shows that the 2199 TWh/year of overall import will increase to 28438 in 2047. However, it could be lowered down to 35% import only by employing heroic efforts (Figure 6).

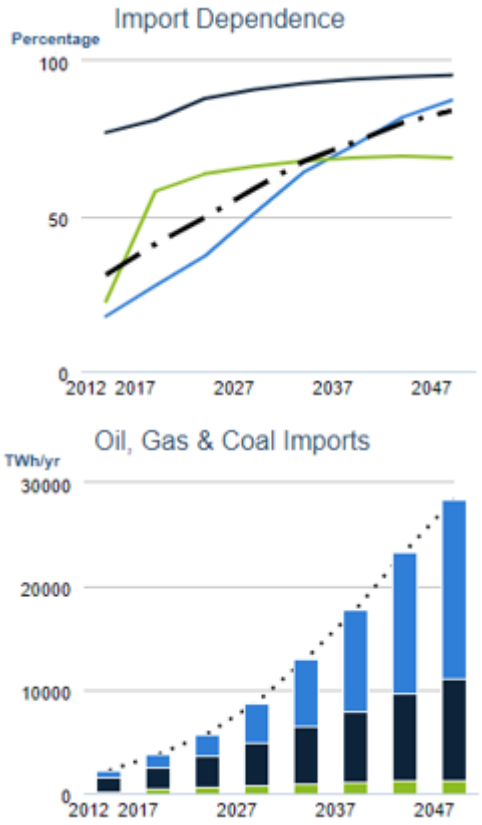

Fig. 6 Comparison of import dependence in 2012 and 2047 (Least effort pathway)

The promotion of renewable energy sources and development will also reduce the oil and coal import from the other countries. It will also save the foreign currency along with fulfillment of the goals set up for the sustainable development. However, the policies made in the recent years and the follow up of the current trends in future ensures the green energy development of the country [10].With the development of better technologies and hybrid power sources solar installation will become more prominent and economical[27]. Solar PV capacity addition could be seen as per four different pathways.

If there is no barrier offered to the installation of solar PV whether it is economic, social or technical 479 GW powered solar power plant could be installed. On the other hand, if the capacity addition is at worst rate, the capacity addition would be 37 GW in 2047. The corresponding generation of electricity will be 65 TWh and 865 TWh in 2047 respectively in case of least effort and heroic effort as shown in Figure 7 and Figure 8.

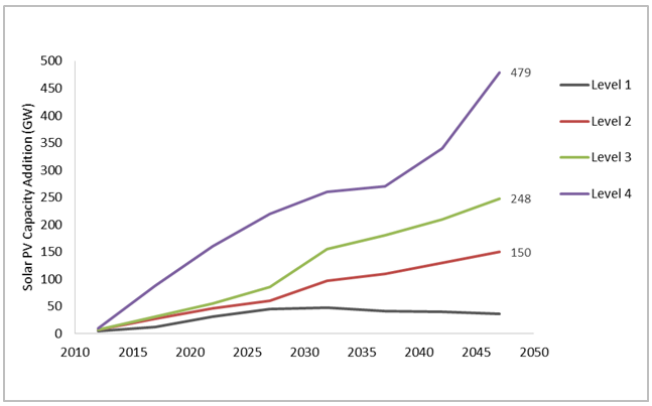

Fig.7 Solar PV capacity addition till 2047

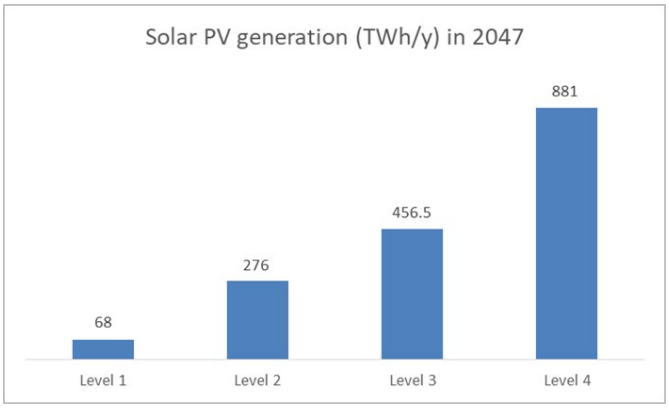

Fig.8 Solar PV power generation till 2047

4. Conclusions

On the basis of India's stated policies and current trends, International energy agency (IEA) projects a rise of energy consumption to 13% by 2030 and 17.5% by the year 2040. The share of traditional biomass will experience a decline from 22% to 8% in 2040. It shows a good transition towards clean energy. Renewable electricity generation also sees a substantial growth from 18% in 2020 to around 50% of electricity by 2047, along with the decrease in coal share from 74% to 44% in 2040. The IESS tool has been used to estimate different security scenarios. India is also going to achieve its target of 175 GW of renewable energy by which shows a good sign for future targets also which expects a growth up to almost 881 GW by 2047. The achievement of these targets will also ensure the attainment of SDG (sustainable development goals) set up by UN reflecting India as a responsible nation towards sustainable future.

Nomenclature

TWh	Terawatt hour
GW	Gigawatt
IESS	India Energy Security Scenario
g/m^3	Gram per meter cube

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