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Global Renewable Energy Indicators for Sustainable Development

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***Abstract*—**Energy supplies from renewable sources are the essential components of every nation's energy strategy because of their positive environmental impacts and sustainability. It is economically competitive with fossil fuels. It is one of the pillars of sustainable energy. Climate change, global warming that harms the environment, massive depletion of fossil fuels and hike in rate of oil has driven the governments to support renewable energy legislation and policies. The application and contribution of renewable energy are prominent for sustainable energy development. Renewable energy scenarios such as wind energy, solar energy, bio-energy, geothermal energy, hydro energy and hydrogen energy are presented in this paper. The upward trends of renewable energy installation give motivation and encouragement to enhance the efficiency of renewable energy systems.

***Keywords*—** *Application, Bio-energy, Renewable sources, Solar energy and Wind energy.*

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I. INTRODUCTION

The burning of conventional resources such as coal and oil increases CO_2 emissions. It damages the environment and affects global warming [1]. Energy derived from natural resources such as sunlight, wind, rain, biomass, tides, ocean and geothermal heat is called as renewable energy, which is naturally replenished [2]. Renewable energy technologies are used to develop ecologically sustainable systems and to mitigate greenhouse gases emission. Electricity produced from renewable energy resources without any negative impact to the environment is called green power which is a subset of renewable energy.

There are three generations of renewable energy technologies. Hydropower, biomass combustion and geothermal power and heat are considered as first-generation technologies which have challenges related to the environment and social acceptance. Second-generation technologies include solar heating, cooling, wind power, modern bioenergy and solar PV. It is contributing to total cost reductions and performance improvement. Third-generation technologies consist of advanced biomass conversion technologies, bio- refinery technologies, concentrating solar thermal power, hot dry rock geothermal power and ocean energy and they are still under development and are attracting financial funding from research and development organizations [3].

The world is developing renewable energy by providing incentives and making it commercialized. The renewable resources displaced conventional fuels and it has the following applications such as water heating, space heating, electricity generation, transportation and off-grid rural energy purposes: cooking and lighting.

Renewable energy in many developing countries are providing indirect contributions in education, poverty alleviation, helped in pollution control and reduced the primary energy requirements. At present, about 173 countries have effective renewable energy policy to promote renewable energy. Biomass and wind resources are the oldest forms of energies prior to the development of coal. U.S. President Barack Obama's American Recovery and Reinvestment Act of 2009 has included more than $70 billion in direct spending and tax credits for clean energy. A green bank is a quasi-public financial institution formed by governments of many countries. It has several financial tools to leverage private investment in clean energy technologies and to bridge market gaps. The US military has already committed to have 50% of its energy consumption from renewable sources [4]. The Installed Grid Interactive Renewable Energy Capacity in India as of April 30, 2016 is depicted in Table I

TABLE I
Installed Grid Interactive Renewable Energy Capacity in India as of April 30, 2016 [5]

Types of renewable energy	Installed capacity in GW	Percentage %
Wind energy	26.86666	62.7
Solar energy	6.76285	15.8
Biomass energy	4.83133	11.3
Small hydro energy	4.27347	10.0
Waste to energy	0.11508	0.3
Total	42.84938	100

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In early 1980s, India was the first country in the world which formed an exclusive ministry for renewable energy called Ministry of New and Renewable Energy. Grid interactive installed capacity of renewable energy except large hydro power has reached 42.84938 GW in India [5]. The total estimated renewable potential is greater than the current total installed energy generating capacity of India [1]. There are nearly 40 sites on the Earth which has minimum of 5m tidal ranges [2]. This range is favorable for the construction of tidal power plant. The status of renewable energy and its various critical technologies involved in the power production is explained in this paper.

II. WIND ENERGY

Wind energy is one of the fastest-growing sources of energy in the world. The growth has been achieved by the following factors such as government subsidies and tax incentives, improved technology, high cost of fossil fuels and low carbon emissions. The modern rated capacities of WTGs are vary from 600 kW to 5 MW. However, the rated capacities of the most common commercial WTGs are in the range of

1.5-3 MW [4]. A wind farm with an output of 4,000 kWh per year could save the following emissions: SO2 - 2 to 3.2 tonnes, NO- 1.2 to 2.4 tonnes, CO2- 300 to 500 tonnes and particulates- 150 to 280 kg [1].The stronger and more stable areas have been considered for location of wind farms as power output increases with wind speed. The annual full load hours of WTGs have varied from 16% to 57%. The technical potential of wind energy has 40 times higher than the current electricity demand. The global wind power generation has been achieved as 706 TWh i.e., 3% of the global total electricity generation in 2014. Global wind energy capacity has reached around 4% (369,553 MW) of the worldwide electricity in 2014 and it is developing quickly.

The global wind energy generation has grown from 47 GW to 369 GW within a period of 10 years (from 2004 to 2014) and half of this is contributed by China, United States and Germany. The global existing wind power capacity in 2008 and 2015 was 121GW and 433 GW respectively. Many other countries such as Denmark, Portugal, Spain and Ireland have achieved 21%, 18%, 16% and 14% of wind power penetration respectively. On a commercial basis more than 80 countries have contributed towards of wind energy. The world's largest wind farm installed at California is with capacity of 1,020

MW. The total shares of electricity generation by wind energy in Denmark and Northern German state of Schleswig-Holstein are 49% and 40% respectively [4]. Wind energy has contributed 62.7% of renewable energy in India as on 30th April 2016. India has become the fourth largest wind installed capacity in the world. In India has produced 14% of its total electricity from wind energy. India has a plan to produce 60,000 MW of electricity from wind power by 2022. India has seven largest wind farms with the capacities varies from 144 MW to 1500 MW [5].

Global offshore wind power installed capacity has reached up to 8,771MW in 2014 and it is two times greater than that in 2011. The global off-shore wind power capacity contributed to 2.3% of the total wind energy capacity. The world's largest offshore wind farm is the London Array wind farm with a capacity of 630 MW. The U.K is the world's leading generator of offshore wind power closer to Denmark, Germany, Belgium and China. The offshore wind farm could contribute more energy than on-shore wind farm as it experiences approximately 90% greater wind speed than the later [4].

John Conti-Ramsden and Kirsten Dyer have discussed the opportunities and challenges in the material innovations for more efficient wind turbine blades. The installed capacity of next generation wind turbine would be 7 MW and it would satisfy the electricity requirements of 5000 homes on an annual basis. The longer blades produce more wind electricity. The length of the next generation wind turbine blades would be increased from 80m to more than 100m. Rain in the high humidity salty sea air combined with extreme and high wind speed would affect durability and it would increase the repair and maintenance cost of blades. Hence finding suitable materials to extend the life of blades would be a priority for the wind industry. The modern wind turbine blades are being manufactured by fiber-reinforced composite materials which have high strength-to-weight ratio. Glass-fiber has higher density than carbon fiber. Addition of self-healing polymers in composites would release a high-performance adhesive into the cracks that form during use.

An active area of research is to strengthen the blade at the fiber-matrix interface with the help of nano-components, such as carbon nano tubes and grapheme and to reduce erosion. Coating materials such as epoxy and polyurethane gel-coats, polyurethane paint systems and tapes are currently used as a durable coating to product the blades from a highly erosive environment. The leading edge of a turbine blade experiences the highest level of erosion. The mechanical properties of the wind turbine blade at leading edge would be enhanced by novel thermoplastics materials. An innovative research and development on blade design, materials choice, new coatings and structural solutions are required for a advanced high- efficiency wind turbines [6].

The efficiency of WTG has been increased by 30% with the formation of donut shape structure around the

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turbine rather than increasing the blade size of the turbine. The efficiency of the turbine has been boosted to 20 percent with an innovative technique of increasing its height. The Fuller Wind Turbine has no blades and it has only one rotating turbine-driveshaft. It requires less maintenance. It does not kill birds and bats and does not produce noise. It is suitable for military surveillance and radar installations. It is very much loved by environmentalists. The operating cost of this turbine is about $0.12/kWh [2]. [The capital cost of a wind farm varies in the range of 4.5 crores to 5.5 crores [1].

Genetic algorithm is used for the selection of optimum number and type of WTG which are matching with the available sites. It is a powerful search technique to obtain the maximum economic and reliability benefits [7]. Non-linear control of a variable-speed wind turbine using a two-mass model is used to optimize wind power capture with limiting transient loads on the drive-train components of wind turbine generators [8]. Doubly fed induction generators are subjected to intense stress during the grid voltage sag. A series voltage compensator is adopted with wind turbine to increase the stator voltage to a level that creates the required flux to keep the rotor side converter current within an acceptable range [9]. It has been shown that a split winding alternator with a cascaded H-bridge multilevel inverter can be successfully used to interface a large wind turbine to the grid with better power quality at the point of common coupling [10]. The micro-scale WTG with a novel maximum power point tracking controller is proposed to achieve higher efficiency and lower total harmonic distortion. The increase in power output is 13% [11].

III. SOLAR ENERGY

The solar energy is another renewable source of energy. It mitigates climate change, produce affordable clean energy and maintain sustainability. Solar energy has been extracted with the following methods such as solar heating, PV, concentrated solar power, concentrated PV, solar architecture and artificial photosynthesis. Grid connected solar PV renewable technology has grown fast at the rate of 60% in 2009. The global solar power generation has been achieved as 186 TWh which is slightly less than 1% of the global total electricity generation in 2014. The U.S. is one of the top countries in the world in harnessing solar electric power. In 2013 U.S. has installed a largest parabolic trough solar plant (280MW) using molten salt as a heat absorbing medium. Spain has constructed 873 MW solar thermal power plants [4]. Solar energy has contributed 15.8% of renewable energy in India as on 30th April2016 [5]. The global existing solar PV grid-connected capacity in 2008 and 2015 was 16 GW and 227 GW respectively. China has made an important contribution in solar water heating. It has met 50–60 million of home's hot water requirement from solar water heating. The solar energy has been widely used to power many solar-charged vehicles propulsion and solar powered boats which are commercially available. Solar power is projected to reach the largest source of electricity globally by 2050. Solar energy will be dominating among all other renewable energy sources by 2060.

Solar cells are arranged in solar arrays to convert large amount of sunlight in to electricity. PV system is fast developing technology and it has been installed in small and large utility scale. It is an inexpensive, low-carbon technology to harness energy from sun. Crystalline silicon solar cell and thin-film solar cell are importantly used in PV technology.

Global PV installed capacity has reached up to 177,000 MW.

Germany is the largest producer of global photovoltaic power and it contributes 7.0% of overall electricity generation. PV technology is growing fast in many countries like Europe, China, Japan, U.S and Italy. Italy has the highest share of global PV power and it satisfies 7.9% of its power requirements by PV technology. The world largest solar PV power plant is situated in U.S with the capacity of 579 MW. Global photovoltaic capacity was increased to 227 GW in 2015 which was sufficient to satisfy 1% of the world's electricity demands. Global PV capacity is forecasted to research more than 430 GW by 2018 [4].

Photovoltaic systems have provided power supply for the remote area in the 1980s and early 1990s. Power plants for grid connected applications and building integrated PV systems have been developed from 1995 onwards. The Nellis solar power plant with the capacity of 15 MW is the largest photovoltaic power plant in North America. The capacity of the world's largest PV power station (154 MW) is located in Australia. Since the late 1980s, solar thermal power stations have successfully being operated in California. The largest capacity of solar thermal power plant is 350 MW [3].

The maximum solar irradiance received on earth is more than 1000 W/m2 [12]. India has high solar insolation. The solar power has been used for main applications such as water pumping and off-grid lighting. India has received the important Energy Globe World award for an establishment of solar home power systems. More than 16,000 solar home systems (over the span of three years) have been set up in rural areas of South India where the grid electricity is not available. India would become as a global leader in solar power generation by

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2020. There are 26 largest photovoltaic (PV) power plants have been installed with their capacities varying from 1 MW to 214 MW. The Charanka solar park is the largest PV power plant in India (Gujarat) with the capacity of 214 MW [5].

The annual average temperature of India is in the range of 25°C – 27.5 °C. It indicates large solar potential. The efficiency of single crystal silicon solar PV cell is low. Solar cell with concentrator would operate at low sunlight intensities with high efficiency [1]. Spherical Solar Cells absorbs the sunlight from all possible angles for generating power with better efficiency and flexibility. Gallium arsenide solar cells are more efficient than silicon solar cells when used with reflective dishes. 1,000 megawatts of electricity has been produced from a 4.6 square miles solar energy system in Negev [2].

IV. BIO ENERGY

Bio-energy includes bio-mass, bio-gas and bio-fuels. Bio- mass is a type of biological fuel obtained from living organisms. Biomass is referred as biological materials and it is obtained from energy sources such as garbage, wood, plants, waste, landfill gases and alcohol fuels. Biomass is being converted in to biofuel in the form of solid, liquid and gas fuels using various conversion techniques [13]. It reduces CO2 emissions, reduce GHG emissions, promote rural economies and provide energy benefits. Bio-fuels are 50–70% better than fossil petrol and diesel in CO2 savings. 100% bio-diesel reduces CO2 emissions by more than 75% over petroleum diesel [14]. Bio-fuels are considered in both developing and industrialized countries for several reasons such as energy security, environmental concerns, savings of foreign exchange, socio economic, locally available, accessible, sustainable, and reliable fuel obtained from renewable sources. Biomass such as wood, straw, and even household wastes could be economically converted in to bio-ethanol. It is the best alternative fuel instead of petrol [15].

The largest source of bio-mass is wood. Bio-mass needed for industries can be extracted from different type of plants including bamboo, sugarcane, hemp, corn, sorghum, palm oil, eucalyptus, switch grass, miscanthus [4]. Agricultural residues are potential renewable energy resources if they can be properly and biologically converted to methane [16]. The regions with the highest quantities of agricultural residues are the Marmara, Mediterranean, Aegean, and Central South regions, in decreasing order. The residue density of these regions changes between 28.0–43.2 t/km2.

The highest quantities of agricultural residues are found in wheat, barley, chickpea, corn, and cotton stalks as well as in the pruning residues of vine, apple, hazelnut, olive, and orange trees which are referred as category A. The production residues of grape, hazelnut, sunflower oil, tomato, and olive oil are referred as category B. The calorific value of category B residue is 20.7 MJ/kg where as that for category A is 18.5

MJ/kg [17]. The degradation of cellulose to glucose from plant residues can be done using a series of chemical processes and the product obtained can be used as a 1st generation bio-fuel [4]. Ethanol is produced from cellulosic feedstock.

Biogas is produced from biodegradable materials such as manure, sewage, municipal waste, green waste, plant material, and crops without oxygen by fermentation process [13]. Anaerobic biogas production is an effective process for conversion of agricultural biomass to methane to substitute natural gas and medium calorific value gases [16].

The IEA has estimated that the bio-fuels have the potential to meet quarter of global demand for transportation. Some of the crops like sugarcane and corn can be fermented to produce ethanol which is a transportation fuel [4]. Vegetable oils and animal fats are used to produce biodiesel by transesterification process [13]. Biodiesel is predominantly used for the transport

sector in any diesel engine without modification [15]. Bio- fuels contribute 2.7% of the transport fuel of the world in 2010. Brazil produces ethanol fuel from sugar cane and it satisfies 18% of its automotive fuel requirements [4]. Modern biomass-based transportation fuels such as ethanol and biodiesel are produced by Fischer-Tropsch synthesis process [18]. There exists a great challenge in producing bio-fuels from algae because algae are non-edible and also it grows at a relatively faster rate than agricultural products [4]. An average acre of algae produces 19,000 liters of biodiesel per year and it contributes zero emissions to greenhouse gases. Algae are suitable for water treatment and it removes nitrogen from wastewater [2].

The raw materials available for production of bio-mass vary from one region to another. Agricultural waste is common in Mauritius and Southeast Asia. Poultry litter and animal husbandry wastes are common in UK. Forest by- products are common in USA. Brazil is the second global largest manufacturer of ethanol after U.S. Currently, ethanol compatible vehicles have been designed to reduce emission and approximately 6 million 85% ethanol blended vehicles are running on U.S roads. The global annual ethanol production in 2008 and 2015 was 67 x109 litres and 98 x109 litres respectively. The global annual biodiesel production in 2008 and 2015 was 12 x109 litres and 30 x109 litres respectively. Ethanol is used as a

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gasoline addictive and biodiesel is used as diesel addictive to improve emissions from gasoline and diesel vehicles.

Bio-mass also contains some disadvantages. Pollutants such as nitrous oxides, sulphurous oxides and particulate matter are produced due to the combustion of bio-mass. According to WHO survey 7 million deaths are caused due to air pollution [4].

Biomass has created significant employment for the people living in extreme poverty in conflict-affected areas for producing biofuel such as biomass briquettes which has replaced illegal production of charcoal [3]. Every year, about 55 million tonnes of municipal solid waste (MSW) and 38 billion litres of sewage are generated in the urban areas of India [5].

Biomass components such as vegetable fats and oils, lignin, corn starch, pea starch are used to produce bio-plastic. The different forms of bio-plastic include cellulose bio-plastic, bio-polyester, poly-lactic acid and bio-polyethylene. The global estimated production capacity of bio-plastic is 327,000 tones. Bio-asphalt is also made from renewable resources such as sugar, molasses, rice, corn, potato starches, vegetable oil based waste [13]. Modern biomass conversion technologies are used to produce electricity and heat based on thermo- chemical conversion processes such as pyrolysis, gasification, and liquefaction. Biomass cogeneration and fluidized bed combustion are the efficient, economical and flexible methods. Cogenerators prevent pollution and it enhances the efficiency of total energy use by up to 80% or more where as efficiency of electricity-only generation mode is in the range of 33-38%. This is moderately low because of heat to the environment is nearly 67% [12]. Coupling of biomass gasifier with gas turbine is also referred as a modern electricity generation method at a range of 30–100 MW [18].

A Multi-period Weighted Goal Programming model with three constraints such as water, soil and labour availability is used to identify the optimal land use combinations. It is used with the objective of maximizing farmer's income and bio- energy production [19].

V. GEOTHERMAL ENERGY

Geothermal resources have the potential to produce cost effective, reliable, sustainable, and environmentally friendly power. The temperature of matter is determined by thermal energy. Geothermal energy is a type of high temperature energy which is produced and stored by the Earth. Geothermal energy is formed by radioactive decay of minerals and also from the original formation from the planet in approximately equal proportions. Geothermal energy is obtained from the core of the planet. Geothermal gradient is the difference in temperature between the core and the surface of the planet. This difference in temperature causes the conduction of energy continuously in the form of heat. Our earth's core is 4,000 miles (i.e.) 6,400 km down from the surface. The temperature at the core is above 5,000 °C (9,000 °F). Due to this high temperature the rocks melt and form magma. The molten rocks are lighter than original rocks and it heats the water and rocks at the crust about 371 °C (700 °F).

Geothermal energy is received from the geothermal fields in the form of liquid, gases, steam, minerals and ashes and it is used for cooling and heating buildings with geothermal heat pump and also for other industrial needs. Moving the heat outside the earth for heating and inside the earth for cooling using ground coupled heat exchanger and geothermal heat pump [4]. The global estimated potential of geothermal energy is 85 GW over the next 30 years. According to International Geothermal Association capacity of geothermal power has been reached up to 18,500MW in 2015. Geothermal power plants are available in limited counties such as United States, Central America, East Africa, Iceland, Indonesia and Philippines. Currently, the U.S. Department of Energy is doing research on enhanced geothermal system [3]. The U.S. (3,086 MW capacity) and Philippines (1,904 MW capacity) are first and second in production of geothermal power respectively in 2010. Philippines meet 18% of its power from geothermal power. The rated capacity of the world's largest geothermal power plant installed in California is 750 MW [4].

VI. HYDRO AND HYDROGEN ENERGY

The global hydroelectric power (HEP) plants have produced 16.6% of the global total electricity production. In 2010, China was recognized as a largest producer (721 TWh) of HEP in the world and it has installed more than 45,000 small HEP plants (up to 50 MW). HEP is being produced by about150 countries. The global existing hydropower capacity in 2008 and 2015 was 885 GW and 1,064 GW respectively. The two forms of hydropower such as wave power and tidal power has not been yet widely installed commercially. Currently, OTEC plants have no economic feasibility [4].

Hydrogen as an energy has the potential to improve global climate change, energy efficiency, and air quality and it also reduce dependence on petroleum and reduce pollution and greenhouse gas emissions. Hence it is also called as a clean and environmentally friendly fuel. It is a promising sustainable energy source owing to its high conversion efficiency, recyclability, and nonpolluting nature. During combustion, it produces water instead of

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green house gases. It is a potential energy source for better energy economy [20].

VII. GROWTH AND FUTURE OF RENEWABLE ENERGY

The renewable energy has been promoted by the environmentalists in the 1970s. In 2009, International Renewable Energy Agency was created by 75 countries in-order to promote global renewable energy. Renewable energy is growing at the annual rates of 10–60% with many technologies from the year 2004 onwards. Renewable technology has boosted in the year 2009 with respect to the previous few years. The global warming and ecological as well as economic concerns have motivated the use of 100% renewable energy supply globally. The IEA has projected that the half of global electricity demand will be met through renewable energy sources by 2060. It could tremendously reduce green-house gas emission that affects the ecosystem.

Iceland, Norway and Brazil have met 100%, 98% and 86% of their electricity requirements by renewable energy resources respectively. The global renewable power capacity in 2008 and 2015 was 1,140 GW and 1,849 GW respectively. In 2008, the global annual investment on the new renewable capacity was182 x 109 US dollar and that in 2015 was 285 x109 US dollar. The number of countries with policy targets for renewable energy use in 2008 and 2015 was 79 and 173 respectively. The World's electricity production from renewable energy has increased from 21.7% to 23.7% between the year 2013 and 2015 [4].

Scientists have planned to use to produce 100% of global energy from renewable sources like solar power, wind and hydroelectric power plants by 2030. The World Energy Outlook has predicted the future growth of renewable energy as 4,550 GW in 2040. The government of Denmark has planned to supply 100% renewable energy by 2050 [4]. The following renewable energy technologies are still under development that includes cellulosic ethanol, hot-dry- rock geothermal power, marine energy, experimental solar power, floating solar array, solar assisted heat pump, algae fuels and space based solar power. ANN technique is used to find optimal solutions in the estimation of future trends of energy consumption and also to find more viable energy application [21].

VIII. CONCLUSION

Renewable energy development has provided high energy efficiency, security and lifts the poorest nations to the new economic levels of prosperity. It has provided 7.7 million jobs in Global level. Renewable energy is becoming cheaper and its average cost of electricity is dropping for critical technologies such as wind power, solar photovoltaic, concentrated solar power and biomass. The following growth of selected renewable energy indicators have been studied from this paper. They are such as investment in new annual renewable capacity, renewable power capacity, hydropower capacity, wind power capacity, solar grid-connected PV capacity, annual ethanol production, biodiesel production and countries with policy targets for renewable energy use. As the global indicators are showing upward trend year by year, it could motivate the various government and private owners to invest on renewable energy systems. Renewable energy could offer the best economic solution for a new grid connected location with good resources. It increases the scope of renewable energy application for sustainable development.

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