INDIAN RENEWABLE POWER SECTOR: POTENTIAL, POLICIES, BARRIERS, AND ITS PROSPECTIVE

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Abstract: *Increasing prices, green house gas emission, and depleting nature of fossil fuel makes the world to think about alternate sources of energy particularly renewable energy sources which are green sources, and freely available. Carbon dioxide emissions can be reduced by replacing the existing fossil fuel based systems with renewable energy sources as far as possible and increasing the energy efficiency of existing systems. Policies of Indian government to adapt more renewable energy sources are rigorous in the last decade. Various strategies taken by Indian government for the last two decades have increased the renewable share in the electricity sector. But the energy demand is increasing at about 10% every year. Renewable energy sources are added in a phased manner into the Indian electricity sector. This paper presents different renewable technologies, developments, potential, and barriers to renewable energy adaption in India. Unused potential of various renewable sources in India are indicated. Also, policies of Government and current, future status of renewable sources are summarised.*

***Keywords**: Renewable Energy status in India, Renewable Energy Technology in India, Indian Electricity Sector, Renewable Energy potential in India, Renewable Energy Policies, Barriers for renewable Energy.*

1. INTRODUCTION

Fossil fuels usage cannot be replenished up to two or three decades, due to higher growth of energy needs worldwide. Presently about 80% of energy needs in the world are satisfied by fossil fuels [1]. The surfeit consumption of non-renewable fuels makes emission of greenhouse gases and pollutants into the atmosphere, which leads to global warming and climate change [2]. Also it create huge amount of waste, affect biological systems and accelerate climate change [3]. Extinction of fossil fuels, global warming and pollution etc. lead the scientist and governments to think about alternate energy sources. The world tries to reduce the consumption of fossil fuels, in that too coal & oil. As the gas price is lesser than oil & coal, one-third in carbon emissions, its use is increasing continuously [2, 4].

Renewable energy sources such as wind, solar, biomass, biogas, small hydro, wave, tidal, geothermal etc. are considered as substitute for fossil fuels [3]. Renewable source based energy generations offer an opportunity to reduce green house gases, reduce pollution in the air, and provide sustainable place to living beings. In addition it offers improvement in energy security and economic development to the countries around the world [5].

In 2017 and 2018, a remarkable addition of renewable energy installed capacity was made because of diminishing prices, more capital investments and advances in related technologies. Recently, deployment of renewable energy is impacted by the factors such as low price quotes for renewable power worldwide, considerable increase in electrification of transport, growing digitalisation, decision to convert into pollution-free environment, new policies and partnerships on carbon pricing, new initiatives and targets set by groups of countries at all levels [6].

Many nations and private players are increasing their deployment of renewables and investment in renewables and related infrastructure. Recently in 2017, many nations formulated its renewable energy policies and targets. The total energy consumed worldwide from renewable energy sources had a share of 18.1% in 2017 whereas in 2017 the share was about 10.6%. The year 2017 was an important year for Solar PV, in which capacity addition of solar PV is higher than the cumulative capacity addition of coal, natural gas and nuclear power. Installed capacity of Solar photovoltaic (PV) added in 2017 was remarkably increased than wind power (in second place) also it is more than net installed capacity of coal, natural gas and nuclear power together [6].

Renewables 2019 Global Status Report indicates that total installed capacity of renewable energy sources worldwide account for 1238 GW. If hydro power also taken into account, the total installed capacity amounts to 2378 GW worldwide. The renewables capacity addition is more than fossil fuel based additions for the last four years 2014 to 2018 globally. At the end of 2018, 181 GW of renewable energy capacity have been added in total. Renewable energy generation contributed a share of 26.2% of global total energy generation in 2018 (Fig.1). Hydropower contributes majority of energy generated which is 15.8% of global total energy generation. Remaining energy has been obtained from wind, solar PV and Bio-power which accounts for 5.5%, 2.4%, and 2.2% respectively of global total energy generation. In 2018, the cost of energy obtained from renewable sources was less than fossil fuel based power plants [6].

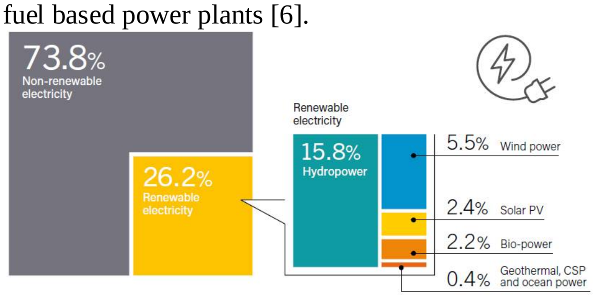

Fig.1. Renewable Energy Generation share out of Total Energy Generation, 2018

2. INDIA'S ELECTRICITY SECTOR STATUS

The total installed capacity of electricity generations in India (Fig.2) is about 369.4 GW at the end of February 2020. Renewable energy installation has a share of 86.8 GW which accounts for 23.5%, excluding large hydro power plants of 45.7 GW which is 12.4% of total capacity. Nuclear Power generation contribute 1.8 % (6.8 GW). Remaining electricity capacity is obtained from fossil fuels accounted for 62.4%, out of which coal and lignite together has a major share of 55.4% (204.8 GW), gas has 6.8% (25 GW) and oil 0.13% (0.5 GW). Installed capacity of renewable energy sources in India at the end of February 2020 are 4683.16 MW of Small Hydro, 37669 MW of Wind, 9861.31 MW of Bio-Power, 139.8 MW of waste to energy and 34405.67 MW of Solar PV [7].

The energy requirement and energy availability of India are shown in Fig.3 for the financial year 2018-19 and 2019-20. The energy demand is around 100000 MU and 110000 MU during the financial year 2018-19 and 2019-20 respectively. Energy availability is less than the requirement in all the months in 2018-19 and is less by 0.1 to 0.7%. But in 2019-20 the energy availability is surplus means that the installed capacities are more than the demand, which is clear from Fig.3. The peak demand and available power are illustrated in Fig.4 for the financial year 2018-19 and 2019-20.

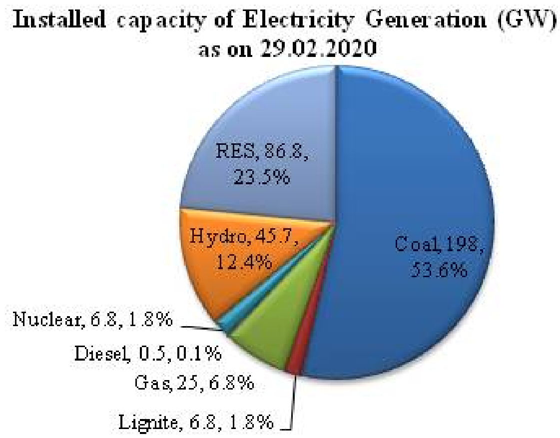

Fig.2. Installed Capacity of Electricity Generations in India (February 2020)

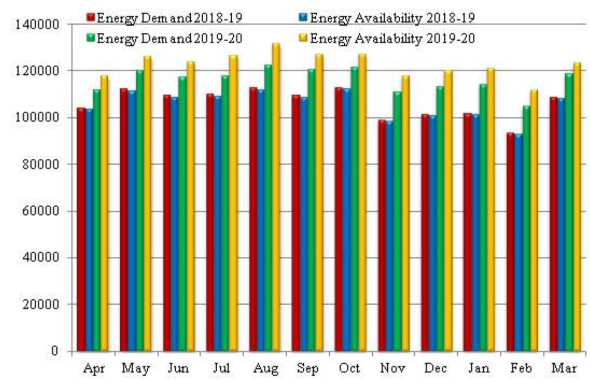

Fig.3. Energy required and Energy generated in India (2018-19 & 2019-20)

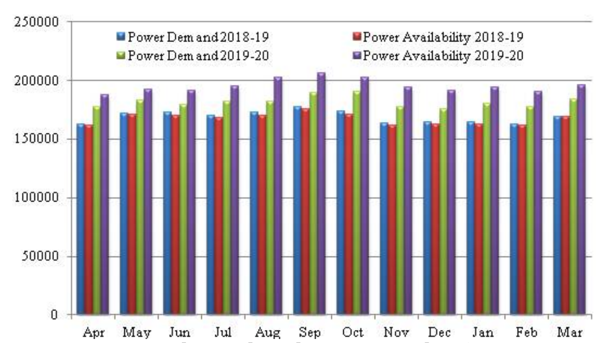

Fig.4. Power demand and Met in India (2018-19 & 2019-20)

The peak demand varies from 162 GW to 177 GW during 2018-19 but in 2019-20, it varies from 176 GW to 190 GW. The power deficit varies in the range 0.3% to 1.7% in the year 2018-19. So there was a small deficit always exist throughout the year in the power generation. But in 2019-20, it is expected that the demand will be less than the availability of power, because of new generating capacities are added during 2019-20 [8].

3. RENEWABLE ENERGY STATUS IN INDIA

India's future energy growth depends on both International norms on climate control and National development objectives [2]. India's political agenda is to provide electricity and clean cooking to its citizens. International energy Agency (IEA) has highly commended Indian Government's reforms in electricity market and shift in investments towards variable renewable energy (VRE) [9]. According to World Energy Council's report 2018, India is one of the world's renewable growth leaders. Presently, 80 % of India's electricity generation is dependent on coal, oil, and gas [10]. Coal is imported in huge amounts from many countries. In order to increase the self-reliance, energy security and reduce emissions, India has set the renewable energy target of 175 GW by 2022 and 275 GW by 2027 [10]. This will have a share of around 30-40 % of total installed capacity of electricity generations. The target of 175 GW by the year 2022 comprises of 100 GW of solar, 60 GW of wind, 10 GW of biomass and 5 GW of small hydropower capacity [11, 12]. Renewable energy growth in India has many challenges such as i) the sources are available in western and southern parts mostly: ii) Power sector is administered by both State and Central governments iii) Integrating Renewables with existing grid iv) creation of manufacturing and service facilities for Renewable Technologies v) unplanned urbanisation vi) rigid operating nature of base load thermal power stations etc [10, 12].

India's increasing installations of renewable energy generating facilities help to reduce import of expensive fossil fuels [10]. Estimated renewable energy potential in India is about 1096 GW from commercial renewable installations viz., 750 GW of solar power, (assuming 3% wasteland), 302 GW of Wind (at 100-meter hub height); 21 GW of Small Hydro ; 25 GW of Bio-energy [13, 14].

India is one of the larger contributors for the emissions by using fossil fuels for its energy needs. For satisfying international norms and to have clean environment, India is in a position to choose alternatives for the fossil fuels. Renewable energy technologies are providing a solution to this problem and becoming realistic economically and technically because of rapid advancements in that sector and fall of prices. Clean energy transition depends on the rapid adaptation of renewable based power plants and electric vehicles. Uninterrupted electricity to all people by 2022, and electrification of all villages by 2018 are the set goals of Indian Government. India aimed to reduce emissions by 33-35% less than in the year 2005 by the year 2030. Also the renewable energy share of electricity generation in 2030 will be more than 40% [10].

India stands at 5th position all over the world for its installed capacity of renewable energy with a total capacity of 73.35 GW as on 31.10.2018. Wind and Solar power installed capacities reached 4th and 5th positions in the world with wind energy 34.98 GW and Solar energy 24.33 GW respectively. The capacity additions of grid connected Solar, wind, Small hydro power, and Bio-Power during 2014-15 to 2018-19 (Upto October 2018) are shown in Fig.5. In the same duration, other off-grid renewables such as waste-to-energy, biogasifiers, Solar cumulatively have a capacity addition of 1100 MW. During the fiscal year 2017-18, cumulatively 101.83 billion units of electricity were produced from renewable energy sources in India. In 2017-18, out of overall energy generated in the country, renewable energy generated is 8%. The Government has set the target to add 60 GW capacity of solar energy and 20 GW capacity of wind energy by March 2020. As per the target of Indian government, by the year 2022, the solar installed capacity will surpass the wind capacity [15].

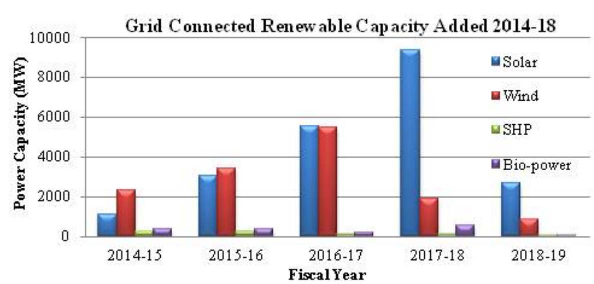

Fig.5. Capacity additions of grid connected Renewables 2014-2018

Government of India to aims to achieve 225 GW of renewable energy capacity by the year 2022, much ahead of its target of 175 GW as per the Paris Agreement. The country stands at fourth and fifth position in the installed capacity of wind and solar respectively as of 2018 [15]. Under National Biogas and Manure Management Programme introduced in 2014, about 5 million houses are installed with biogas plants for cooking and lighting purpose [16].

The four objectives of India's energy policy are i) Access at affordable prices, ii) Improved security and Independence, iii) Greater Sustainability and vi) Economic Growth [4, 17]. National Energy Policy suggested actions to make energy ready India by 2040. The energy demand in India during 2040 will rose to 270-320% than 2012, because of i) manufacturing sector's share of 30% in GDP ii) 47% people live in urban areas and iii) population of 1.6 billion [4].

India has 86.8 GW of the total renewable power generations till February 2020 which is illustrated in Fig.6. In which the share of sources are: Wind 43.6% (37.6 GW), Solar 39.4% (34 GW), Bio-power 11.4% (9.86 GW), and finally Waste to energy has a least share of 0.2% (0.14 GW) [7].

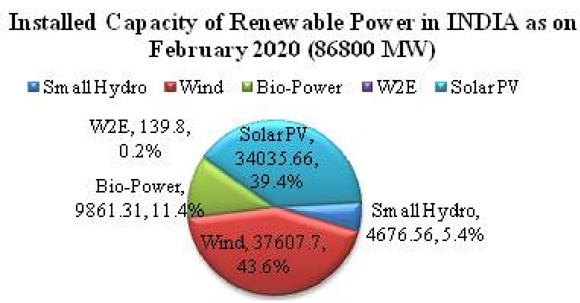

Fig.6. Share of Renewable Energy Installation in India (February 2020)

With the different categories of Renewable energy sources, the electricity generation share by them is increasing year by year. In financial year 2018-19, renewable power including hydro power contributed about 19 % (261,797 GWh) of India's total energy consumption of 1,371,517 GWh [18]. The electricity production from each source in the year 2018-19 is illustrated in Fig.7.

In the next decade, Renewable energy's development in India seems to be very prospective. Hundreds of companies have promised to invest about $350 billion to construct and operate 250 GW Renewable energy power plants primarily of solar, wind, SHP and biomass power. Indian Power sector has opportunities for significant growth with the investments over the next four to five years in power generation, transmission & distribution facilities, and related equipment. Need of energy storage in India will be in huge amounts because of the growth of renewable power and electric vehicles [19].

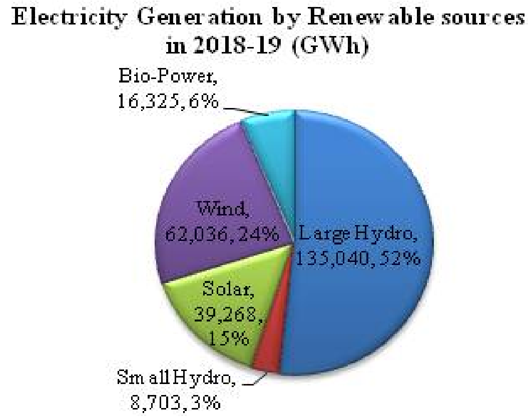

Fig.7. Electricity Generation by Renewable sources in 2018-19

3.1 Solar Energy

In India, yearly solar radiation incident over its land mass is about 5,000 trillion kWh. The daily average of solar energy potential of 4 to 7 kWh/ m^2 is possible with the commercially proven technologies [3]. The total solar potential available in India is 750 GW, out of which only 34 GW is installed at present. The solar power target of 20 GW was achieved four years ahead instead of the year 2022 by the Indian Government. The solar PV power capacities of 3 GW, 5 GW, and 10 GW have been added in the years 2015-2016, 2016-2017 and 2017-2018 respectively. In January 2015, another target of 100 GW up to the year 2022 was set by the government which includes 40 GW of rooftop solar and remaining is large-scale grid-connected solar PV [20].

The generated electricity form solar PV is 39.27 TWh out of 1372 TWh, which is 2.86% of total electrical energy generated in India in the year 2018-19. The installed solar power capacities of top 10 states are listed in Table 1. The Major Solar Power plants which are above 100 MW are listed in Table 2 [20]. The International Solar Alliance is headquartered in India, has the vision to provide clean and affordable energy to people [15].

Table 1
Installed capacity of Solar Power Plants in top 10 states

S.No.	State	Cumulative Capacity as on 31-03-2019 (MW)
1	Karnataka	6096
2.	Telangana	3592
3.	Rajasthan	3227
4.	Andhra Pradesh	3086

5.	Tamil Nadu	2575
6.	Gujarat	2440
7.	Madhya Pradesh	1840
8.	Maharashtra	1634
9.	Uttar Pradesh	960
10.	Panjab	906

Table 2
Major Solar Power Plants in India

Plant	Place	DC peak power (MW)	Commiss -ioned
Bhadla Solar Park	Gujarat	2,245	March 2020
Pavagada Solar Park	Karnataka	2,050	December 2019
Kurnool Ultra Mega Solar Park	Andhra Pradesh	1,000	2017
Rewa Ultra Mega Solar	Madhya Pradesh	750	2018
Charanka Solar Park	Charanka, District Patan, Gujarat	690	2012
Kamuthi Solar Power Project	Kamuthi, Tuticorin District, Tamil Nadu	648	September 2016
NP Kunta	Andhra Pradesh	500	2018
Ananthapura mu - II	Andhra Pradesh	400	2019
Mandsaur Solar Farm	Madhya Pradesh	250	2017
Gujarat Solar Park-1	Gujarat	221	April 2012
Welspun Solar MP project	Bhagwanpura village, Neem -uch District, Madhya Pradesh	151	February 2014
ReNew Power, Niza mabad	Dichpally, Nizamabad District, Telangana	143	April 2017
Sakri solar plant	Sakri, Dhule district, Maharashtra	125	March 2013

3.2 Wind Energy

National Institute of Wind Energy (NIWE), Chennai, is an organization for wind energy research in India under the Ministry of New and Renewable Energy. This institute has installed about 900 wind monitoring stations (WMS) [21] throughout India and 117 WMS are in operating condition as of March 2020 [22]. The wind assessment has been carried out at heights ranging from 20 m to 120 m. In Addition hundreds of private wind monitoring stations is also operational in the country. It was assessed that 237 locations have the wind potential of 200 W/m^2, based on the data collected from WMS. By considering the sites having power density 200 W/m^2 at 100 m hub height and 2% land availability, 302 GW of wind power potential is available to extract. The total installed wind power capacity in India was about 35.6 GW as of 31 March 2019, and becomes the fourth largest in wind power capacity in the world [21].

In India, 10% of total installed capacity is by wind. In 2018-19, 62.03 billion Units of electricity have been generated form wind resources with utilisation factor nearly 19.33%, which contribute 4% of total energy consumption. During Southwest Monsoon, which falls from April to September, 70% of wind energy is generated. The state wise installed capacity of wind turbines and larger wind farms in the country are illustrated in Table 3 and Table 4 respectively [23].

Table 3
Installed wind power capacity by state as of 31 October 2019

S.No.	State	Total Capacity (MW)
1.	Tamil Nadu	9231.77
2.	Gujarat	7203.77
3.	Maharashtra	4794.13
4.	Karnataka	4753.40
5.	Rajasthan	4299.73
6.	Andhra Pradesh	4077.37
7.	Madhya Pradesh	2519.89
8.	Telangana	128.10
9.	Kerala	62.50
10.	Others	4.30
	Total	**37090.03**

Table 4
India's largest wind power production facilities (More than 50MW)

S.No.	Power plant	Producer	Location	MWe
1.	Muppandal windfarm	Muppandal Wind	Kanyakumari, Tamil Nadu	1500
2.	Jaisalmer Wind Park	Suzlon Energy	Jaisalmer, Rajasthan	1064
3.	Brahmanvel windfarm	Parakh Agro Industries	Dhule, Maharashtra	528
4.	Dhalgaon windfarm	Gadre Marine Exports	Sangli, Maharashtra	278
5.	Vankusawade Wind Park	Suzlon Energy Ltd.	Satara District, Maharashtra	259
6.	Vaspet	ReNew Power	Vaspet, Maharashtra	144
7.	Beluguppa Wind Park	Orange Renewable	Beluguppa, Andhra Pradesh	100.8
8.	Mamatkheda Wind Park	Orange Renewable	Mamatkheda, Madhya Pradesh	100.5
9.	Anantapur Wind Park	Orange Renewable	Nimbagallu, Andhra Pradesh	100
10.	Damanjodi Wind Power Plant	Suzlon Energy Ltd.	Damanjodi, Odisha	99
11.	Jath	ReNew Power	Jath, Maharashtra	84
12.	Welturi	ReNew Power	Welturi, Maharashtra	75
13.	Acciona Tuppadahalli	Tuppadahalli Energy India Pvt Ltd	Chitradurga District, Karnataka	56.1
14.	Dangiri Wind Farm	Oil India Ltd.	Jaiselmer, Rajasthan	54
15.	Bercha Wind Park	Orange Renewable	Ratlam, Madhya Pradesh	50

3.3 Small Hydro Power

Another important renewable energy source under the purview of Ministry of New and Renewable Energy is Small Hydro Power (SHP). SHP is chosen to meet the electricity demand mainly in rural and remote areas, which use free water flow for clean electricity generation. The estimated potential for SHP in India is about 21 GW [21]. Numerous of the SHP sites are located in rivers of Himalayan region and rivers & irrigation canals of other parts of the country. Hydro projects up to 25 MW capacities are categorized as Small Hydro Power (SHP) projects, and they are further classified as i) Micro Hydro-Up to 100 kW ii) Mini Hydro-101-200 kW iii) 2001-25000 kW. Alternate Hydro Energy Centre, IIT Roorkee identified 7,133 promising SHP sites with cumulative capacity of 21,133.65 MW according to its report in July 2016. The cumulative capacity of SHP installed is 4593 MW till March 2019. Another 16 GW of SHP potential could be harnessed in the near future [21, 24].

A target of 5000 MW of SHP by the year 2022 was planned by the Ministry of New & Renewable Energy (MNRE). In India, SHP projects are constructed and operated by the Private Investors. SHP projects provide energy at low cost because of no fuel cost, advanced technology with high efficiency systems and operational flexibility. The aims of the SHP scheme are to i) maximise utilisation factor ii) maximise reliability iii) minimize investment for equipment [25].

SHP projects guarantee returns in the long run but involve high capital cost. Living beings and landscape are effected less by the construction of SHP plants. Generally SHP provides good capacity utilization factor than the other renewable energy sources. Hence, Indian government promote SHP by providing financial and technical support. MNRE provides financial support for survey, Project report preparation and Construction of SHP plants [24]. State wise details such as potential identified, installed and under implementation of SHP schemes as of November 2016 are illustrated in Table 5.

Table 5
SHP Potentials in India November 2016

S.No	State	Projects Installed	
		Number	Capacity (MW)
1	Andhra Pradesh & Telangana	72	241.98
2	Arunachal Pradesh	152	104.605
3	Assam	6	34.11
4	Bihar	29	70.7
5	Chhattisgarh	10	76
6	Goa	1	0.05

7	Gujarat	6	16.6
8	Haryana	9	73.5
9	Himachal Pradesh	184	842.11
10	J&K	42	161.03
11	Jharkhand	6	4.05
12	Karnataka	167	1230.73
13	Kerala	32	213.02
14	Madhya Pradesh	11	86.16
15	Maharashtra	65	347.375
16	Manipur	8	5.45
17	Meghalaya	4	31.03
18	Mizoram	19	41.47
19	Nagaland	12	30.67
20	Odisha	10	64.625
21	Punjab	54	170.9
22	Rajasthan	10	23.85
23	Sikkim	17	52.11
24	Tamil Nadu	21	123.05
25	Tripura	3	16.01
26	Uttar Pradesh	9	25.1
27	Uttarakhand	101	209.32
28	West Bengal	24	98.5
29	A&N Islands	1	5.25
Total		**1085**	**4399.355**

3.4 Bio-Energy

Biomass plays a vital role among the renewable energy sources, in particular in rural areas, as it is one of the main energy sources in majority of households in India. Bio-energy is obtained from organic matter derived from trees, plants, crops or from human, animal, municipal and industrial wastes [26]. Biomass resources in India are estimated as 18,000 MW by EAI. Investment of about Rs. 64500 Crores made every year on Biomass related projects, which leads to 5 TWh of electricity generation. MNRE has set 10 GW power generations from biomass as the target by the year 2022. Resources for bio-energy are Biomass, Biogas and Bio-fuel. In India, 450-500 million tonnes of biomass is produced every year. At present Biomass contributes 32% of all the primary energy use [27].

The vision of National Policy on Biofuels 2018 is to augment usage of biofuels in the energy and transportation sectors during the next decade. Increased use of biofuels reduces usage of fossil fuels which warrant National Energy Security, Climate Change mitigation, and new employment opportunities. Also the policy encourages the use of advance technologies for production of biofuels [27]. The primary goal of the policy is to enable market availability of biofuels and increase its blending percentage in petrol and diesel. The proposed goal of the policy is to increase blending of ethanol in petrol to 20% and blending of biodiesel in diesel to 5% by the year 2030. At present blending percentage of ethanol in petrol is around 2.0% and blending percentage of biodiesel in diesel is beneath 0.1%. These goals of the policy [27] are to be achieved by

(a) enhancing supply of ethanol/biodiesel through increasing domestic production

(b) setting up of Second Generation (2G) bio-refineries

(c) development of new raw materials for biofuels

(d) development of new technologies for conversion to biofuels.

(e) creating suitable environment for biofuels and its integration with the main fuels.

3.5 Geothermal energy

Fig. 8. Locations of Major Geothermal Resources in India

Geothermal energy is the natural heat available underneath earth, created from fiery collection of dust and gas more than 4 billion years ago. This energy is renewable in nature, regenerated continuously by the decomposition of radioactive components created in earth layers. The temperature increases by 17 °C to 30 °C for every kilometre depth. In general, the geothermal energy resources are classified as Hydrothermal, Geo-pressurised brines, Hot dry rocks, and Magma. The estimated geothermal potential of earth up to the depth of 10 km is around 403x106 Quads [28].

India has convincingly high potential of 10,600 MW of geothermal resources. For electricity generation, no geothermal plant is operating at present; but direct usage of heat from geothermal is utilised for drying applications at few places. The installed capacity of such plants accumulates about 203 MW and producing 1606 TJ/year with capacity factor of 0.25 [29].

In India, around 340 geothermal locations have been identified until now by diverse studies and surveys carried out. The regions of geothermal sites are illustrated in Table 6. The majority of geothermal basins are situated in the north-west of the Himalayas and Tatapani fields on the Narmada in central India. Other regions are Godavari Basin Manikaran (Himachal Pradesh), Bakreshwar (West Bengal), Tuwa (Gujarat), Unai (Maharashtra), and Jalgaon (Maharashtra). The important sites of geothermal energy are indicated in the map of India in Fig.8 [28].

Table 6
Potential Geothermal regions/sources in India

Province	Surface Temp ^{o}C	Reservoir Temp ^{o}C	Heat Flow	Thermal gradient
Himalaya	>90	260	468	100
Cambay	40-90	150-175	80-93	70
West coast	46-72	102-137	75-129	47-59
Sonata	60 – 95	105-217	120-290	60-90
Godavari	50-60	175-215	93-104	60

3.6 Ocean Energy Sources

Ocean energy technology is currently under-developed in India. Significant ocean energy sources are such as Tidal energy, Wave energy, Water Current Energy and Ocean Thermal Energy. Government of India looking forward for variety of promising technologies and considers supporting its development. Research and development activities in these fields are to be stimulated in a phased manner to make the ocean energy sources a part of Indian grid. Development of Ocean energy sources provide economic growth, creation of new kind of jobs and help reducing carbon emissions. India's vision named as 'Blue Economy' aims at developing home-grown technologies for extracting ocean energy [30].

3.6.1 Wave Energy

Indian seashore of 7517 km with plentiful estuaries and gulfs makes it suitable for the development of marine energy projects. Indian Wave energy technology developments are in the budding stages. The estimated potential of wave energy is in the range of 40-60 GW with 5-15 MW/m energy densities. IIT Madras and Credit Rating Information Services of Indian Ltd (CRISIL) have made a study and identified many locations along the western coastline in Maharashtra, Goa, Karnataka and Kerala states [31].

Indian Institute of Technology, Madras with the funding from Department of Ocean Development of Government of India established a 150 kW pilot wave energy plant at Vizhinjam in Thiruvananthapuram, Kerala in 1991. This was the world's first Oscillating Water Column (OWC) based technology project but was in operation for few years only. Being out of service for long period it was decommissioned in 2011 [32].

Technological and economical challenges such as low turbine efficiencies, extension of grid connections to potential sites, high turbine costs, lack of experience and stochastic environmental conditions are to be addressed to make wave energy economically feasible. Wave energy doesn't have place in the target of 175 GW by 2022 for renewable energy [32].

3.6.2 Tidal Energy

Tidal energy can be harnessed by utilising the high tide and low tide made in the sea level by the gravitational force of the moon and sun. The energy can be obtained for 6-10 hours a day because the tidal cycle alternates every 12 hours. During high tide, Sea water enters into a barrage constructed across an estuary. During low tide, the collected water made to flow through water-turbine makes use of potential energy to electrical power. At least 5 m height tide is required to acquire the tidal energy. India is one among 20 such locations worldwide. In India, western coastal region has higher tidal height [30]. The Gulf of Cambay has potential of 9000 MW, the maximum and average tidal range of 11 m and 6.77 m. The Gulf of Kutch has the potential of 1200 MW, the maximum and average tidal range of 8 m and 5.23 m respectively. Around 100 MW of tidal energy potential exist in Ganges delta region.

Kalpasar Tidal Power Project located at the Gulf of Khambhat is a promising site for tidal power generation. For encouraging the private investors, MNRE announced in February 2011 that it offer financial incentive of half of the total project cost [30, 31].

3.6.3 Ocean Thermal Energy Conversion (OTEC)

The temperature difference between the upper surface of sea water and water at deep sea, are used to extract energy is nothing but Ocean thermal energy conversion, or OTEC. A temperature difference of about 20°C could produce usable energy [31]. In general, two types of OTEC concepts are adapted namely closed cycle and open cycle. In the closed cycle system, the temperature difference is used to vaporize a working fluid, like ammonia and the turbine utilize this pressure to rotate. Cold water at the depths of the ocean is condensing the vapour and it is pumped back to the heat exchanger. In the open cycle system, the warm surface sea water is pressurized in a vacuum chamber and converted to steam which is used to run the turbine. The steam is taken to the depth of the sea where it is condensed by cold ocean water and working fluid is pumped to heat exchanger [30].

Indian south coast about 2000 km length has the temperature difference of above 20^oC throughout the year. In the Exclusive Economic Zone around the Indian coast of 7500 km long, about 1.5x106 square kilometres of tropical water has the power density of 0.2 MW/km^2. The total estimated OTEC potential in Indian coastal is estimated as 180,000 MW. However, OTEC needs more capital costs and is economically feasible in large scales. Construction of offshore OTEC plants in large scale has many complexities and challenges. Hence a 200 kW land based OTEC plant has been planned at Kavaratti, capital of the Lakshadweep Archipelago supplying power to a thermal desalination plant [33].

4. CHALLENGES FOR RENEWABLE ENERGY GROWTH IN INDIA

In India larger share of Electrical power is obtained from coal based power plants although coal will be available till 2050 and huge amount of CO_2 emission contributing to global warming and are the reason for many health hazards to the people. Promoting renewable energy programs in the rural areas for encouraging distributed hybrid power generations which help to create basic facilities and increase job opportunities. Indian Government has a policy on renewable energy to increase the share of renewable power to 40% in 2030. Even though there is huge scope for development and investment in renewable energy in India, there are many hurdles and constraints make the growth slower [34].

4.1 Political and policy barriers

The multi-layered governance system in India (Central and State Governments) produces a mixed result of fruitful and unfruitful [10]. The policy of Renewable purchase obligation (RPO) compels states to attain a certain amount of energy from renewable sources. Perform, Achieve and Trade (PAT) scheme for industries made the energy demand of industries less. Energy Efficiency Services Limited has achieved considerable progresses in replacing LED lamps for the existing less efficient incandescent lamps and fluorescent lamps. Another achievement of NDA government is provision of LPG gas for cooking purpose for the poor people. Since 2015, through the Pradhan Mantri Ujjwala Yojana scheme, about 50 million LPG stoves and initial refills have been provided freely to poor households [35].

Even though there are encouraging results of many policies and schemes, there are obstacles due to India's multi-layered governance system which prevent the full implementation of policies. Many states are opposing the rational electricity pricing concept formulated during 1970s for political benefit in the state, which provides subsidized minimum price for electricity for agriculture purpose and domestic customers [36].

Industries and business organisations are reluctant in adopting RET because of insufficient and implicit policies of government. Expectations of new ventures such as subsidies for capital investment, tax benefits, power transmission facilities, grid code for interconnection, licensing requirements, environmental clearances from government agencies are lacking [37].

4.2 Technological barriers

Renewable Energy Technology development in India is slower because of many technological factors. Resource assessment, Geographic conditions, distributed and intermittency nature of renewables, and lack of storage technologies are some of the technology issues. Few other obstacles such as i) lack of design and technical standardization of system components ii) nonexistence of long term policies for renewables which resulted in manufacturing, servicing and maintenance difficulties; iii) inadequate training of personnel; and f) lack of co-ordination between government agencies, renewable industry and research groups in academic and research institutions [37].

4.3 Economic and financial barriers

Indigenous technology developments help to reduce the investment cost and adapt by the investors. Growth of RET demands the economic factors such as small payback periods, subsidies for investment and incentives for production, economic benefits etc. Government decided to introduce performance linked incentives for the power producers instead of the subsidy for capital investment. Provisions in GST to be made included for the existing tax rebate for accelerated depreciation. Feed-in-tariffs will continue to drive the Renewable Energy market. The tariff support to be continued till the renewable energy cost comes down than coal based energy cost [36].

State owned distribution companies (Discoms) have dept over USD2.4 billion. Because of this the Discoms are unable to reach the Renewable Purchase Obligation (RPO) introduced in the Electricity Act 2003. Indebted Discoms are unable to invest on improving grid facilities, which leads to more losses & debt for Discoms and power generated from renewables less viable [36].

4.4 Organizational structure barriers

Inadequate coordination and mutual aid between various central and state ministries, nodal agencies, institutes and other stakeholders delays the progress in RE development. For example, after the acceptance of applications for wind projects under GBI scheme by IREDA, MNRE rejected the applications because the notification was not released in the gazette at that time. In practice, IREDA might have accepted the applications after the gazette notification, so that this confusion might have been avoided. Such implementation gaps among the nodal agencies make investors feared about their investment towards RE [35, 37].

4.5 Technical barriers

Developing countries face technical challenges such as deficient technology and infrastructure to support the growth of RET. Another issue is that inadequate trained manpower to operate and maintain renewable energy systems, specifically in rural areas. Energy cost of renewable power is comparatively higher than fossil fuel power as the technology is matured and resource is readily available. Required Transmission and distribution networks for renewable power projects, is another challenge. Such barriers result loss of investor's confidence in RETs and force them to choose fossil fuels [4].

4.6 Social-cultural barriers

India has lakhs of villages in its geographical structure. The rural people's reluctance to adopt renewable energy due to its unreliability nature and cost involved. Also, awareness and knowledge about renewable energy technologies is lacking in rural communities, which plays a role in restraint growth of RET [4].

4.7 Land rights

Renewable power plants especially solar and wind require larger area of land for its installations even though India has the problem of land scarcity. The previous congress government in order to reinforce rights of the land owners passed a law which made the land price four times the market price, land acquisition complicated and time consuming. The NDA government reformed the law and have paid the same compensation but acquired the land without the consent of farmers and social impact. The opposite parties holding majority in 'Rajya Shaba' opposed the law of land reforms and it was defeated. These shows how difficult are imposing a law in Indian politics [4].

5. RENEWABLE ENERGY POLICIES OF INDIAN GOVERNMENT

5.1 Top Government Programmes in the Solar Sector

5.1.1 Rooftop Scheme

Solar Energy Corporation of India sanctioned 200 MW of rooftop solar projects under the rooftop scheme, in which 45 MW have been commissioned. The projects with 50 MW capacity for the CPWD (Central Public Works Departments) and 73 MW capacity for warehouses have also been sanctioned. As part of MNRE's target of 40 GW rooftop capacity by 2022, SECI initiated a tender which offer 30% subsidy to the residential sector, non-profit private educational institutions, hospitals, social buildings. [38].

5.1.2 Solar Park Scheme

MNRE aims to install number of solar parks under this scheme across the country with a capacity of around 500 MW. This scheme offers financial support to establish solar parks and provide support for acquisition of land, grid facilities, road facilities, water, etc. This policy augurs to construct Solar parks in partnership with the State Governments. The duty of the state governments is acquisition of land and finding private investors/developers of solar park. Local population may get employment opportunities under this scheme. The states may get the benefit of reducing of equivalent carbon emissions. The scheme is implemented by SECI for Government of India [38].

5.1.3 Viability Gap Funding (VGF) Scheme

Viability Gap Funding scheme implemented by SECI supports developing of grid-connected solar PV projects of minimum 2000 MW capacity by the private investors on build, own and operate basis [12, 38]. Under this scheme a budget of Rs. 8580 Crore has been announced by MNRE for the state-run power producers to install 12 GW of grid connected solar PV power projects. Also it is stated that the purchase of equipments should be from domestic manufacturers. This capacity will be added in the years 2019-23 and the power plant may be constructed for self-use or use by government organisations. The bid will be conducted by SECI for allocation of the power capacity [39].

5.1.4 Government Yojana Solar Energy Subsidy Scheme

Government of India announced this scheme for the benefit of power loom and small textile industries which enables to increase textile production. The subsidy for such applicants on capital investment will be provided to the extent of 50 %, 75 % and 90 %. Another benefit of this scheme is reduction of electricity bills of power looms and demand on conventional power plants [38].

5.2 National Wind-Solar Hybrid Policy

Stochastic nature of Solar and wind power makes difficulty in grid connection and introduces stability issues. Due to the complementary periods of availability of wind and solar power during a day, making use of both sources at the same location would provide sustainable power to the loads. Exploitation of both the resources makes possible extension of renewable power plants to new locations and existing locations of solar and wind farms. In the vacant lands of existing wind farms solar PV panels can be installed and similarly wind generators can be added in and around existing solar PV plant [24]. Changes in existing Policies are required to install wind-solar hybrid plants at new locations and also hybridizing existing wind and solar plants. Further, storage facilities may be created to smoothen the wind solar hybrid power [40].

5.3 UDAY Scheme for state distribution Companies

UDAY or Ujjwal Discom Assurance Yojna was initiated by the Government of India in November 2015, with the objective of reforming the power sector, development in renewable energy, reduction in electricity generation cost, energy efficiency, operational improvement, and conservation. This scheme is expected to provide permanent solution to the existing and future issues of electricity industry. The state governments have the option to join the scheme [37].

5.4 National Policy on Biofuels – 2018

This policy targets the increase of blending biofuels in petrol/diesel. The policy aims to substitute fossil fuels which also support for climate change programme, ensures energy security and creates employment opportunities. This policy importantly considers the development of second generation biofuels and pay way for undertaking the Research & Development activities. The areas such as development of new raw material for biofuel production, plantations, processing and conversion technologies will be concentrated in the R&D activities. Primary importance will be given to indigenous technology development in biofuels and patents. At present 2% of ethanol and 0.1% biodiesel are blended jn petrol and diesel respectively. The policy proposed the blending of ethanol in petrol to be 20% and blending of biodiesel in diesel to be 5% by 2030 [27].

5.5 Green Corridor Scheme

Ministry of Power authorised to build transmission lines to enable the integration of large scale renewable energy power plants in various states under the Green energy Corridor Scheme in 2015-16. This project have been adopted in VRE rich states such as Tamil Nadu, Rajasthan, Karnataka, Andhra Pradesh, Maharashtra, Gujarat, Himachal Pradesh and Madhya Pradesh by the respective transmission companies of states. This scheme provides the option to RE project developers to transmit power through Green Energy Corridors without any charges till the year 2022. In Phase I, 33 GW of RE projects have been integrated by this scheme. In Phase II, it has been planned to install and integrate 100 GW of Solar and 60 GW of Wind within 2022. It is targeted to construct 9400 circuit kilometers of transmission lines and substations with different capacities [9].

5.6 Electric mobility mission of India

The Previous Congress led Indian Government formed 'National Electric Mobility Mission Plan (NEMMP) 2020' in 2011 and subsequently the present government formulated the scheme called, “Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME) in India” in the year 2015 [41]. This scheme was introduced with the aim to focus in the areas of Technology Development, Reinforcing the commitment towards the Paris Agreement, Indian Government has planned a major shift to electric vehicles by 2030 ie., 30% of mobility will be by electric. Nodal agency for the scheme is the Department of Heavy Industry (DHI), GoI and is responsible for the planning, implementation and review of the scheme [42].

A Nodal body named Technology Advisory Group (TAG) under the supervision of DHI and Department of Science and Technology (DST) was constituted to look after the technology foresight and road mapping, Project nucleation and proposals. TAG set up two Centre of Excellence (CoE) namely CoE for Battery, Battery Management System, Power Electronics and Vehicle System Integration and Non Ferrous Technology Development Centre (NFTDC). These centres will be acting as bridge between Industry and Academia with an aim to support the prototyping of system components, Validation and commercial applicability [42].

6. ENERGY STORAGE

In present day situation of allowing greater share of Variable Renewable Energy (VRE) sources in the power system require Energy Storage system for flexible operation of grid. As the renewable sources are variable and distributed in nature, in order to achieve stable operation of power system and meet the load demand, electricity is stored in storage systems. Energy Storage System (ESS) is becoming essential part of Renewable energy Systems in the 21st century. India has set a target for the year 2030 of achieving 30-35% reduction in carbon emissions from the 2005 level and also 40% of total electricity generating capacity from Renewable Energy Sources [43]. So it is assessed that Energy storage Systems has massive economic opportunity in India.

Electricity Storage Systems (ESS) enhances decarbonisation as it is utilised in variety of energy utility applications. Electricity storage applications are increasing in usage such as Medium voltage/low voltage (MV/LV) grid-connected, off-grid, e-mobility, Telecom Towers, Data Centres, UPS & Inverter, and DG Replacement applications. The estimates of ESS requirements from different sectors in India for the period 2019-2022, 2022-2027 and 2027-2032 are consolidated in Fig.9 [44].

	Consolidated Energy Storage Roadmap					
	Applications 2019-2022		Energy Storage (GWh)			
			2019-2022	2022-2027	2027-2032	Total by 2032
Stationary Storage	Grid Support	MV/LV	10	24	36	70
		EHV	7	38	97	142
	Telecom Towers		25	51	78	154
	Data Centres, UPS and inverters		80	160	234	474
	Miscellaneous Applications (Railways, rural electrification, HVAC application)		16	45	90	151
	DG Usage Minimization		0.5	3.5	10.5	14.5
	Total Stationary (GWh)		138.5	321.5	545.5	1,005.5
Electric Vehicles	E2W		4	55	496	555
	E3W		26	69	136	231
	E24		8	110	725	843
	Electric Bus		2	13	57	72
	Total Electric Vehicles (GWh)		40	247	1,414	1,701
Total Energy Storage Demand (GWh)			**178.5**	**568.5**	**1,959.5**	**2,706.5**

Fig.9. Energy Storage Requirement in India

For the estimate of ESS capacity, Stationary storage and Electric Vehicle Applications are considered. Under stationary applications, LV/MV/HV grid support, Telecom towers, Data Centres, UPS & Inverters, Railways, Rural Electrification, HVAC Applications, and DG usage minimisation are taken into account. Two Wheelers, Three Wheelers, Four Wheelers, Buses & Trucks are considered under Transportation Applications. The estimates are listed for each segment for the periods 2019-2022, 2022-2027 and 2027-2032 in Table #. The total energy storage requirement estimate for the periods 2019-2022, 2023-2027, and 2028-2032 for all kind of applications is 178 GWh, 568 GWh and 1960 GWh [44].

Among the variety of storage systems available, commercially viable technologies are Pumped hydro storage, Batteries, Supercapacitors, Thermal storage, Compressed air storage, and Flywheel storage. Lithium ion batteries (LiB) are comparatively cheaper, occupy less space, more energy density, and provide backup for longer hours than Supercapacitors, Flywheel, and Compressed air storage. So, future trends of Pumped hydro storage and LiB are discussed below.

6.1 Trends of Pumped hydro storage

Pumped hydro storage is globally adapted, commercially matured technology which is having larger share of total storage power capacity (in GW) and the energy storage capacity (in GWh). Presently, Pumped hydro storage system is economic to construct and operate and providing flexibility in operating with the power system. It has a share of 96% of total installed storage capacity of 176 GW in 2017. More than 75% of these kinds of plants are installed in ten countries. Major contribution from three countries as of 2017 – China (32.1 GW), Japan (28.5 GW) and the United States (24.2 GW) – accounting for 48% of global energy storage capacity. India has only 6.8 GW of pumped hydro storage power systems as of 2017 as the water resources are not ample. But there are no significant improvements and flexibility of grid operation is reported and has many issues in its operation. The installation cost of Pumped hydro storage is 1780 USD/kW in 2016 and 1560 USD/kW in 2017. The Levelised cost of energy from Pumped hydro storage is typically ranging between USD 0.04 and 0.06/kWh depending on the location and terrain [45].

6.2 Trends of Battery Storage

Battery storage is other kind of possible electricity storage. Even though the capital cost of batteries are high at present, because of technology advancements and mass production the cost is expected to reduce in future. Battery storage capacity has a share of 1.6 GW and 1.1% of total storage capacity globally in 2017. India's Target of Roof Top Solar PV systems are integrated into LV/MV grids. These integrations have many issues such as voltage, frequency variations and harmonic injection etc. In order to achieve flexilbe and stable operation of power system Battery Energy Storage Systems (BESS) are suggested in India. Energy Storage India Tool (ESIT) has been developed for assessing the battery capacity for different locations/applications [45].

7. ANALYSIS OF RENEWABLE ENERGY COSTS

The capital cost of solar and wind technologies are continuously declining due to deployment of capacity additions worldwide. The Global weighted average total installed cost of various renewable energy sources are listed in Table 7. The installation cost of solar PV, onshore wind, Bio-Power, Hydro Power systems are cheaper than thermal power plants. Even though the installation costs of offshore wind, and Geo-thermal energy systems are comparatively equal or slightly higher than thermal power plants, the energy cost are lesser due to lesser operating and maintenance cost. The installation cost of CSP is higher than thermal power plants presently, but it is expected to fall in future by improvements in technology and more capacity deployment [44].

Table 7
Global weighted average total installed cost of Renewable Energy Sources in 2019

S.No.	Renewable Source	Total Installed Cost (USD/kW)
1	Solar PV	995
2	On Shore Wind	1473
3	Off Shore Wind	3800
4	Concentrated Solar Power	5774
5	Bio-Power	2141
6	Geothermal Power	3916
7	Hydro Power	1704
8	**Fossil Fuel**	3661

Cost of Electricity from renewables is falling in the last decade because of the factors such as technological advancements, large scale installations, increasing supply chain and rising user experience, improvement in capacity factor. The Global average of Levelised Cost of Energy (LCOE) of different renewable energy technologies commissioned in the year 2019 is listed in the Table 8 and also LCOE of fossil fuel power plants at last for comparison. According to this data, except concentrated solar power all kind of renewable energy cost are found to be cheaper than electricity from fossil fuel power plants. Power purchase agreements made in some parts of the world for the year 2021, indicate that there is a fall in the energy costs. LCOE of solar PV could have an average price of USD 0.039/kWh in 2021 which is 42% fall when compared to cost in 2019. Similarly, the auction data indicate that energy cost of onshore, offshore, and CSP will fall to USD 0.043/kWh, USD 0.082/kWh, and USD 0.075/kWh in 2021 which are 18%, 29%, 59% fall respectively from the 2019 prices [44].

Table 8
LCOE of Renewable Energy sources in 2019

S.No.	Renewable Source	LCOE (USD/kWh)
1	Solar PV	0.068
2	On Shore Wind	0.053
3	Off Shore Wind	0.115
4	Concentrated Solar Power	0.182
5	Bio-Power	0.066
6	Geothermal Power	0.073
7	Hydro Power	0.047
8	**Fossil Fuel**	0.05 - 0.177

8. CARBON EMISSION ANALYSIS

It is accessed that the coal based power plants produce an average carbon dioxide emission of 820 gCO_2Eq/kWh. But solar and onshore wind power plants have very less average emission of 48 gCO_2Eq/kWh and 11 gCO_2Eq/kWh respectively during their production process. So by deploying renewable energy sources for electricity, the carbon emissions could be reduced in huge amounts [43].

If solar PV and onshore wind energy systems replaces the least economical 500 GW of existing coal-fired power plants globally, would replace 2170 TWh of coal power generation and reduce emissions by 1.8 Gt of carbon dioxide (CO_2) which is about 5% of global CO_2 emissions in 2019. Replacing coal power plants will reduce the power generation costs and provide an investment stimulus option for renewables worth around USD 950 billion. For replacing 500 GW coal-fired power plants minimum installation of 860 GW of Renewable Energy sources are required, which may pave path for achieving renewable additions for two to three years in compliance with agreement made in UN Climate Conference, Paris 2015 [43].

9. NEEDS AND COST OF DISMANTLING RENEWABLE POWER PLANTS

Recently hundreds of power plants operated for long time become to end of its lifetime and more number of power plants will complete its lifetime in the forthcoming decades. So proper planning is needed to dismantle the facilities and dispose the wastes from these plants. Decommissioning process ensure minimization of negative impacts to local environments, economies, electricity users, and reuse of the land. Fig 10 presents an estimate of decommissioning cost of different power plants [46].

Fuel type	No. of estimates	2016$ (thousands) Minimum	Mean	Maximum
Offshore wind	7	$123	$212	$342
Coal	28	$21	$117	$466
Concentrated solar power (CSP)	5	$24	$94	$138
Solar photovoltaic (PV)	22	–$89*	$57	$179
Onshore wind	18	$2	$51	$222
Petroleum/petroleum + gas	19	$2	$31	$103
Gas (various types)	28	$1	$15	$50

Fig. 10 Decommissioning Cost Estimates per MW of Capacity

Also now because of the technology advancements, new wind turbines are having one to few MW capacities. But the turbines installed earlier to 2012 are having less than 1 MW range having total capacity of 10 GW. A concept called repowering the wind sites was adapted to replace the existing large number of less capacity machines with less number of higher capacity machines. The repowering capacity till 2007 in India for the machines of less than 1 MW capacity is about 4400 MW. In India Solar Systems are installed starting from last decade. So they have life of another 15-20 years. As of now there is no dismantling issue of solar systems [47].

10. CONCLUSIONS

Indian renewable energy developments are steered by the factors such as economic growth, environmental protection by green energy initiatives, and energy security etc. This paper reviews the potential, growth, policies of government, schemes of government, challenges/barriers for the growth of various renewable energy sources in Indian context. Also it presents cost analysis of renewable energy such as their installation and energy cost in comparison with fossil fuel fired power plants. The effect of penetration of renewable power sources on decarbonisation is also presented. Need and cost of dismantling renewable power plants are also discussed. Renewable energy sources such as Solar, Wind, Biomass, Small Hydro, Ocean energy sources, Geo-thermal energy are considered for the analysis. India considers Wind and Solar as the important sources and it is expected that there is significant growth in near future. There is a hope for growth of Biomass, Biodiesel, and small hydro energy sources. But it is noted that the Ocean energy and Geo-thermal energy developments are in its natal stage. Non-availability of Technology, random nature of sources and insufficient funds for investments are the major hurdles for the developments of these sources.

Indian power market provides different options for the RE generators to sell the energy, such as feed-in tariffs, renewable energy certificates, captive and open access sales. The investors can choose the selling option according to their expected risk-return profile. The financial regulatory terms are formed in such a way to offer cost advantage to generators and buyers. The modified grid norms which include forecasting, scheduling and levy of imbalance cost make an obvious and practical path for the development of the renewable energy industry. Nevertheless, the total share of renewable energy in 2030 would be 30% of total energy consumption in India. Also India targeted 30% of vehicles would be electric in 2030. So, in the next decade there is a huge scope for the growth of Renewable energy & Electric Vehicle industry, related Research & Developments, and Jobs in India.

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