International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:11, No:6, 2017

Perspectives of Renewable Energy in 21st Century in India: Statistics and Estimation

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***Abstract*—**With the favourable geographical conditions at Indian-subcontinent, it is suitable for flourishing renewable energy. Increasing amount of dependence on coal and other conventional sources is driving the world into pollution and depletion of resources. This paper presents the statistics of energy consumption and energy generation in Indian Sub-continent, which notifies us with the increasing energy demands surpassing energy generation. With the aggrandizement in demand for energy, usage of coal has increased, since the major portion of energy production in India is from thermal power plants. The increase in usage of thermal power plants causes pollution and depletion of reserves; hence, a paradigm shift to renewable sources is inevitable. In this work, the capacity and potential of renewable sources in India are analyzed. Based on the analysis of this work, future potential of these sources is estimated.

***Keywords*—**Energy consumption and generation, depletion of reserves, pollution, estimation, renewable sources.

I. Introduction

ACHIEVING energy security is not only helpful to India's economic growth but also to alleviate poverty, unemployment and meeting the Millennium Development Goals(MDGs) [1]. The installed capacity of energy in India has increased from 145755 MW to 284634 MW on 31.3.2014 registering a Compound Annual Growth Rate (CAGR) of 7.72% [1]. CAGR here is the measurement of increment in generating capacity over a year span of time. The annual CAGR is 6.75% [1]. An influential rate of annual growth (11.66%) of thermal power plant is recorded which is followed by hydropower (2.63%) over a span of time from 2012-13 to 2013-14 [1]. With the conclusion of March 2014, thermal power plant accounted for about 70.25% contribution in the installed capacity of India, i.e. of 199947MW. Whereas the nuclear power plant accounted for 1.68 % (4.78GW) and hydro power plant accounted for 14.24% (40531MW). Non-utilities accounted for 13.28% (39375MW) of total installed generation capacity [1]. The highest CAGR (9.46%) was in the case of thermal utilities followed by nuclear (3.99%) and hydro (2.55%) [1]. To understand the need for renewable sources, we need to understand the energy trends. Following the advent of the industrial revolution (18th-19th century), a surge in the consumption of coal was observed. The transition from wood and bio-mass to fossil fuels was swift due to increasing demand for high- grade energy. The use of fossil-fuels only ever increased till 1973 oil embargo and 1979 energy crisis. By this time, however, over 80% of the total fossil fuels had been depleted during just a period of 60 years (Fig. 1) [2].

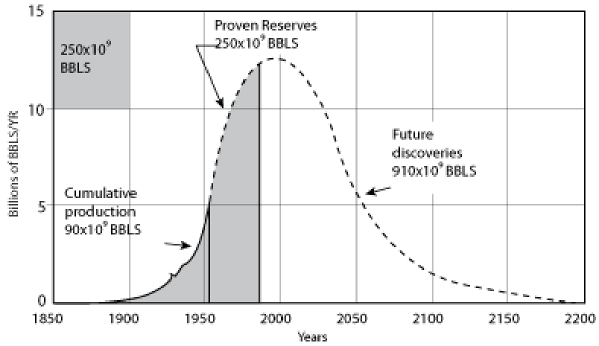

Fig. 1 Hubert's Curve

The depleting resources are not the only reason to move towards renewable energy resources, the emissions caused by conventional energy sources leading to global warming demands the world's intention towards renewable energy sources. The greater is the global warming the greater threat is to our environment causing climatic change and melting of polar ice caps.

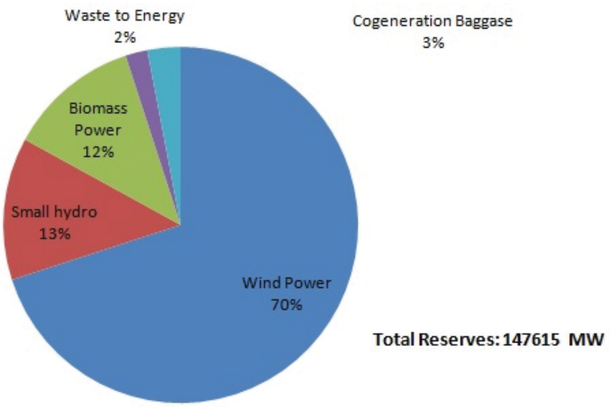

Fig. 2 Estimated Potential of Renewable Sources in India as on 31.03.2014 [1]

Fig. 2 shows the distribution of estimated potential of renewable sources of India as on 31.03.2014 [1]. It shows that we have a considerable amount of potential in the wind power,

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followed by small hydro and a very less share of the waste to energy.

II. Consumption and Per capita Generation

To understand the need for Renewable sources, we need to carefully look at the consumption and per capita generation of a country and hence make suitable inference.

A. Consumption

Consumption is account of net electricity consumed by different sectors of Economy (e.g. Domestic, Industrial and Commercial). The consumption can be calculated using the following formula:

Electric Consumption (in Wh) = [Total population electricity consumed (in MWh/yr)] *1,000,000/365.25*24/population

The authors have studied the consumption of electricity in India from [4] and carried out trend analysis, with an approximate prediction of next five years (as shown in Fig. 3).

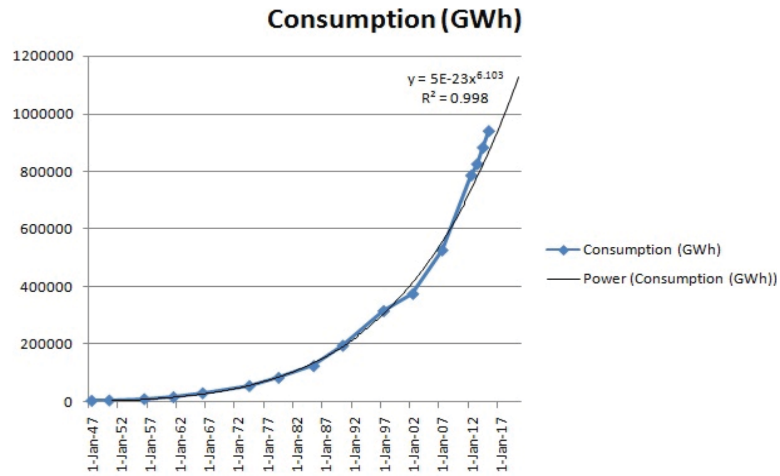

Fig. 3 Consumption of Electricity in India since Independence

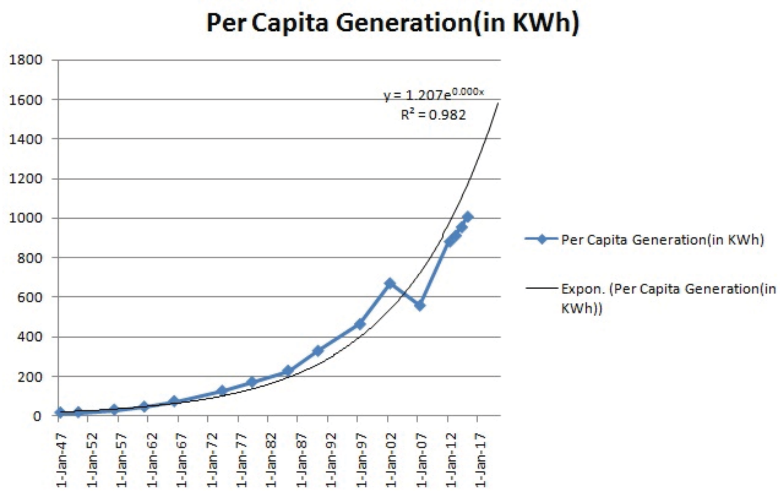

Fig. 4 Per Capita Generation of Electricity in India since Independence

The Fig. 3 shows that the trend follows a power series with a regression around 0.998 which is close to 1 indicates that model fits the data. Since there are many other factors which are responsible for good prediction such as new industries being set-up and the demand in growing economy cannot be restricted to a particular trend.

B. Per-Capita Generation

The Per- Capita generation of a country is defined as the amount of electricity generated annually with the conventional as well as non- conventional energy sources. The authors have studied the Per-Capita generation of electricity in India from [3] and carried out trend analysis with an approximate prediction of next five years (as shown in Fig. 4).

Fig. 4 shows that the trend follows an exponential series with a regression around 0.99 which is close to 1 indicates that model fits the data. Since there are many other factors which are responsible for a good prediction such as innovation and discovery of new reserves we cannot restrict to a particular trend. As we can clearly see the consumption increasing and so is the per capita generation which implies depleting of coal reserves and also increasing pollution in atmosphere, this so because in India major portion of generation is with the thermal (Fig. 5).

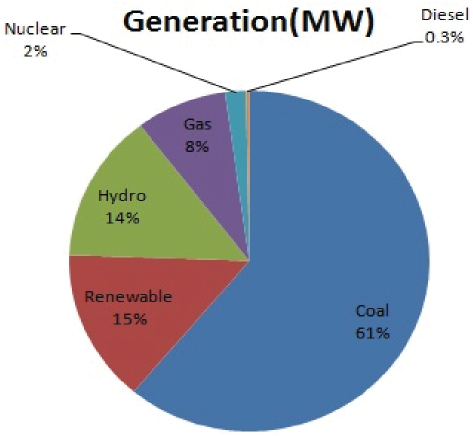

Fig. 5 Generation from Different Sources

A brief analysis of thermal energy and related issues of reserves and emissions is being done in Section III.

III. Thermal Power Plants

In these plants, heat energy is converted into electrical power. In the majority of power plants, the turbine is usually steam-driven. Water is first converted to steam and spins a steam turbine which runs the generator. After it passes through the turbine, the steam is condensed and recycled to where it was started, this is known as Rankine cycle. An Indian thermal power plant usually uses fossil fuels such as coal (as shown in Fig. 5). Am abundant supply of coal locally and sustained high prices for imported natural gas and oil make coal as the usual source for electricity generation [4]. However Indian coal has relatively lesser calorific value, with high ash content and inefficient combustion technology aggravates emissions of greenhouse gases and other pollutants from India's coal and lignite based thermal power plants [4].

A. Emissions from Thermal Power Plant

Carbon dioxide, NO_x, SO_x, airborne inorganic particles such as fly ash, the carbonaceous material such as soot, suspended particulate matter is the usual emissions from thermal power plant. The emissions can be calculated using methodology given in [4]. During elemental analysis of coal, the percentage of carbon, hydrogen, nitrogen, oxygen, ash and moisture can be found [4].

B. Carbon Dioxide and Sulfur Dioxide

Let C, H, S, O_2, and N_2 be the mass of carbon, hydrogen, sulfur, oxygen, and nitrogen, then Oxygen (O_b) required to burn one kilogram (Kg) of coal:

$$O_b = C * \left(\frac{32}{12}\right) + H * \left(\frac{16}{2}\right) + S * \left(\frac{32}{32}\right) - O_2 \quad (1)$$

Mass of air required for O_b Kg of oxygen = (O_b/mass fraction of O_2 in air)

$$= \frac{O_b}{0.233} \quad (2)$$

Suppose α is the percentage of excess air used to burn the coal in furnace, the air mass used

$$\text{Air (Used)} = (1 + \alpha) * \frac{O_b}{0.233} \quad (3)$$

Once the air mass to burn one Kg of coal is known, mass of oxygen and nitrogen could be calculated as:

$$\text{The oxygen used in air } (O_2) = (1 + \alpha) * O_b \quad (4)$$

$$\text{The nitrogen used in air } (N_2) = (1 + \alpha) * 0.767 \quad (5)$$

Mass of carbon dioxide, sulphur dioxide, nitrous oxide, and water are calculated by balance as

$$CO_2 = C * \left(\frac{44}{12}\right) \quad (6)$$

$$SO_2 = S * \left(\frac{64}{32}\right) \quad (7)$$

$$H_2O = H * \left(\frac{18}{2}\right) \quad (8)$$

The emission of CO_2 (Fig. 6) and of SO_2 (Fig. 7) are plotted for the time span of 2001 to 2010 using the data tabulated in [4].

Computed estimates show that there is hike in total CO_2emissions from about 323474.85Gg for the year 2001-02 to 498655.78Gg in 2009-10 [4]. Estimated range of emission per unit of electricity is 0.91 to 0.95 Kg/KWh for CO_2 [4].

From the period 2001-02 to 2009-10 sulphur dioxide emission has increased from 2519.93Gg to 3840.44Gg [4]. The emissions per unit of electricity are estimated to be in the range of 6.94 to 7.20 g/KWh for SO_2 [4].

C. Oxides of Nitrogen

Nitrous oxide (N_2O), Nitric oxide (NO) and Nitrogen dioxide (NO_2) are respectively oxides of nitrogen (NO_x). The NOx formation is a very complex process involving both homogenous and heterogeneous reactions. Most of it is emitted during combustion process in the form of NO [4]. The formation of NO is carried by following methods (a) 'Thermal NO' which is formed from the oxidation of atmospheric nitrogen. (b) 'Chemical NO' within the fuel matrix chemically bound nitrogen. The thermal formation is sensitive to temperature comparatively in the case of formation of chemical NO which is insensitive to temperature and occurs on a scale of time which is comparable to that of combustion reaction [4]. To understand the mechanism of formation of NO in flames and the prediction of NO concentration in combustion products we need a kinetic model [4]. According to variations in boiler conditions, the emissions of NO varies widely [4] as a function of flame temperature, oxygen concentration on the system, percentage of boiler load, nitrogen content and rate of gas cooling. The actual mechanism involving oxidization of atmospheric nitrogen involves a complex chain of reaction initiated by oxygen atoms [4].

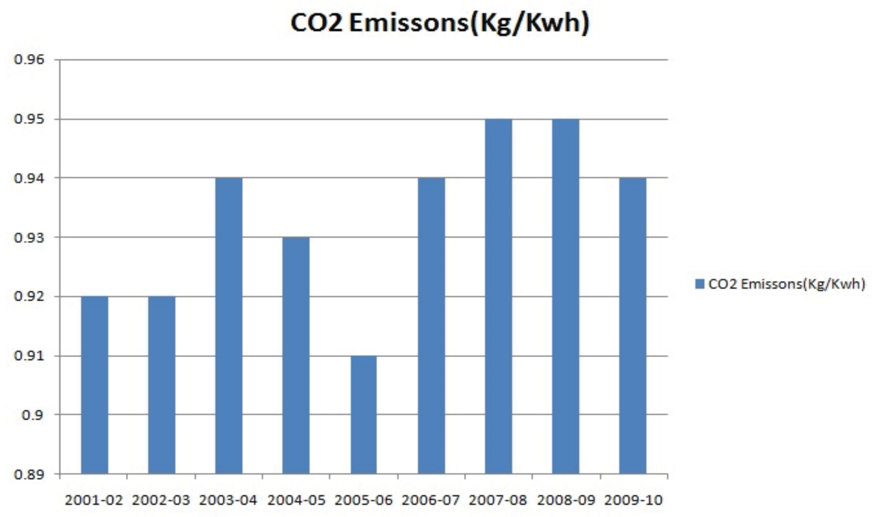

Fig. 6 CO 2 Emissions from 2001-10

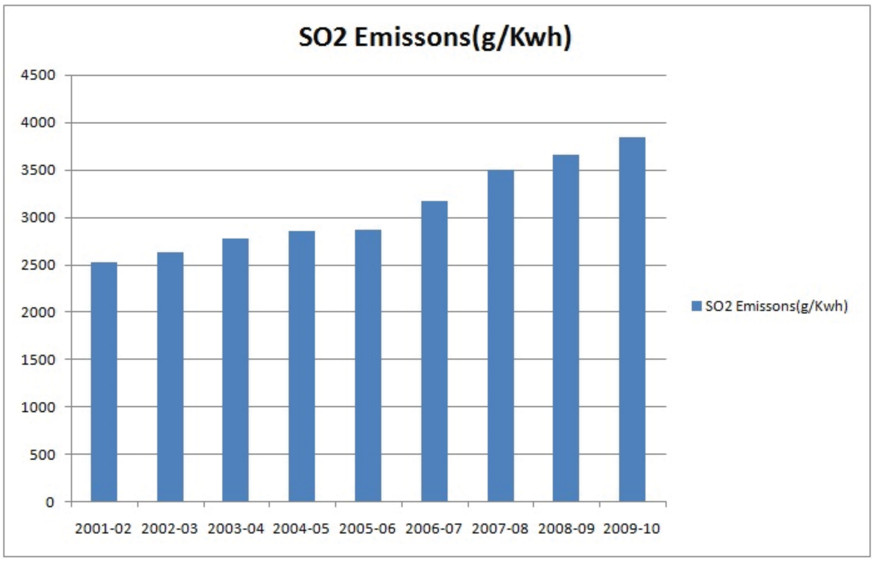

Fig. 7 SO 2 Emissions from 2001-10

Generally accepted principal reactions (Zeldovich, 1946) for thermal NO formation are:

$$O + N_2 = NO + N \quad (9)$$

$$N + O_2 = NO + O \quad (10)$$

$$N + OH = NO + H \quad (11)$$

With the assumption of long residence time as found in large boilers, present estimates give the equilibrium concentration of NO. Here kinetic model is not considered [4].

$$N + O_2 \rightarrow 2NO \quad (12)$$

Equilibrium NO concentration can be calculated using simple stoichiometric as in (13) [4].

$$\chi_{NO} = K_{10.1}(\chi_{N2})^{0.5}(\chi_{O2})^{0.5} \quad (13)$$

where χ is the species concentration and $K_{10.1}$ is an equilibrium constant that depends upon temperature of gas. At 1200K, $K_{10.1}$=0.00526 [5].

The emission of NO (Fig. 8) is plotted for the time span 2001-2010 using the data tabulated in [5].

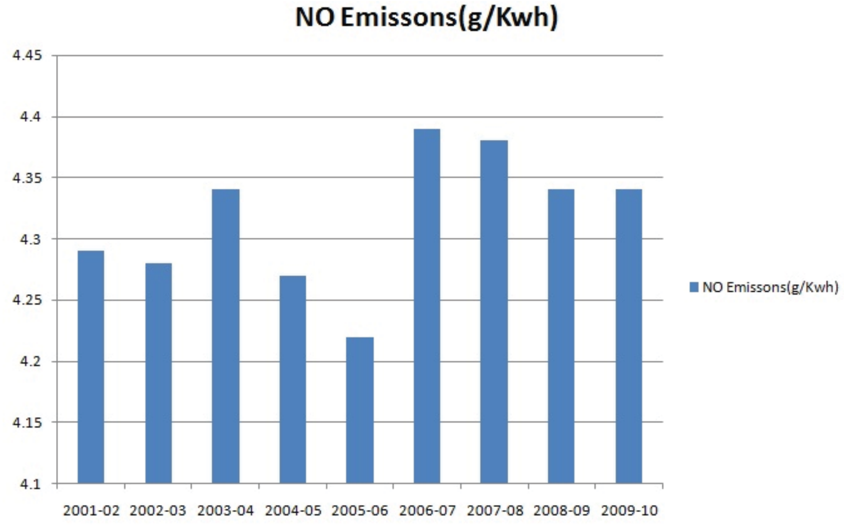

Fig. 8 NO Emissions from 2001-2010

Computed estimates show that total NO emissions are increased 1502.07 Gg in 2001-02 to 2314.95 Gg in 2009-10 [5]. The emissions per unit for electricity are estimated to be in the range of 4.22 to 4.38 g/KWh for NO during the period of 2001-02 to 2009-10 [4]. Though emissions can be reduced using suitable technologies we cannot make changes in the physical attributes of coal, hence a significant amount of emissions will be present in the thermal power plants. According to [1] there is certain increase in reserves of coal but considering the net effect due to increasing consumption and pollution due to thermal power plants we must look out for alternatives, hence we move towards renewable energy sources.

IV. Renewable Energy Sources

The energy which is derived from the sources which can be replenished and can use without being depleted usually natural resources which are available in abundance such as air, wind, sun, water etc. The different source of renewable energy can be listed as follows: (a) Wind Power, (b) Solar Power, (c) Small-Hydro Power, (d) Waste-to-Power. According to [1] the total installed capacity of grid connected renewable power can be distributed as shown in Fig. 9.

According to [1] the total installed capacity of grid interactive renewable power which was 28067.86 MW as on 31.03.2013 had gone up to 31692.18 as on 31.03.2014 marking a growth of 12.92% during this period.

Section IV A shall include brief introduction of these renewable energy sources.

A. Solar Energy

Solar energy is a high -grade energy source. The earth receives 174 PetaWatt of incoming solar radiation (Insolation) at the upper atmosphere [5]. Approximately 30% is reflected back to space while the rest is absorbed by clouds, ocean, and land masses [6]. Fig. 11 gives a graphical representation of solar insolation. The total solar energy absorbed by earth's atmosphere, oceans, and land masses is approximately 3,850,000 ExaJoules/ year [7]. The available technical potential from biomass is about 100-300 EJ/year [8]. The amount of solar energy is such that in one year is about twice as much as will ever be obtained from earth's non-renewable sources. Solar energy is being actually implemented and improved upon and it is not just potentially useful energy. With the target of about US $ 100 billion of investment, the Indian government expanded its solar plans in January 2015. [9] and 100GW of solar capacity [10] by 2022. Solar gives the boost to rural electrification in India, by the end of 2015 a cumulative total of 1 million solar lanterns had been sold in the country reducing the need of expensive kerosene [10]. In addition, 30,256 (cumulative) solar powered water pumps for agriculture and drinking water had been installed [10]. During 2015 alone 118700 solar home lightning systems were installed and 46,655 solar street lightning were provided under national program [10]. Also, 1.4 million solar cookers are distributed or sold in India [10].

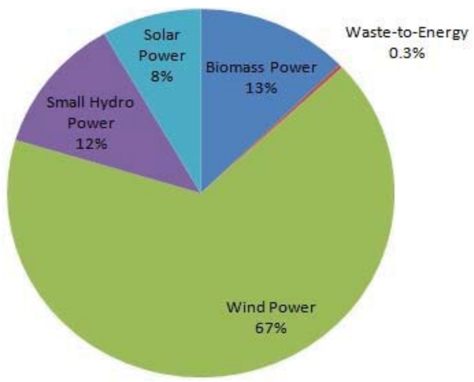

Fig. 9 Installed Capacity of Grid Connected Renewable Power

The Prime Minister of India and President of France lay the founding stone for headquarters of International Solar Alliance

(ISA) in Gwalapahari, Gurugram, this institute will focus on promoting and developing solar products for countries lying between the Tropic of Cancer and Tropic of Capricorn on January 2016. At the Paris COP21, climate summit alliance of over 120 countries was announced [11]. The trend in installed solar capacity can be seen from Fig. 12.

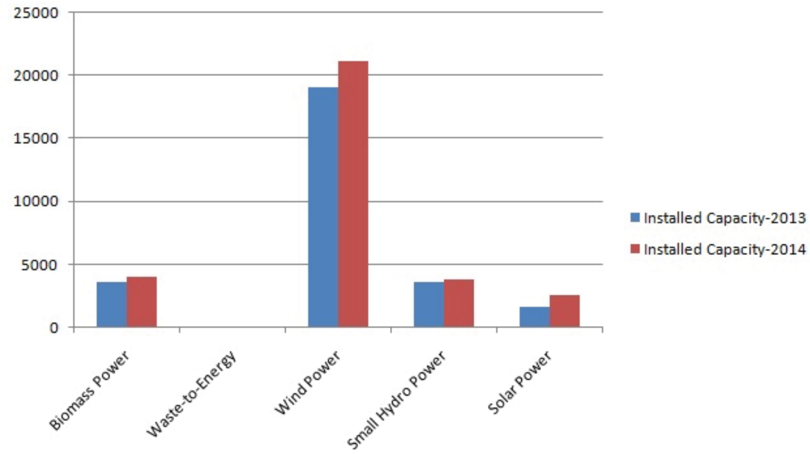

Fig. 10 Installed Capacity Comparison on 2013 and 2014

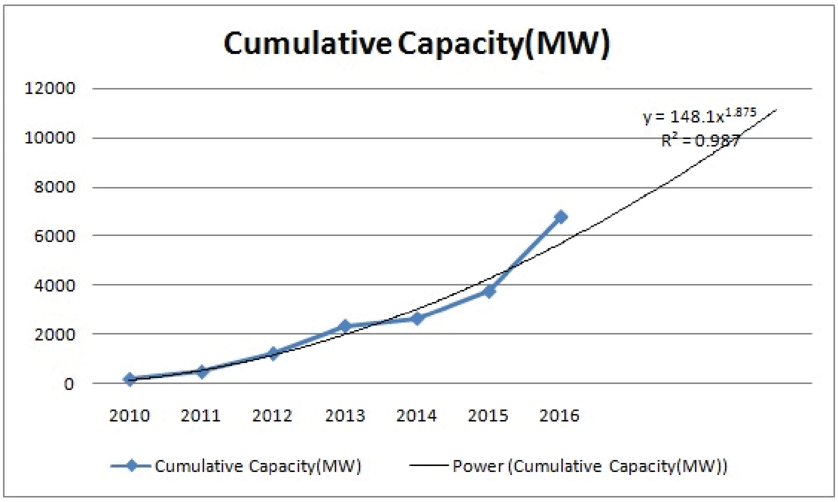

Fig. 11 Installed Solar Capacity over the Years

The trend follows a power series with regression of 0.993 which shows trend follows the time series but looking at the remarkable discoveries and innovations in technology the output growth for the coming years is expected to be more.

India ranks number one in terms of solar electricity production per watt installed having an Insolation of about 1700-1900 KWh/KWpeak [12]. Region wise distribution to solar installed capacity as on Sep 2016 can be observed from Fig. 13.

The challenges faced in solar power are requirement of land, a large amount of land, India being densely populated the need of land for solar power has to compete with other basic requirements. Hence while choosing a land government should have a proper planning. The other challenge faced for solar is its production and installation cost, though trends show that there is considerable reduction in recent years. And is estimated with the new innovations and discoveries the challenge faced due to price might be reduced.

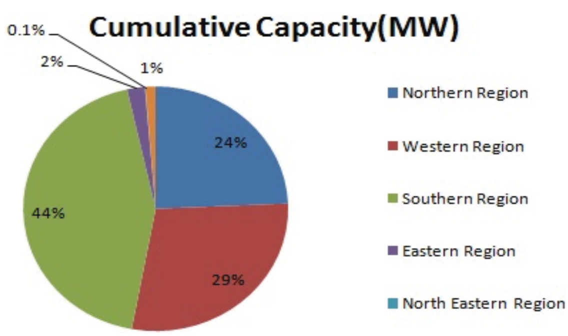

Fig. 12 Region Wise Distribution as on Sep 2016

B. Wind Power

In wind power systems, the air flow is being used to mechanically rotate the turbine of generator consequently producing electricity. Wind power systems have numerous wind turbines connected to electrical transmission network. On shore wind is an inexpensive source of electricity, competitive with or in many places cheaper than coal or gas plants [13]. Offshore wind is steadier and stronger than on land. Small onshore wind farms can feed some energy into the grid or provide electricity to isolated off- grid locations. Wind power is usually used in conjunction with other electric power sources to give a reliable supply, though the power through wind is variable which is consistent from year to year but it has significant variations over shorter time scales.

India being the new comer in the wind power with its first wind power installed in 1986, now has reached on 4thlargest in production of wind power surpassing Spain in 2015. In 2009-10 India's growth rate was highest among the other top four countries. Wind power accounts nearly 8.6% of India's total installed power generation capacity and generated 28604 million KWh in the fiscal year 2015-16. 70% of wind generation is for five months duration from May-September coinciding with South-west monsoon duration. Fig 14 shows growth in wind power capacity over the years from 2005 onwards.

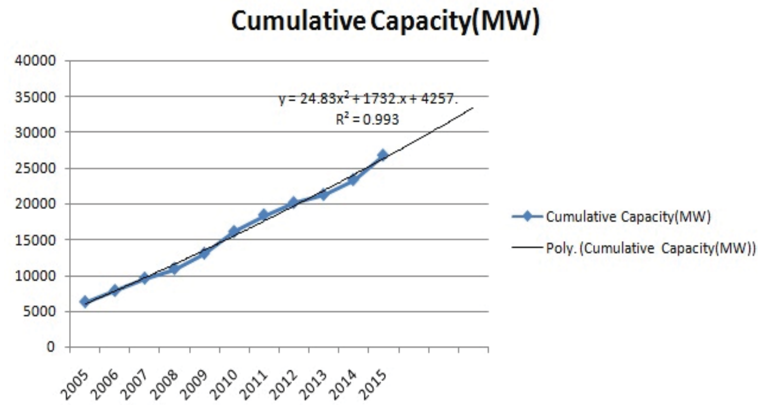

Fig. 13 Wind Power Capacity 2005 Onwards

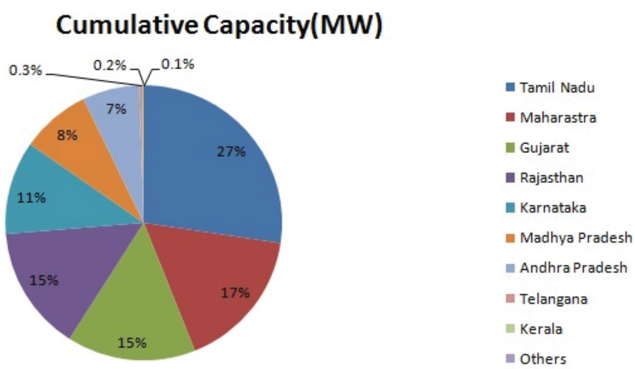

Fig. 14 State Wise Contribution in Wind Power

Fig. 15 shows state wise contribution of wind power in India, the figure reveals that Tamil Nadu has highest contribution in field of Wind Power in India.

The challenges associated with wind are its installation costs, and heavy size of micelle which is attached to wind farms and variable wind though these problems can be overcome by proper design and innovations in technology.

C. Biomass, Small-Hydro, and Waste to Energy Power

Biomass is one of the renewable and sustainable source of energy used for creation of electricity and other forms of power and is developed from organic materials. Few examples include scrap lumber, forest debris, certain crops, manure and some types of waste residues. It is renewable source of fuel due to the following reason (1) In terms of scrap mills, mills residuals and forest resources waste residues shall usually exist. (2) With properly managed forests we would have crops and residual biological matters from these crops as there are more number of trees. Wood waste or other waste is burned to produce steam in biomass power plants which in turn used for rotating turbine and hence producing electricity. Generating power with the use bio mass is the cleanest and cost-effective way to provide renewable energy in biomass potential regions. The estimated power from surplus agro residues in the country is about 17000

MW. In addition, about 5000 MW of power can be produced, if the sugar mills in the country switch over to modern techniques in cogeneration. The electricity so produced is carbon neutral and therefore helps to combat global warming. It is estimated that primary energy use in country derived from biomass is about 32% and 70% of the population depends on it for energy needs. India has over 5940 MW biomass based power plants comprising 4946 MW grid connected and 994 MW off grid power plants. According to data collected in the state wise achievement in biomass power can be shown by Fig. 15.

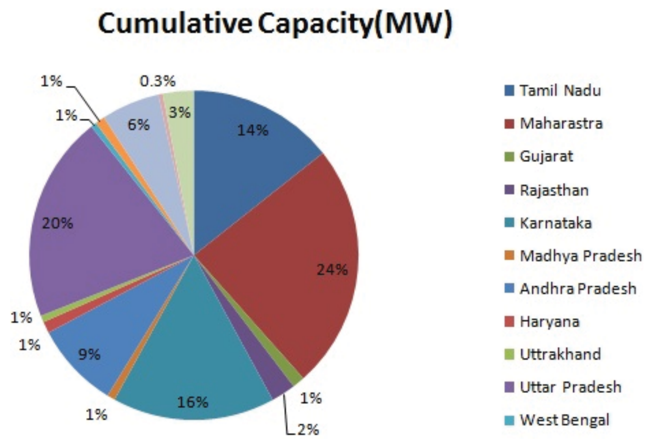

Fig. 15 State Wise Achievement in Biomass Power

As we can clearly see major contribution in biomass power is provided by Maharashtra.

Though the biomass power is a much reliable source as compared to solar and wind power, free of fluctuation and doesn't need storage as in the case of solar power. Till today biomass is not a preferred renewable energy source due to the enlisted barriers: (a) information unavailability on biomass, (b) lack of formal markets for biomass power, (c) lack of proper transportation processing, storage, and other associated management problems, (d) setting up of large biomass plant is also a problem, (e) the cost effective sub-megawatt system is not available, which is used for the conversion of biomass to energy in decentralized manner, and (f) with the financial and liquidity problems, there is lack of capability to generate bankable projects.

Small hydro can be defined as development of hydroelectric power for a small community or industrial plant, generating capacity of 1 to 20 megawatts is generally accepted as small hydro power plant. Since it requires a lesser civil construction and is for a smaller area it is usually considered as one of renewable sources. Small hydro can be subdivided into mini hydro and micro hydro where mini hydro covers the range of power from 100 to 1000 KW and micro hydro covers from 5 to 100 KW. Micro hydro is the application of hydroelectric power sized for smaller communities.

For developing small hydroprojectsupto 25 MW capacities, the responsibility is vested with the Ministry of New and Renewable Energy (MNRE). About 20,000 MW is the estimated potential of power generation in the country from such plant. Mostly the potential lies in the Himalayan states with river based projects and irrigation canals in other states. Now essentially SHP program has now become private driven. The ministry's aim is that at least 50% of the potential is harnessed in the country in next 10 years.

V. Conclusion

The people of the world must be educated with change in climate, global warming and all ill effects of industrialization. Course curriculum must educate us about the emissions from the conventional energy sources and their limited availability in form of reserves. So that generation is forced to look upon innovation, not only in established renewable energy sources but also development of new science which could save power, fuel required, and keeps mother earth away from threat of pollution. Looking at installation cost and limitation of renewable energy sources technologist must not be hesitant to use them as we can see from history as well whenever a new technology comes in the field it does have cost issues but later with incoming innovations and discoveries these problems can slowly be overcome. The pace with which we have accepted new technologies for making work easier for mankind exploiting resources from nature should also be seen in saving nature in 21st Century or else we only will be the sufferers. In India, renewable power is produced mainly from wind, solar, small hydro, biomass power and waste to energy. Though India is a new comer in the renewable field it has shown a promising growth and today the world looks with a hope for a better future towards India. India is the first country ever to set a ministry for renewable energy. Thanks to efforts of our prime minister the world is now investing in a large scale in India for renewable power.

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