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COMMERCIALISATION OF EMERGING RENEWABLE ENERGY TECHNOLOGY

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ABSTRACT

Md Jahangir Alam: Commercialisation of emerging renewable energy technology
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The consumption of electrical energy is enhancing globally for long time. In the meantime, the conventional fossil fuel resources are also decreasing day by day and we will be out of fossil fuel one day. However, this fossil fuel-based system is causing significant impact on the planet due to carbon-dioxide gas emissions. This results to the rise of the global temperature which caused the gradual change of the climate conditions and impacting on the environment.

This kind of causes raised a serious concern to think of an alternative source of energy and the renewable energy technologies are the best solutions to mitigate the current and upcoming energy crises. The solar power, wind power, hydropower, bioenergy and geothermal power are among the best source of renewable to replace the existing technology. It is notable that these sources of power technology are already in place to power up the world in small scales. However, in the long term, renewable energy will play a vital role in the future energy market.

The importance of technology development and their widespread availability with lower cost is one of the key challenges in the evolving energy market. The renewable energy can contribute in major areas like electricity production, heating, cooling and in transport sectors. Therefore, more investment on different renewable energy technology development along with reducing subsidies on traditional technology can boost the growth rate of sustainable energy sources. In this paper, several renewable energy technologies are described with their technology development and current market situations with the progress rate. The aim of the study was to analyse the technology development of different renewables energy technology notably solar power, wind power, hydropower, bioenergy and geothermal energy, their emerging market conditions, energy transitions and to forecast the feasibility of future market till 2030. The trend of development in the past years considered as a reference value and regulation and policy initiative by major contributor's nation towards those technologies are also taken into account while forecasting the future energy market.

Keywords: Energy production, growth rate, installation capacity, levelized cost, estimation, forecast, Internet-of-things

The originality of this thesis has been checked using the Turnitin OriginalityCheck service.

PREFACE

This thesis is a part of Master's Degree in Electrical Engineering and written at Tampere University (2019). First, I would like to thank Tampere University for providing me the opportunity to purse Master of Science degree in Electrical Engineering.

I would like to thank the examiner and supervisor of this thesis Professor Seppo Valkealahti for such topic, excellent supervision and assistance during the process. I'm very grateful to him for all the support and his lectures regarding my work. I want to thank my uncle Mr. Abdul Bahar who always supported me in every journey of my life. I would like to thank the almighty Allah (SWT) for everything that I have achieved.

Finally, I want to remember my mother who left me at very early age, she was my first and best teacher ever, it would a special moment if at least I could notify her anything. May the almighty Allah (SWT) grant her the highest position in the heaven.

Tampere, 28 October 2019

Md Jahangir Alam

CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

PV	Photovoltaic
CSP	Concentrated solar power
FITs	Feed-in tariffs
PERC	Passivated emitter rear contact
HDR	Hot-dry-rock
EfW	Energy-from-waste
MSW	Municipal solid waste
SDS	Sustainable Development Scenario
LCOE	Levelized cost of energy
Ren21	Renewable Energy Policy Network for the 21st Century

1. INTRODUCTION

Energy is the core of the development of modern civilisation, with the continuation of the advancement of global society, the demand for energy is rising in every aspect. The global energy consumption is largely dominated by fossil fuels-based technology. The production of fossil fuels including coal and nuclear power fulfils more than 70% of the world energy requirements. However, renewable energy has a significant potential in the contribution of global energy needs. According to a report published by ren21 in 2019, [1] around 26% of the worldwide consumed energy is produced from renewable energy sources in 2018 which are largely dominated by hydropower, solar photovoltaic energy, wind power, bioenergy and geothermal energy. Historically, renewable energy is a part of human well-being, some renewable resources were being utilised from the ancient time to till now with its upgradation. For example, wind power which was used generally for lifting water from streams to irrigate gardens or in agricultural purpose and now commercially generating electricity, geothermal energy for cooking and currently producing electricity to meet the worlds energy demand.

New installation capacity of renewable energy technology is expanding every year compared to the fossil fuels and nuclear power-based technology. The competitive cost of the renewable energy and the advancement of technology in contrast with the conventional fuel operated systems largely helps in the growth of renewable energy. According to IRENA renewable energy capacity statistics 2018, around one hundred and fifteen million people utilised solar lights as their fundamental energy needs around the world, while more than twenty-five million people consumed renewable energy for home electricity. [2] Besides, hydropower is providing service to above six million people while over three hundred thousand people utilise bioenergy in the globe. However, due to environmental impacts and greenhouse gas emissions, after the year 2000, the sustainability of energy production became a major point while considering any types of energy installation. This actually further assisted to the expansion of renewable energy installation capacity and production worldwide, as the renewable energy sources enable the sustainable way of production and thus reducing the emissions in the environment.

The united nations climate conference in Paris held on 2015 known as COP21, where all the countries in the world agreed to reduce the carbon emissions and emphasized towards on sustainable power production. Policies are being taken by almost all the countries to increase the renewable power generation. Conferring to ren21, worldwide investment increased to USD 305 billion dollars on renewable energy during 2018. In short, it’s clear that the renewable energy is emerging towards bright future where it is expected that it will increase around 7.1% (British petroleum 2019) every year until next few decades. The competition of widely available traditional fuels with renewable energy utilisation made further to pay attention on the importance of commercialisation of renewable energy technology in the world. This paper focuses on the development of different renewable energy technologies, their generation and installation capacity including the costs for a certain period of time to present days and finally a forecast about how this can compete in the future energy market based on the current trends.

2. BACKGROUND OF RENEWABLE ENERGY

Renewable energy is very familiar as clean energy that comes from natural sources which provides energy from the sources that will never deplete. It is the most efficient way of producing electric energy with zero carbon emissions compared to the traditional fuel-based energy sources. The original source of renewable energies is mostly from the sun. The sunlight to the earth converts different forms of energy for example, the heat from sunlight drives wind which is then captured through wind turbine. Again, sun helps to grow plants and their stored energy can be used as bioenergy. There are other types of renewable power notably hydropower, geothermal energy and marine energy. On the other hand, solar radiation creates also hydropower, waves, ocean currents etc. Hydropower produce energy with the flow of water, marine energy uses the power from the surface wave and tidal power of moving wave to produce energy and geothermal energy used the earth's internal heat to produce energy. According to Global status report 2019 published by REN21, the estimated share of worldwide renewable energy in electricity production was above 26 percent by the end of 2018.[1] This means that globally more than one-third of net installed power capacity is from renewable sources. In this instance, the major contributed renewables source of energy productions are as solar power, wind power, hydropower, bioenergy and geothermal energy. The study focuses on these particular five renewable energy sources and a brief history are described accordingly.

2.1 Solar power

Solar power is the power which generates electricity by converting energy from sunlight either directly via using photovoltaics (PV) or using concentrated solar power. The solar photovoltaics (PV) technology is selected for closer examination due to its high efficiency and low-cost production instead of less efficient and comparatively upper cost concentrated solar power for the chosen studies. There is a long history in the discovery of solar photovoltaic effect and in fact it was a tremendous breakthrough in the field of solar energy. During 1839, French physicist Alexandre Edmond Becquerel invented and built the first photovoltaic cell. The light sensitivity of selenium revealed to sunlight where its enhanced the conductivity was first observed and reported by an electrical engineer Willoughby Smith (1828-1891) in 1873. Later in 1876, professor William Grylls Adams (1836-1915) and his student Richard Evans Day proved that exposing light on selenium bars can produces an electrical current which created the idea of photovoltaic cells. Charles Fritts (1850-1903), an American inventor created the first working photovoltaic cell. In the year 1883, he coated selenium in the middle of a semi-transparent gold top layer and an iron plate, and this was the first functioning solar cell with an efficiency of 1% which leads the foundation of present developing areas of the technology. Besides, in mid-1880 century, Fritts placed a test array on a New York rooftop by connecting several selenium modules and that makes him one of the famous users of earlier solar panel.

In 1905, one of the most famous theoretical physicist Albert Einstein (1879-1955) discovered ''the law of photo electricity'' where he describes how photons connected in a circuit can generate electricity. Later in 1921, he was awarded Nobel peace prize for his tremendous contribution in theoretical Physics, and further for the invention of the law of the photoelectric effect. The revolution begins in solar energy in 1954, when the three American scientists named Daryl Chapin (1906-1995), Gerald Pearson (1905-1987) and Calvin Fuller (1902-1994) developed a solar cell while experimenting silicon transistors in Bell Laboratories. The developed solar cell could convert solar energy into electricity which could run an electrical equipment. This was the first developed solar cell which could provide 6% efficiency and it was the beginning of the new era. The efficiency then gradually increased to 11 percent in 1958 and 14 percent in 1960 although the price was too high around 1000 USD/W. [3] Due to the oil crisis in 1970 century, the demand for solar power increased and the investment in this technology rises. In 1973, with the funding from Exxon corporation, Dr. Elliot Berman design a solar panel which was very much cheaper around 20 USD/W that was 100 USD/W before. He also described that the efficiency is higher using monocrystalline cells although it is more expensive than using multiple crystals. [3] The growing semiconductor industry in 1970s leads to the ultimate price reduction of solar photovoltaic silicon cells.

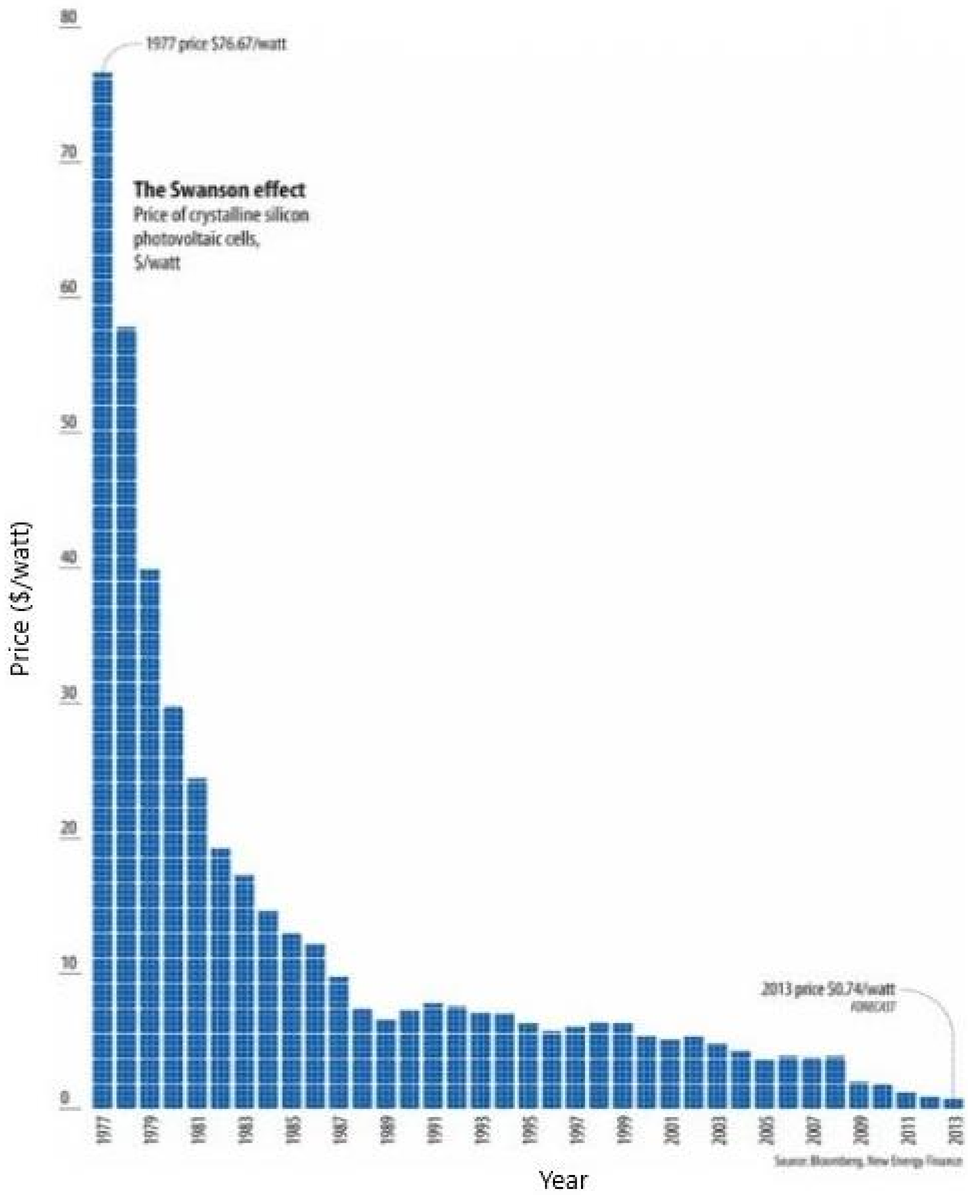

Figure 1. *History of crystalline silicon solar cell prices [5]*

The Figure 1 illustrates the price reduction history of 36 years of solar technology. The earlier price of crystalline photovoltaic cell was 76.67 dollars per watt in 1977. Hence, with the increase of funding in the photovoltaic (PV) technology from the period of 1975 to 1980 in the United States around 150 million dollars. This leads to the research in semiconductor technology so that it can be used in thin-film solar cells which will help to improve the performance of solar cells as well as to reduce the production cost of solar energy.[6] This huge investment helps to reduce the production cost from 76.67 USD/W to almost 25 USD/W in 1981. With the continuation of the development in solar technology, prices of solar cells dropped to 7 USD/W in the year 1989. This leads to the commercialisation of the solar PV in generating electricity that helps to support the distributed systems with 500-kilowatt photovoltaic array in California in 1993 by the Pacific Gas and Electric. [3] The price of solar cell was almost running steady from the period of 1993 until 2002 with an average price of 5 USD/W. Surprisingly, within this period the National Renewable Energy Laboratory developed a solar cell from the gallium indium phosphide and gallium arsenide which could provide a conversion efficiency of more than 30%. Later, they developed a thin-film solar cell that could provide 32% of sunlight into useable electricity.[7] It is remarkable that worldwide solar photovoltaic installation exceeds over one gigawatt in the year 2000. [3] The price then gradually decreases year by year around 4 USD/W in 2003 to around 0.74 USD/W in 2013. Within this duration, it is commercialised from industries to local rooftops to provide electric energy with a conversion efficiency of around 20%.

To discuss about the technological advancement, with the increasing competition between different companies in the world, several companies introduce factory automation which made the major differences in the production of solar thin-film photovoltaic cells production. With the introduction of robotic production line by the first solar thin-film PV manufacturer in Ohio at the beginning of 2017, it could produce a solar panel only in three and half hours that would require almost three days to produce a conventional crystalline silicon panel earlier. The introduction of automation in manufacturing industry helps to cut out the number of workers resulting to the reduction of production costs to approximately 0.20 USD/W and time. The company also explained that it’s a great achievement that can provide an efficiency of 30% lower cost compared to its Chinese counterpart. [8] The Solar manufacturers are trying to increase the efficiency by improving their product designs and also to reduce the cost. This are usually done by reducing the size of the gap between the cells so that it is possible to increase the size of cells while maintaining similar amounts of cells in a panel, this will help to improve the output power. Another way could be by texturing the surface of the cells which includes the metal-catalysed chemical etching and reactivation etching to make them less reflective. This helps to increase the lights in black cells and can convert into electricity.

Nowadays, considering the grid connection, module manufacturers are producing solar panels with built-in inverters that can supply power to the grid by converting DC power from the panels to the AC power for the grid and optimizes using the algorithms to extract the highest output power. Moreover, different sensing and trucking devices are also in placed for positioning the solar panels towards the sun to absorbs maximum power from the sunlight in various times of the day. However, with the sensational improvements of the technology, the industries are also focusing on the conversion of higher efficiency cell designs such as passivated emitter rear contact or in short PERC. Research is ongoing in the universities and companies to enhance the efficiency in the new photovoltaic materials that can perhaps change the current situation of solar cells efficiency. According to an ongoing research conducted by a UK company named Oxford Photovoltaics Limited on perovskite, the company announced a target of 250-megawatt production line by the end of 2020.[9] Perovskite is a kind of crystalline materials for solar cells commonly tin halide-based material or hybrid organic-inorganic lead materials. The fundamental difference between silicon and perovskite is that, silicon is usually used in solar cells and perovskite is used as thin-film form which is more effective to absorb solar energy. According to the chief executive of the company, they are making tandem cells to absorb much of the blue part of the spectrum from sunlight so that it can reach maximum efficiency for the conversion of solar energy to electricity. The developed tandem based on perovskite solar cell could achieved already around 28% conversion efficiency compared to the average current silicon solar cell efficiency of 22%. [9]

2.2 Wind power

Wind power or wind energy is a kind of renewable energy that uses moving air flow to capture energy via wind turbines and convert it into electricity. Wind power has a history of over 3000 years with the vertical axis windmills discovered around 200 BC at the Persian-Afghan borders. [10][11] Historically, wind power was first used by Egyptians in around early 3100 BC to pump water. At the 10th century AD, the primitive windmills were found turning in the blustery region of Persia known as present Iran, this was followed by modern standards usually built using vertical sails of reed bundles to grind grain and to lift water from streams to irrigate gardens.[12] Furthermore, these wind wheels with vertical axis of rotation were being used in different countries of the world including by the Chinese and Indian farmers for centuries to drain rice fields, crush sugarcane etc. [10][12] Later, the horizontal axis windmill was discovered likely in Europe, and was first found in the Duchy of Normandy in 1180.[10] In early 1880s, a French inventor named Camille Faure had invented a storage battery which he termed ‘box of electricity’ to store energy from the wind. By this, it seemed possible to generate electricity from the wind and storing it enables the use of energy when needed. [12] The widespread use of windmills to generate electricity began after the discoveries of professor James Blyth. In 1887, he built the first windmills in Scotland that could generates electrical energy. Meanwhile, the first person to build large scale windfirm was Charles Brush of Cleveland, Ohio in the year 1888. The wind machine developed by him was a low speed and high-solidity wind turbine of around 12 kW which successfully put into operation on the Atlantic coast. From then, wind power technology gradually began to develop year by year. [10][12] In 1920, aerodynamicist Albert Betz stated the modern physical principles of wind-energy conversion and the latest airfoil also been developed in aircraft engineering. In the same year, utilizing those knowledges and cooperating with Betz, Major Kurt Bilau applied Ventikanten blade, using an aircraft airfoil to design the modern windmills that had an adjustable auxiliary flap which could regulate speed and power of the windmill. [13] Between the period of 1850 and 1970, the US developed largely small-scale wind machines with smaller less than 1 kW for its rural places that was a kind of windmills without electrical systems. During this time, over 6 million of machine were used to pump water in the US. [10][11] In 1941, US built a prototype of the modern horizontal axis wind turbine which were mostly used to provide electricity to the places where electric power lines were unable to reach. [10] Denmark played a key role in the development of wind turbine in European market, by the end of world war I, around more than one fourth of rural power station in Denmark was run using wind turbine. During the period between 1935 to 1970, European countries notably France, Denmark, Germany and UK put tremendous efforts in the development of wind turbine technology which results the Gedser mill in Denmark that had the capacity of 200 kW using three blade upwind rotor wind turbine. The Gedser mill started its operation in 1959 to till 1967. Meanwhile in Germany, Ulrich Hutter developed a series of horizontal-axis wind turbine that laid the foundation of future horizontal-axis design in late 1970s. [11][12] However, the widespread development of electric power lines caused a significant impact on wind energy market in the early 1950s. [10] But, the 1970s oil crises helped to achieve the ultimate development of wind energy technology, especially with the investment from US government in wind energy research and development. Between the years 1973 to 1986, the commercial wind turbine market grown in the US from agriculture and domestic level around 1-25 kW. It was also connected to the utility system which interconnected wind farm applications from 50 to 600 kW. In this meantime, during 1980s, Danish manufacturer took the advantage to export wind turbine technology and also the numbers of European nationals flew to California to seek their fortunes in wind energy where mostly citizens were from Denmark. [11][12] With the support from the government between the period from 1981 to 1990, more than 16 thousands machine rated from 20 kW to 350 kW were installed only in United States.[11] Later, the collapse of California market forced Danish companies to look for new market and they helped Germany to become the world leading country in wind power production. By the end of 2001, Germany alone installed 2600 megawatt of energy from her wind energy. [12]

Considering the technical development, in order to enhance more efficiency with lower production cost, wind power technology is gradually introducing bigger machines which consists of long blades, powerful generators and taller towers. More and more research are ongoing to scale up the wind turbine technology including its design and configurations. As a result, the size of wind turbines corresponding to its rotor diameter, rated power and hub height has expanded dramatically from 30 m rotor diameter to 92.7 m, consistently rated power on average from 300 kW to 2.1 MW and the hub height increased approximately from 30 m to 87.7 m between the late 1980s to the latest 2014. [11][14] However, regarding power regulation, pitch controls are becoming more flexible to the new machines with the increase of pitch to stall ratio from 1:1 in 1997 to the notable 4:1 in 2006. Further, the introduction of the adaptable speed concept allowed to capture more energy even below the rated power area and contentment of loads whilst it induces additional loss of variable speed drive and causing extra costs.[11] New innovations in onshore and offshore wind technology are bringing more efficiency and reliability in wind turbine designs which ultimately contributing in reducing the cost of energy. The discoveries are aiming to introduce new blade designs, control strategies and to minimize noise emission considering the environmental impacts. This also includes grid integration, monitoring of power quality and voltage management, grid stability, grid adequacy and etc.[14] As it is very difficult to conduct practical experiment of windfarm, therefore Computational fluid dynamics (CFD) method is used in the research of wake effect, wind blade, wind farm design, noise and etc to explore wind energy while utilizing the simulation process. [10][11] The research helps largely to the intensive use of the 'internet of things' (IoT) technology in wind farms, and the 'big data' it generates, and to further improve the performance of both individual turbines, project development and the broader processes of product. The IoT technology is contributing largely on predictive maintenance which at the same time is ensuring smoother production and saving huge amount of money. The connection of heat and vibration sensors fitted to the turbine notifying the project managers to anticipate component failures. According to an estimate by GE technologies, this can help to reduce minimum 10% of operating costs while the ultrasonic anemometer shortly iSpin developed by Romo wind can enhance the output efficiency of around 1.8%. [8][14] The development of the wind power technologies largely contributes in the global wind power new generation capacity, which has been increasing rapidly with an average yearly growth of around 30% over the last decades, resulting the decrease of total installation cost from 3847 USD/kW in mid 80s to approximately between 1099.46 USD/kW and 1539.25 USD/kW in 2009 depending on the locations. [10][11]

2.3 Hydropower

Hydropower or hydroelectricity is a system that convert the kinetic energy from falling or fast-moving water into electricity. It is regarded as renewable energy source; hence the water cycle depends on the sun and as long as there is rainfall, there won't be any shortage of energy. The discoveries of hydropower are quite old. It was around 13 BC when the ancient Greeks used the water wheels to grind grain. [15] One of the earliest uses of water to generate power was by China about 2000 years ago during Han Dynasty. During that time, water wheels were mainly used to trip hammers, break ore and to make paper. [16] Meanwhile, the waterwheel became one of the popular devices to generate power in different part of the world during 1500. On that time, it was widely used to drive elevators, pumps, sawmills and for the air supply. The evidence of earliest water turbines is recognised from the sketches of Leonardo da Vinci which was made around 16th centuries that were similar to modern water turbines. The development of the modern hydropower turbine begins in 17th centuries when a French hydraulic and military engineer, Bernard Forest de Bélidor built a waterwheel with curved blades in 1737 and later he wrote the architecture of hydraulique. Besides, Daniel Bernoulli (1700-1782) developed the theory of waterwheels in his book on hydrodynamics in 1738. Leonhard Euler (1707-1783) in 1754 described a theory of water turbines which includes wicket gates, but in his theory he did not mentioned his machinery as turbines [15][17] After 1770 the waterwheels technology gradually being improved and during 1771, utilising hydropower as the main source of energy, the first Cromford Mill was set up in England's Derwent valley by Richard Arkwright to spin cotton. [15] The initial measures towards the turbine was taken by French scientists Jean Victoire Poncelet (1788-1867) by building a waterwheel with curved blades in 1825 which could reduce the internal hydraulic losses. Later in 1827, another French engineer named Benoit Fourneyron improved a water turbine which could produce energy approximately six horsepower and was known as Fourneyron reaction turbine. Meanwhile, the invention of electric generator by Michael Faraday in 1831 laid the foundation of generating electricity with hydropower. [18] Further, the development considering the constructions of the turbine was done by Carl A. Henschel (1780-1861) in Kassel, Germany. In 1837, he designed the fixed wicket gate which was above the runner and a draft tube where the flow was regulated by a butterfly valve. [15][16] The revolution in the field of water turbine began when the British-American engineer James Francis in 1849 developed the first water turbine that is widely used in present days.[16] During 1878, hydroelectricity was used to power a single lamp in the Cragside country house in Northumberland, England which was considered as world's first hydroelectric project. Four years later in 1882, the first hydroelectric power plant started its operation on the Fox River in Wisconsin, USA to serve a system of private and commercial customers. The major difference between these hydropower plant and Edison's Pearl Street Station was using the form of energy. Edison's Pearl Street Station utilised coal to create steam to drive its generators whereas in Wisconsin hydropower plant used the natural energy of the Fox River. [16][17] Later in 1889, the total number of hydroelectric power plant installed only in the US reached approximately 200.[16] By the end of the century, hydropower technology spread worldwide with the introduction of the first three-phase hydroelectric system by Germany during 1891. In this meanwhile in 1895, Australia established their first public own hydropower plant in the region of Southern Hemisphere. In the same year, US developed the largest hydroelectric plant in the world known as Edward Dean Adams Power Plant which was built at Niagara Falls. China took part in the development of hydro energy during 1905 by building a 500-kW installed capacity hydroelectric station near Taipei. [16] The major blast came from the US government policies in 19th century when they took the decision to build numbers of hydropower plant notably the Hoover dams and Grand Coulee dams to meet their nation electric demand up to 40% by 1940. [18] After the end of world war II to till 1970s, significantly economic growth increased, and the developments of hydropower expanded throughout Europe, USSR and as well as Japan and North America region. However, the beginning of 2000 brought more concerns on sustainability of hydropower production and emphasises on the impacts of social and environmental issues increased which resulted to change the current practice of development and production. This leads to rethinking and planning of the modern hydropower installation and upgradation that leads to the tremendous focuses on the designs, planning and technical development of the existing technology to build an environment friendly and efficient systems. From the year 2000 to 2017, the global hydropower installed capacity reached around 500 GW which was approximately 65% increase of the total installed capacity since 2010. Between the period of 2000 to 2016, Chinees banks and companies invested around twenty-five billion US dollars ($25 billions) in different projects at home and abroad and became one of the leading developers of hydropower in the world.[16]

To discuss about the technical development of hydropower, digitalisation has already been in operation to cope with the modern technology. The computers are being using to manage and operate the electricity grid since long time. Digitalization also includes the upgradation of existing hydropower assets including the turbines, draft tubes, and other equipment. Nowadays, with the advancement of the technology, the design and control systems in short, the ultimate architectures are digitalised by converting the plan and drawing into data to create digital twin which is a computer model of the plant and simulate it using several configurations and scenarios. The development of industrial internet mostly contributing to increase the efficiency and lifespan of the plant. During 2011, GE Renewable Energy invested billions of dollars to introduce advance industrial software and analytics and in 2013, it introduced the first software platform for the Industrial Internet Predix™. Later in 2016, GE introduced the Digital Hydro Plant based on data analytics and upon GE's Industrial Internet operating system 'Predix™'. This is a unique blend of hydropower hardware and software to enhance the performance of the hydropower plants. However, the development of the technology has a significant influence on the performance, operation and maintenance of a hydropower plant. Utilizing the digital control system enhanced the performance of the turbines and generators and thus contributing to increase the lifetime of the plants. Operation and maintenance are the two vital features which are optimised and reduced the vast amount of running and maintenance cost using the advanced monitoring analytics and Internet enabled Condition Monitoring Systems (CMS); in GE it is known as iCMS. The predictive maintenance strategy is already in place which is benefiting to track the health of the plant and in detecting the failures before they occurred, so that the plants can be repaired at the best possible time to minimize downtime using a monitoring system intelligent. The monitoring system collects real time data and sends it to the central system where every information is being processed to improve diagnostics and prognostics on faults in the plant that the monitoring system has identified. [17][20] According to IRENA 2019, the LCOE of hydropower is on average 0.05 USD/kWh globally which is the lowest source of electricity generation in many markets. [17]

2.4 Bioenergy

Bioenergy is a kind of renewable energy which is associated with biological resources such as organic materials usually known as biomass. The organic materials consist of wood, agricultural crops and even organic waste. Bioenergy can be utilised in different forms, such as liquid forms as biofuels, in solid forms as in the case when burning wood for energy, or as gaseous forms as biogas. Moreover, it can be used for electricity, transport and heating system.[21] The history of bioenergy begins around ten thousand years ago using grass, crops and trees for food for human being and animals and also to generate heat. Modern global societies have been established utilising its bioenergy around over eight hundred years. According to the history of Mongol empire (1206-1368), the horse was used as vehicle and biomass was the energy resources to maintain the largest empire in the history. The Mongolian controlled around most of the Asia and Eastern Europe where they used approximately 80,0000 horses where more than fifty thousand horse were used to move information for the empire with a precise bioenergy about 77 MJ (modern metabolism rate) per day. Netherlands in 1700s relied on solid biofuels where it transformed around 0.0004 exajoules (EJ) of bioenergy per year, usually built from trees to power 50% of its navy and fifty percent of its windmills. [22] On average forty percent of the global forests have been planted for fuel, building accessories, and to enhance energy harvests from agricultures. More than 2.6 billion of people are using fuelwood as their initial energy source. This largely contributing in global deforestation about 55%. [22] At present, biomass is the only renewable source of raw material to produce liquid fuel. The fermentation of biomass plant helps to produce ethanol (alcohol), thus a technology from around 4000 BC when people used to make alcohol as a drink from grapes, berries, honey and cereals. In 1826, an internal combustion engine designed by an American inventor Samuel Morey which was powered by ethanol and turpentine to run a boat around 7-8 miles per hour. German engineer Nicolaus August Otto in 1860, developed a new internal combustion engine which could ran by ethanol fuel blend and later using ethanol power, American industrialist Henry Ford constructed a tractor. Meanwhile, ethanol was experimented as an engine fuel prior to the commercial production of gasoline in 1913. Alexander Graham Bell in 1917, emphasised the abundance of potential feedstocks to produce ethanol; ‘any vegetable issue capable of fermentation, crop residues, farm waste, grasses and city garbage.’[23] During the world war I, Fritz Haber and Carl Bosch worked on the first Haber-Bosch reactors that processed and drives incredible agricultural production. This actually changed the world by enabling the way to produce ammonia from natural gas and air. German researchers Franz Fischer and Hans Tropsch along with their team discovered how to produce diesel and gasoline from coal and biomass through Fischer-Tropsch process and initially this was used by the German military. During this period, vehicles were designed in such way so that they can run on wood chips and later during world war II, the shortage of oil in Europe leads to the modifications of engine and vehicles. Oil became the preferred energy source just after the war due to its simplicity of use as well as availability compared to the wood chips and ethanol. [24] The major breakthrough happened during the 1970s energy crisis, the economies of major industrial were harshly affected by substantial unavailability and soaring price of crude oil. This leads to the tremendous research in the field of bioenergy. Surprisingly, most of the technologies researched during this time was mainly based on the principle that have been utilised hundred years ago to produce fuels and energy. [23] In 1970s, GE technologies developed gas turbines which is a form of distributed power that could run ethanol and lignin. The combination of ethanol and lignin was quite functional where one provided the vapor characteristics whereas other provided energy contents. About 100 years after the diesel engines, during 1989, the world first biodiesel plant began to operate and produce biodiesel commercially from rapeseed. The vegetable oils could be used as fuel with some engine modifications. Due to the higher price of vegetable oil, it was not an economic option to power the vehicles wide scale. [23][24] However, the global commercial bioethanol production in 1990 reached to 4 billion gallons and by the year 2000, it increased to 4.5 billion gallons. [23] After the year 2000, the sustainability of energy became quite important along with generating power. Modern biofuels of every forms are not equally environment friendly, but their utilisation is rational while balancing against the costs and risks from other energy sources at an exact level of demand. The renewable chemical energy in biomass can be stored as a gas or solid liquid and it generally does not affect to climate change while burning. According to a recent study, the use of ultra-lighting and enriched aerodynamics for vehicles, building insulation, and other techniques can reduce 73% of world energy consumption with a minimum loss of services. This will help to reduce vehicle mass, waste heat and the energy necessary to overcome the force of gravity.[22] In 2012, a US company named KiOR developed a refinery and started to produce renewable diesel commercially. These renewable diesels are often produced through the addition of hydrogen and thermal treatments and not considered as biodiesel. The technology is almost similar compared to other petroleum refineries and KiOR's refinery uses around 500 tons of biomass per day and delivers over 13 million of gallons of fuel blendstock in a year. [24]

The utilization of biomass energy technologies is gradually improving and developing day by day. Due to the extensive research and improve technologies, the level of application is gradually increasing, i.e.; biomass gasification can produce combustible gas and also can be used as fuel for heat and power. Fuels or some of the fossil fuel petroleum used by internal combustion engines can be replaced by methanol and ethanol made from biomass and can be used in transportation. Biomass can be dried for use as charcoal and can be utilised as adsorption agent for smelling metal and environmental industries. It can be dissimilated by marsh gas microorganisms under the anaerobic fermentation conditions and then biomass becomes combustible methane which contains gas and a type of fuel with a very high calorific value. This gas can be utilised for households use and can also be mix-fired with diesel as fuel for internal combustion engines. Bio-gas residue and bio-gas slurry can be employed as an excellent organic fertilizer to enhance the agricultural production. The process of biomass utilisation technologies is presented below in Figure 2 to understand an idea of current biomass technology. [25]

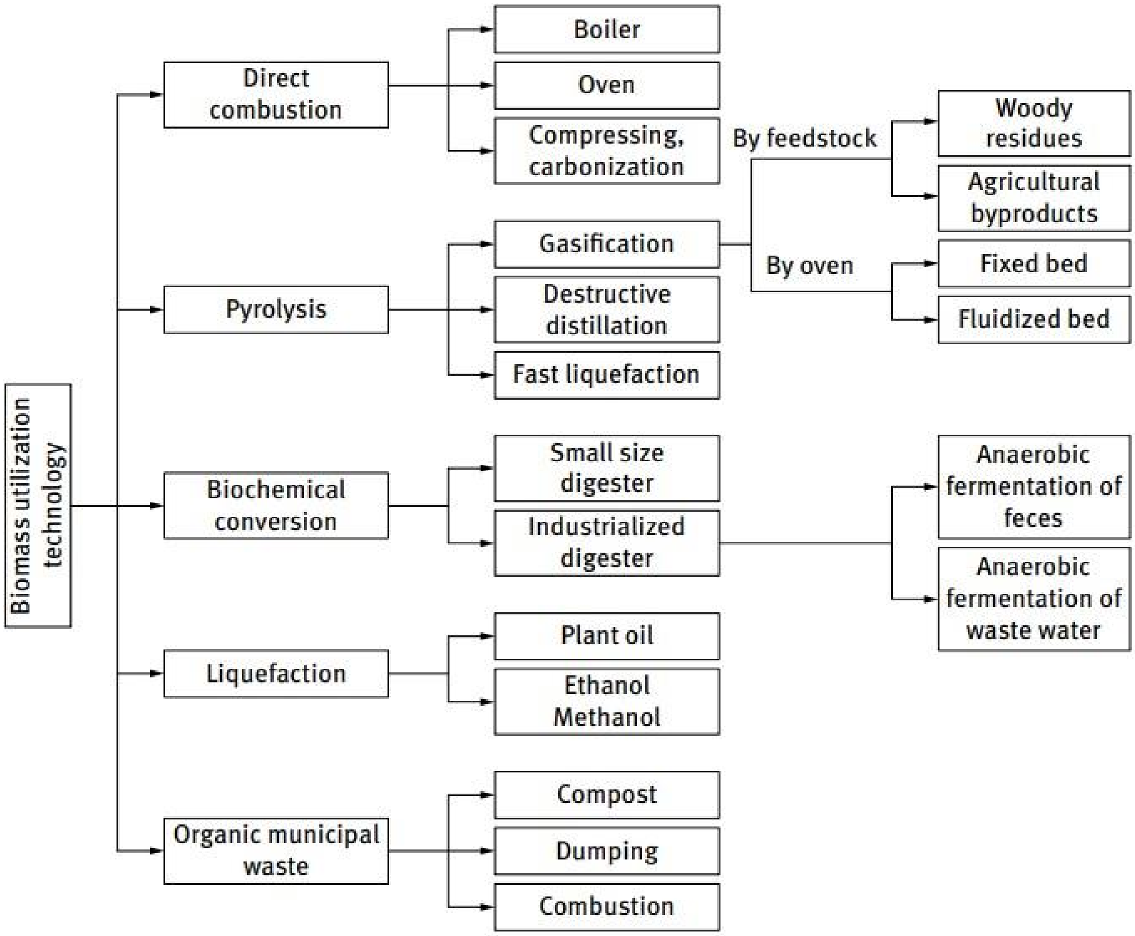

Figure 2. *Current biomass utilisation technologies [25]*

2.5 Geothermal Energy

Geothermal energy is the renewable energy that is stored below the earth's surface or a kind of heat that comes from the sub surface of the earth. The word 'Geothermal' is a Greek word where Geo means 'earth' and the word thermos means 'heat' and it can be utilised instantly for heating or else can be converted into electrical energy. [26] According to archaeologists, the first men from the geothermal point of view, who enjoyed the benefits of the thermal waters, cooking and to the use of volcanic products took place around 13 thousand years ago on a Japanese island and seven thousand years ago on the Asian continent, to settle in the vicinity of areas. [27] The evidence also represent that the use of geothermal resources happened in North America more than 10,000 years earlier with the settlement of Paleo-Indians at hot springs. The springs benefited as a fountain of cleansing and warmth where their minerals served as a resource of healing. [28] Some scholars described that the 'Etruscans' were the real fathers of the geothermal industry, not only due to their building of most settlements and towns at hydrothermal vents, but also for making some geothermal energy commodities such as travertine, alabaster, iron oxides and mud baths. The first to coat their tools with enamel were the Etruscans and they developed a technology where at a high temperature using borax, a boron compound is transformed into an insulating glass which are still in use for welds. Later, the Etruscans technologies were absorbed by the Romans to win widespread support by building more and more luxurious as well as affordable spas which were mainly used for religious purposes, socialising, relaxation and for treatment or in political life [27] Between the 16th and 17th century, the first mines were excavated from around 100 metres below the surface level which is simple physical sensations that humankind assumed that the earth's temperature changes (increase/decrease) with depth. Around 1740, the first measurements by thermometer were taken in a mine near Belfort, France. [29] German researcher Alexander von Humboldt (1799:82) described that 'The average temperature which the observations performed since 1680 exposed is 12 °C, and the seasonal temperature changes are recorded as maximum 0.04 °C. [30] The first European named John Colter visited the Yellowstone area and was considered to grapple with the hot springs in 1807. During the year, European settlers established the city of Hot Springs, Arkansas, where in 1830, one dollar was charged to Asa Thompson for the use of each three spring-fed baths in a wooden tub. This was the first recognized commercial use of geothermal energy occurred. [28] The rapid development of thermodynamics happened during the 18th century when scientists discovered how to convert steam into mechanical energy with increasing efficiency, with the help of turbines and generators and thus converting into electricity. In 1827, Francesco De Larderei, developed the first energetic utilisation of deep geothermal energy sources in Larderello, Italy, where initially, the power of a high enthalpy (dry steam source) was mainly employed for chemical reactions instead of burning wood from the rapidly depleting forests. [26][27][29] Since 1838, ground temperature measurements were performed in Scotland over many years on the fields of the Royal Observatory in Edinburgh. Later, these data were utilised by Thomson (1860) and Everett (1860) to experimentally validate their formulas for the decrease of ground temperature variations towards the depth, and the deceleration of phase.[30] During the 2nd half of the nineteen centuries, practical application of thermodynamic processes was developed initially to produce ice for refrigeration. In 1857, Peter von Rittinger established the foundation of earlier practical application of the heat pump using vapour compression in a closed batch circuit, to vaporize water and thus produce salt from purified brine in the Ebensee salt factory, in Austria. [30] By 1870, new scientific techniques were being applied to research the thermal regime of the Earth, but it was not until the 20th century, the invention of the radiogenic heat helped to fully figure out such as the Earth's thermal history and their phenomena as heat balance. [29] The first effort in generating electricity around the world from geothermal steam was made in 1904 at Larderello, Italy, by Pietro Ginori Conti which was only able to light five bulbs. The achievement of this conduct experiment revealed the industrial significance of geothermal power and commemorated the beginning of the development significantly from then on. During 1915, the geothermal operation at Larderello opened up a new era, by producing an electrical output of 5 megawatt. [26][27][29]Several nations followed the example set by Italy where notably Japan in 1919, drilled their first geothermal wells in Beppu, and The Geysers at California, United States during 1921. The Geysers was the US first geothermal power plant which could produce enough electricity around 250 kilowatts, to light the roads as well as buildings at the resort. At the end of 1942, the annual geothermal electric installed capacity reached to 127650 kilowatts. [28][29] The discoveries of the first ground-source heat pump by Professor Carl Nielsen of Ohio State University in 1948 brought the revolution in geothermal technology, which later helped the engineer J.D. Krocker to develop the commercial use of groundwater heat pump at Equitable Building, in Portland. [28][30] New Zealand in 1958, developed the 2nd geothermal power plant on the earth in Wairakei, where at around 250°C, fifty-four production wells with an average depth of 800 meter delivered wet steam in a high-enthalpy reservoir. Electrical energy is supplied there using a triple flash generator. Because of the high temperature of its fluid, the power plant could produce approximately 1550 GWh of geothermal electricity per year. [26] Meanwhile, during 1960, ''The Geysers'' geothermal power plant in USA produced about 11 megawatts of electricity from a natural source of hot dry steam. [26][28] All of the former geothermal power plants produce their energy from a natural hydrothermal high-enthalpy source. In 1973, scientists developed a system called hot-dry-rock (HDR) which was able to generate power without natural hydrothermal steam source. The common probability of geothermal power production except natural hydrothermal source was primarily investigated at the National Laboratories in Fenton Hill, New Mexico. Though scientists were failed to achieve their goal, but they could prove the overall possibility of electricity production from HDR systems. [26] Due to the oil crisis in 1973, several countries were looking for a solution to meet their energy demand using renewable energy source, and by 1980s, the development of geothermal heat pumps (GHP) gained widespread popularity by reducing heating and cooling expenditures. [30] Between 1995 and 2000, The geothermal power installed in the developing countries increased from 38% to 47% of the world total, whereas the total geothermal power installed capacity reached to 8806.45 MW globally in 2004. Concerning to the non-electric applications of geothermal energy, according to Lund and Freeston, (2001), the most frequent non-electric used as a whole was heat pumps (34.80%), then by bathing (26.20%), space heating (21.62%), greenhouses (8.22%), agriculture (3.93%), and industrial processes (3.13%). It was measured the total non-electric geothermal installed capacity 15145 MW in 2000 while the total energy use was 190699 TJ per year. [29]

At present, modern geothermal power production is based on the four technology options that are illustrated briefly (Long et al., 2003). One is the direct dry steam plants where the conversion tool is a steam turbine constructed to promptly utilise the minimal pressure; high-volume fluid generated in the steam field. This type of turbine varies in size from 8-140 MW (S&P Global Platts, 2016). The second technology is Flash plants which are like as dry steam plants, but the difference is the process how the steam is gained from a splitting process known as flashing. The steam is then led to the turbines, and then at lower pressure or reinjection, the causing condensate is forwarded for further flashing. (IEA-ETSAP, 2010) This type of turbine varies in different size depending on whether single, double or triple-flash plant ranging between 0.2-80 MW, 2-110 MW, or 60-150 MW respectively. (S&P Global Platts, 2016) The third one is binary plants, which are usually applied to the field of low or medium geothermal enthalpy where the resource fluid is utilised through the heat exchangers, to heat a process fluid in a closed loop (IEAETSAP, 2010) This type of plants usually varies in size between fewer than 1 MW to 50 MW. (S&P Global Platts, 2016) The last technology is used in geothermal power generation is combined-cycle or hybrid plants. These types of plant use the combined cycle which includes a conventional Rankine cycle to generate electricity and that two cycles gives comparatively higher electric efficiency. The usual size of the hybrid plants ranges between a few megawatts to 10 MWe.[31]

3. STATUS OF RENEWABLE POWER PRODUCTION TECHNOLOGIES

The growing concern over the effects of green-house gas emissions and the causes of global warming further remind to think about the environments. The importance of sustainable energy production arises in the beginning of 2000. But, due to the widescale availability of the conventional fossil fuels and its lower costs compared to the renewable energy sources made tougher for the renewable energy expansion. Several countries come forward to develop the sustainable renewable energy production, thinking about the impacts of environment caused by fossil fuels and their ultimate lifetime. Gradually, renewable power sources like hydropower, wind power, solar power, bioenergy and other renewable energy installation and production increased year by year. According to Renewable Energy Policy Network for the 21st Century, it is estimated that the worldwide share of renewable electricity generation was above 26 percent which made possible to represent the renewable power as one of the mainstream energy sources in 2018. By the end of 2018, renewable energy made up one third of the worldwide installed power capacity compared to the net capacity of fossil fuels. Global investment on renewable energy production increased to record 304.9 billion US dollars, whereas notably The World Bank Group announced a goal of 200 billion US dollars investment over five years which will begin in 2021 to build and develop the renewable energy infrastructure. [1] In this chapter, the global total installation capacity, production capability and costs for installation and production of selected renewable power production technologies are illustrated.

3.1 Solar power

Solar power is one of the fastest growing renewable energy in the world. According IRENA statistics published on 2019, solar power total installed capacity reached a record installation of total 486085 MW worldwide during 2018 (Figure 3). In fact, it was even more new capacity deployed than fossil fuels and nuclear energy combined. One year earlier in 2017, it was around 388268 MW, after it surpassed about 295828 MW level in 2016 and the 222126 MW in 2015. The period of 2013 to 2014 was another highest growth rate of solar energy installation where more than 36440 MW capacity installed at the end of the year, reaching the total deployment of about 176098 MW. The major contribution of solar power came from China, contributing 175030 MW total installation capacity among the other nations by 2018. [2]

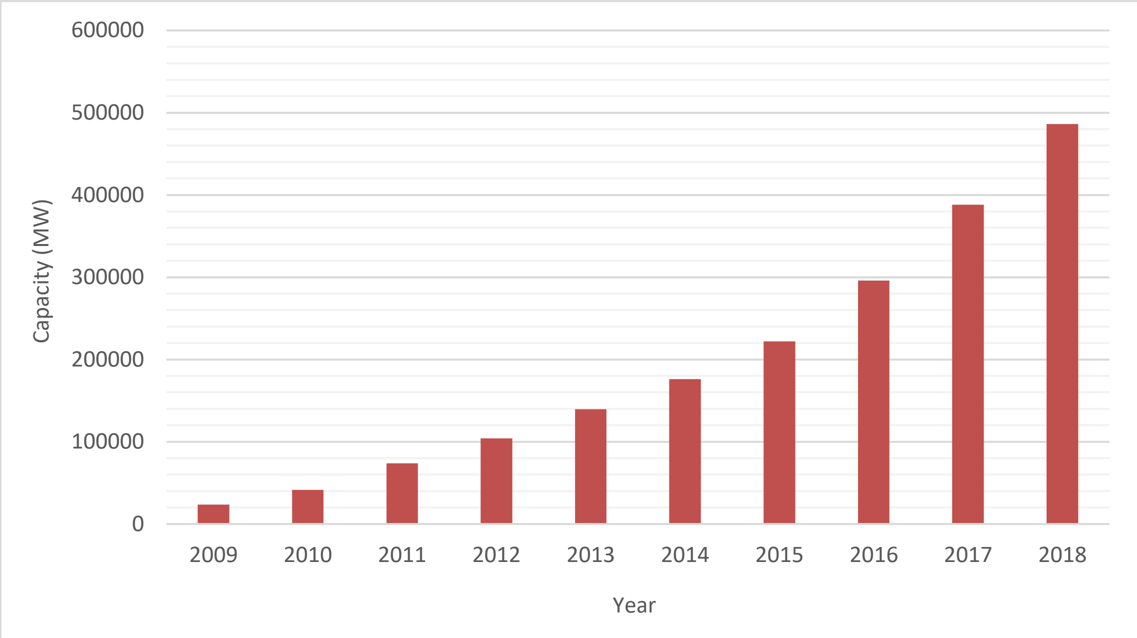

Figure 3. *Global solar power installed capacity by year [2]*

Japan, United states, Germany and Australia combined around 162583 MW total solar power installed capacity until the year 2018 which reflects the domination of the world solar energy by these five countries. They own more than two-third of the world solar energy capability due to the efforts and measures taken by the higher level. To talk about the global solar power production that is described in the Figure 4, the world has seen the uprising growth in the all form of solar energy production. [32]

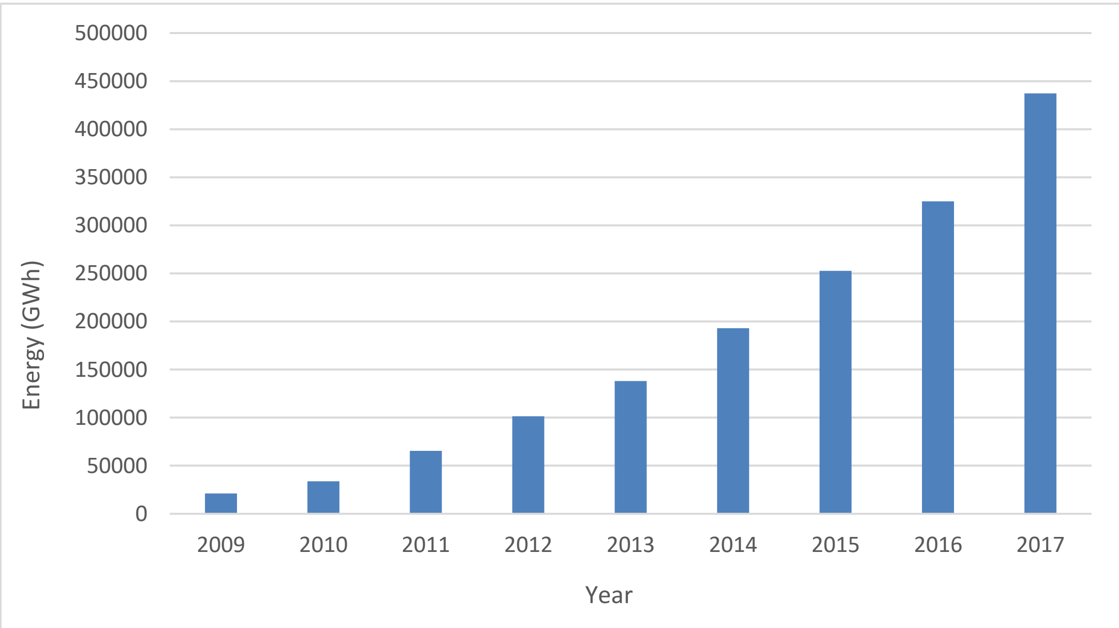

Figure 4. *Worldwide solar power production from 2009 – 2017 [2]*

The annual production of solar power was about 437287 GWh in 2017, while compared to 2016, it was around 112189 GWh higher energy produced that was almost double differentiating with the period of 2014 and 2015 where the increase of production was about 59645 GWh. After the year 2010, the annual production of solar energy was on average 27000 GWh until 2013. (Figure 4) The major contribution again was carried out by China by producing 118267 GWh solar power in its grid followed by the United States, adding 70980 GWh in the year 2018. These two countries along produced nearly half of the world solar energy considering every form of solar technology. [2]

Among all other solar power technologies, the solar photovoltaics (PV) is the most promising and widely installed solar technology. Calculating the annual cumulative solar power installed capacity in all forms and comparing it only with the PV technology in Figure 3 and Figure 5, the overall solar power installed capacity was in 2018, around 486085 MW, where among this total, solar PV contributed about 480619 MW. This is clearly visible that more than 98% of the energy comes from the photovoltaics (PV) technology. In the year 2018, total installed PV power capacity grew by nearly 25 percent to 480619 MW, up from 383316 MW in 2017 (Figure 5).

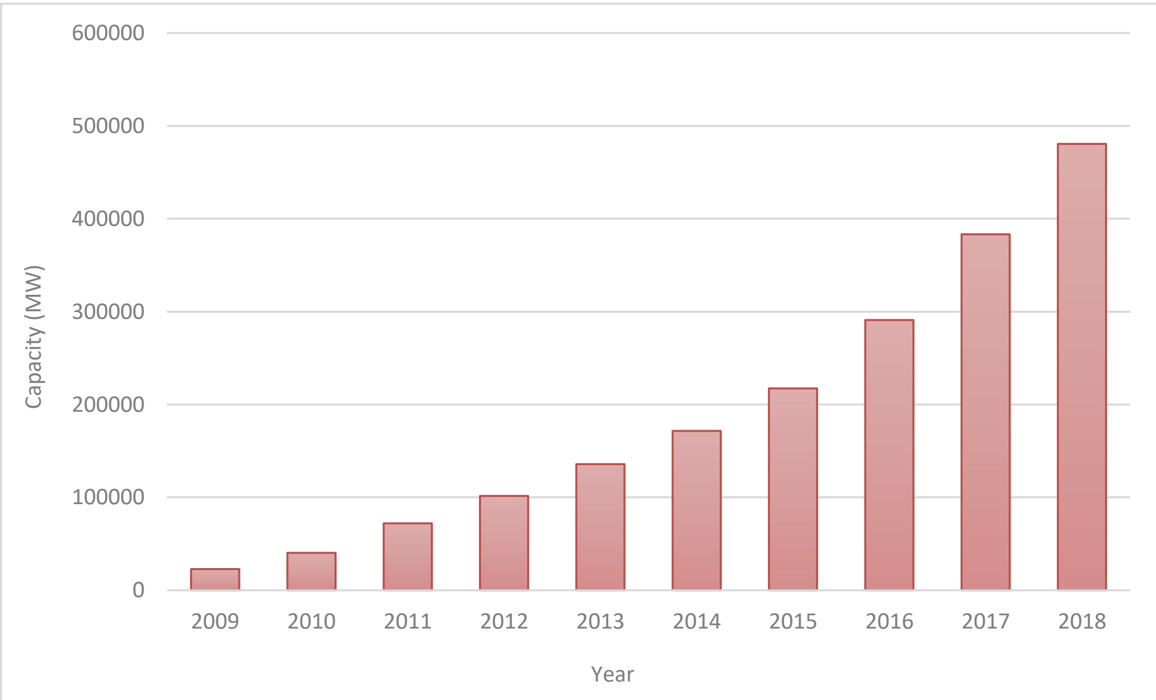

Figure 5. Global Solar PV power installed capacity by year [2]

Similarly, the production of solar photovoltaics (PV) dramatically rose from 314060 GWh in 2016 to 425810 GWh in 2017, which is approximately more than 25% increase compared to before (Figure 6). Since the grid connected solar era began with the introduction of Germany's feed-in tariff scheme, total solar power has grown by nearly 320 times. [2] When looking back to the period from 2009 to 2018, the world's cumulative PV installation capacity increased by average 191642.7 MW where the total installed capacity in 2009 was only 22816 MW. Besides, the average production of solar PV power increased to 167659.44 GWh between 2009 to 2017. These are largely dominated by China contributing 175016 MW total installed capacity in 2018 and about 118258 GWh of power production in 2017. European countries also contributed much by adding 118840 MW total installation capacity in 2018 while their production level reached to 116604 GWh in 2017. Similarly, United States, and Japan contributed much on global solar power installed capacity and in production. [2]

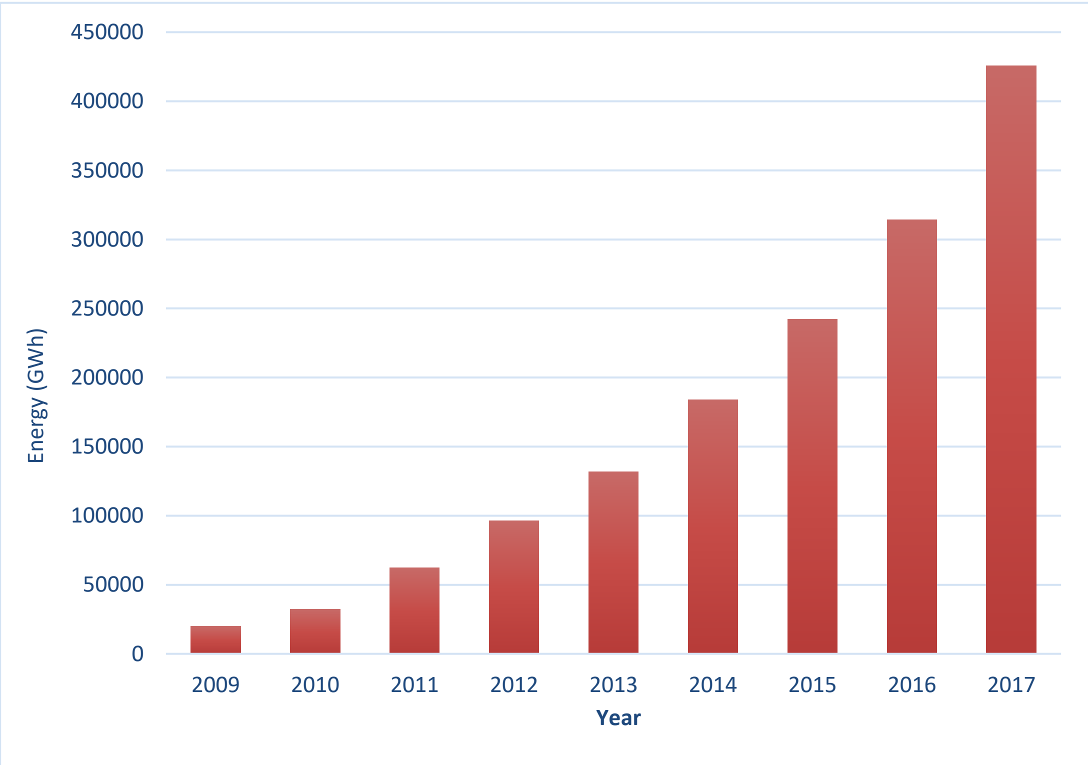

Figure 6. *Global Solar PV power production from 2009-2017 [2]*

The total concentrated solar power installation capacity and power production in the world is less than 5% comparative to other forms of solar power technologies. The concentrated solar energy installed in 2018 was about 5466 MW while the production was around 11476 GWh in 2017. (Figure 7 and Figure 8) The average CSP installed capacity increased to 3468.8 MW between 2009 to 2018, while the average cumulative production increased to 6524.77 GWh from 2009 to 2017. [2]

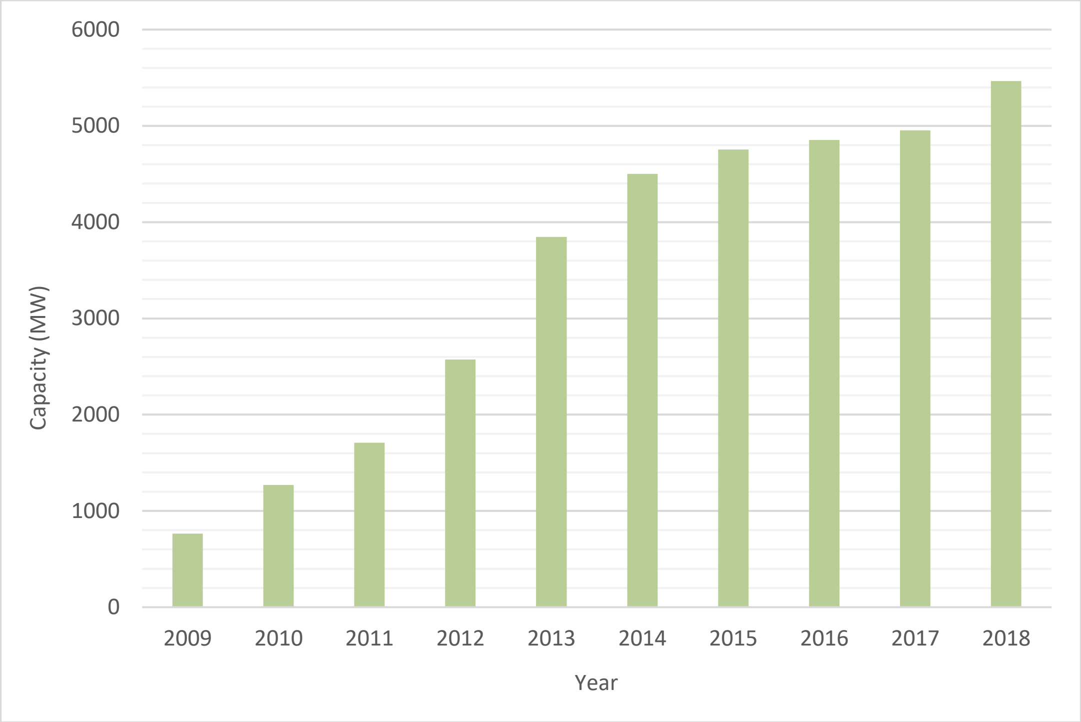

Figure 7. *Global concentrated solar power installed capacity by year [2]*

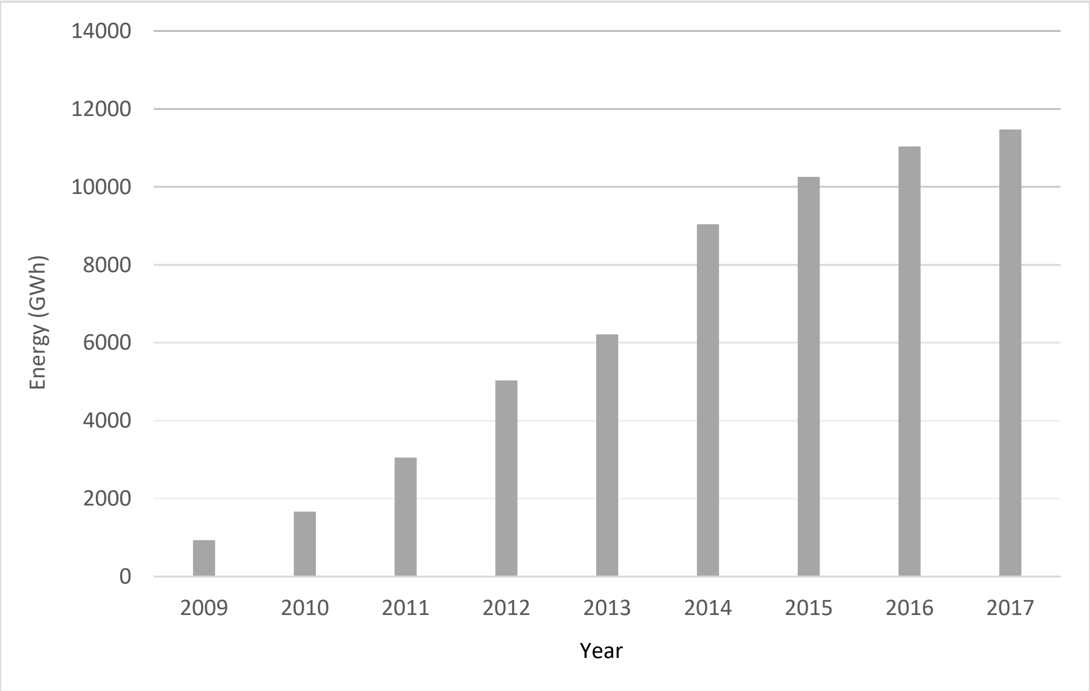

Figure 8. *Global concentrated solar power production by year [2]*

The tremendous growth of solar energy worldwide was possible due to its lower installation and production cost. The lower cost of solar PV module expenses and continuing decline in the balance of system cost remain the key driver to decreases the price of electricity. According to the IRENA 2018 global renewable energy costs report, approximately 13 percent decline in the worldwide weighted-average overall installation expense of utility-scale solar photovoltaic projects was 1210 USD/kW in 2018, lower from 1389 USD/kW in 2017.[33] The total PV installation cost decrease from 4620.7 USD/kW in 2010 to the price of 1210.2 USD/kW in 2018 which is less than half of the price considering the period of eight years. Similarly, the global weighted-average concentrated solar power price decreased by 28 percent in 2018 lowered from 7196 USD/kW to 5204.1 USD/kW in 2018. Between the year 2010 to 2018, the total PV installation cost decrease from 9332.8 USD/kW to 5204.1 USD/kW which is more than 40% decline of the cost of energy by the periods. (Figure 9) [33]

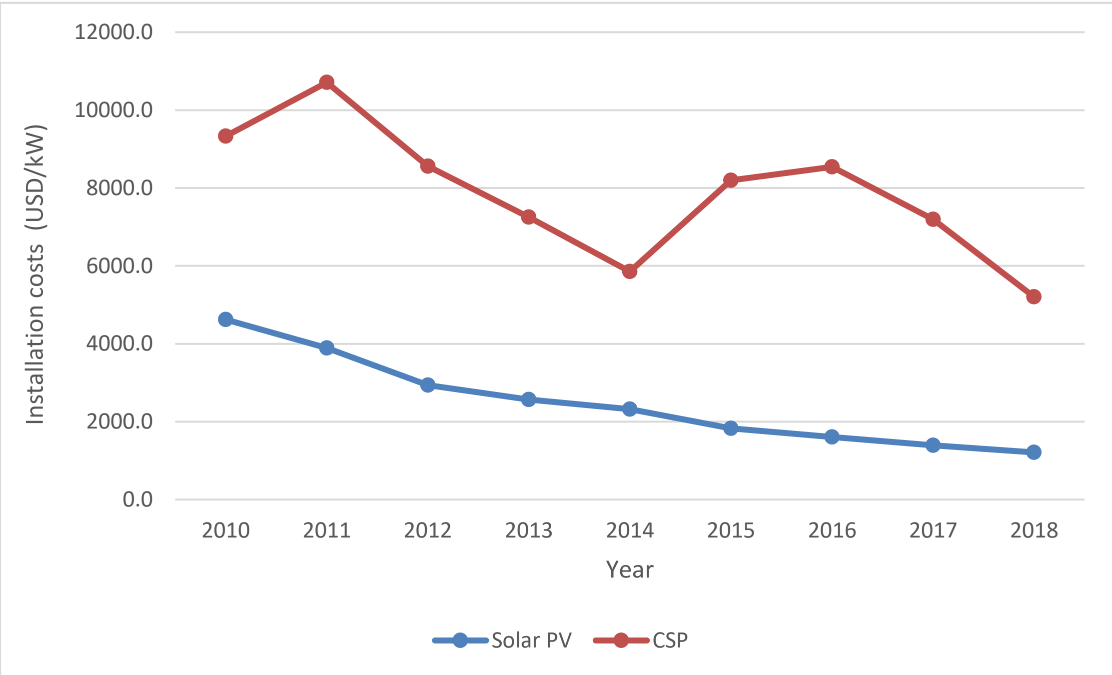

Figure 9. *Worldwide Solar PV and CSP installation costs [33]*

The remarkable fall of electricity cost from utility level solar PV remained in 2018, with a decrease in the global weighted average levelized cost of energy (LCOE) for solar PV 0.085 USD/kWh, about 13% less compared to 2017. Between the period from 2010 to 2018, the solar PV weighted average levelized cost decrease to 77% globally, whereas the actual number in price was 0.370 USD/kWh in 2010 to 0.085 USD/kWh in 2018. Similarly, the data shows that the concentrated solar power weighted average levelized cost decreased from 0.340 USD/kWh to 0.185 USD/kWh between 2010 to 2018. This was overall 46% decline in total price from 2010 to 2018. (Figure 10) [33]

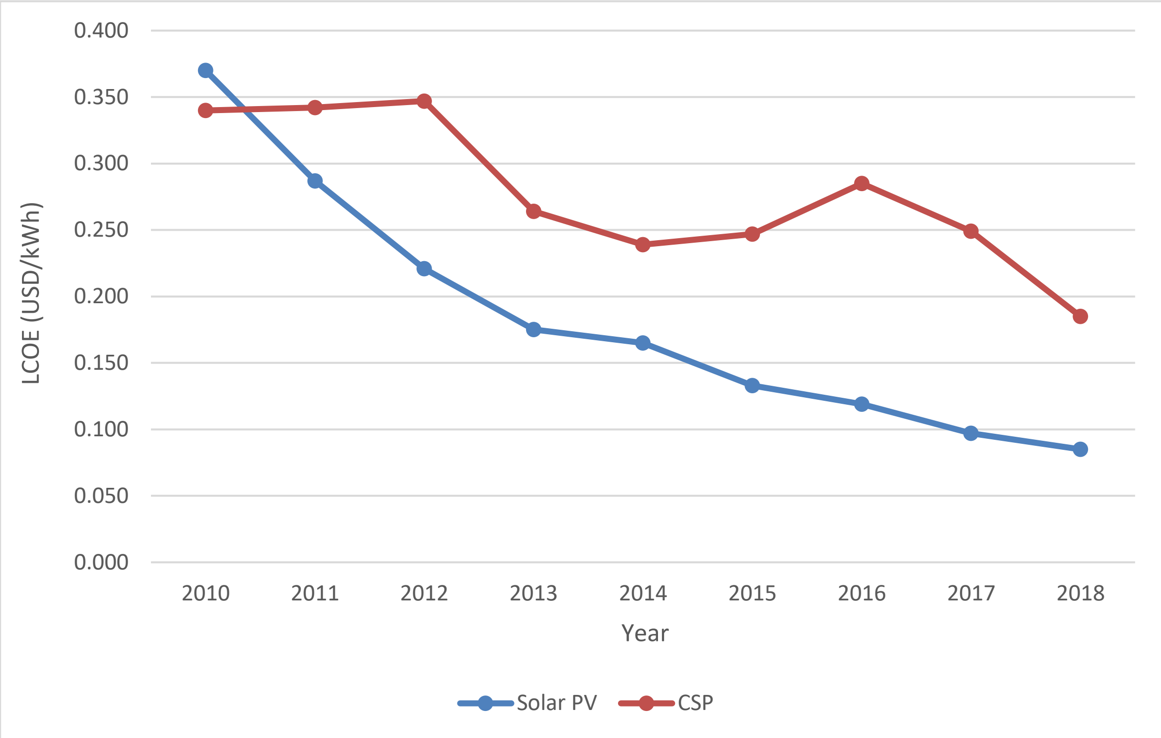

Figure 10. *Levelized cost (LCOE) of solar PV and concentrated solar power globally [33]*

3.2 Wind Power

Wind power is one of the most promising energy technologies that offer sustainable renewable energy production, contributing approximately 25% capacity to the global renewable energy installation capacity. The wind power installation capacity increased slightly in 2018 compared to the year 2017, contributing about 563659 MW in 2018 and 514747 MW in 2017 to the global wind power installation. The amount of increase is more than 16 percent in contrast with the previous year. Following the year 2017, around 15% increase was recorded in the overall wind power installed capacity compared to the year 2016, where the data showed that about 47790 MW more capacity was installed in 2017. Between the year 2009 to 2015, the average wind power installed globally was around 269032.6 MW. However, the period from 2009 to 2018, the world has seen an average wind power installation about 380954.6 MW capacity, where in 2009, the total installed wind power capacity was only 150122 MW and after nine years, its reached to nearly double of the total cumulative installation in 2018. (Figure 11) The major contribution was done by China alone installed 184665 MW in 2018 while countries like US added

94295 megawatts and Germany contributed 58982 MW in 2018. This was about half of the world total wind power installed capacity. Accordingly, these countries are dominating largely in the establishment of more wind energy capacity.

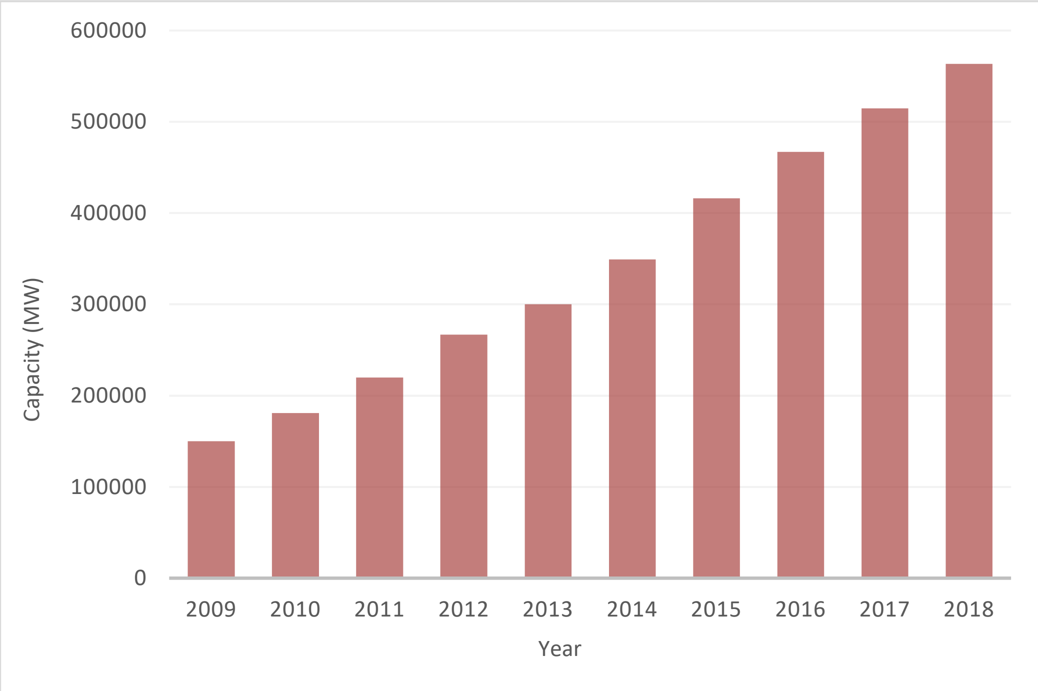

Figure 11. *Overall global wind power installed capacity [2]*

Considering the production of global wind power, it is expanding day by day counting the maximum production on 1134451 GWh in 2017, which was an increase of 179793 GWh compared to 2016. There was a usual increase in the production between 2013, 2014 and 2015 accounting for 635110, 712027, 828251 GWh leading to the annual increase of about 29% in 2013 and 32 percent increase in 2015. (Figure 12) Meanwhile, countries like China contributed around 305015 GWh total energy production in 2017 out of Asia's total production of 367744 GWh. The world wind power production also dominated by the countries like China, US and Germany by increasing the production of wind power.

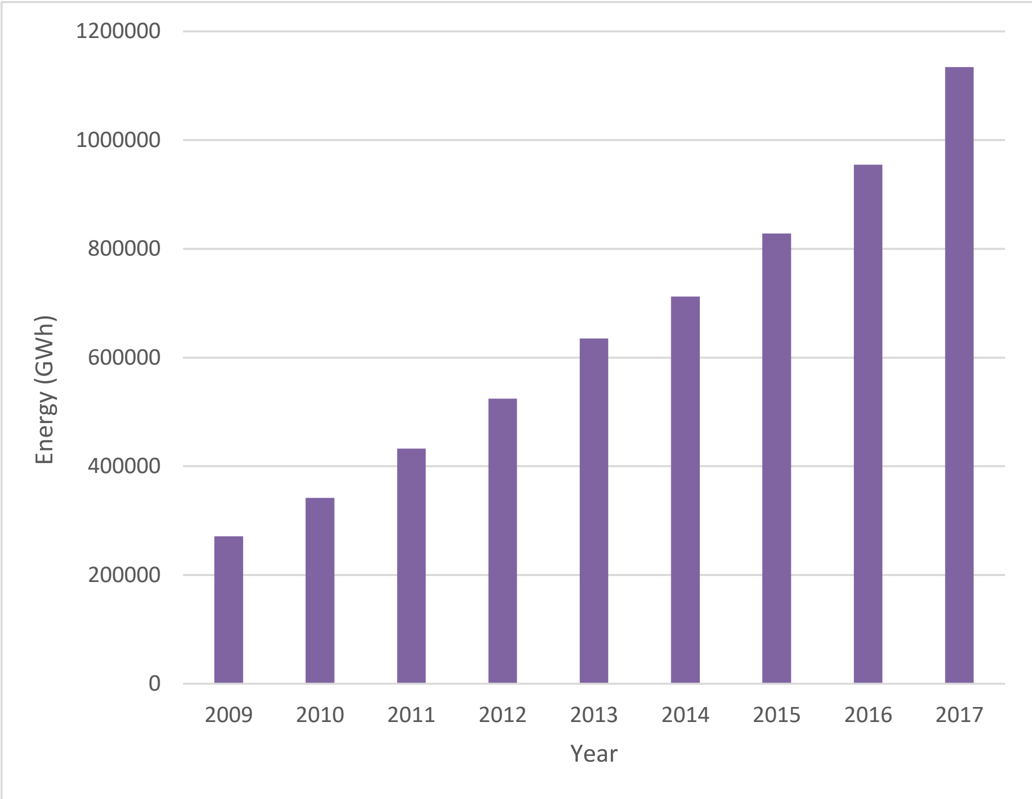

Figure 12. *Global wind power production by year [2]*

Onshore wind power generation is one of the most popular medium of wind energy production contrasted to all other existing wind power production technologies. Its produce the vast amount of renewable wind energy and hold the maximum numbers of annual installation capacity. In 2018, the total volume of onshore wind power was installed around 538854 MW which was 42998 MW higher in contrast with the year 2017. (Figure 13) There was a record 1077120 GWh of total onshore wind power produced in 2017, generating 164066 GWh more energy than in 2016. [2] (Figure 14) Between the year from 2014 to 2016, there was an increase of around 71461 MW installation capacity globally, whereas from the year 2009 to 2018, the annual sum of installed onshore wind power capacity was nearly three times more, calculating the numbers 147988 MW in 2009 to 538854 MW in 2018. (Figure 13) The production of onshore electricity increases exponentially throughout the period of 2009 to 2017. The onshore production of wind energy was 266537 GWh in 2009, where the enhance of investment and installation of the onshore resources increased the generation more to around 790327 GWh in 2015, (Figure 14) which was mostly dominated by China alone.[2]

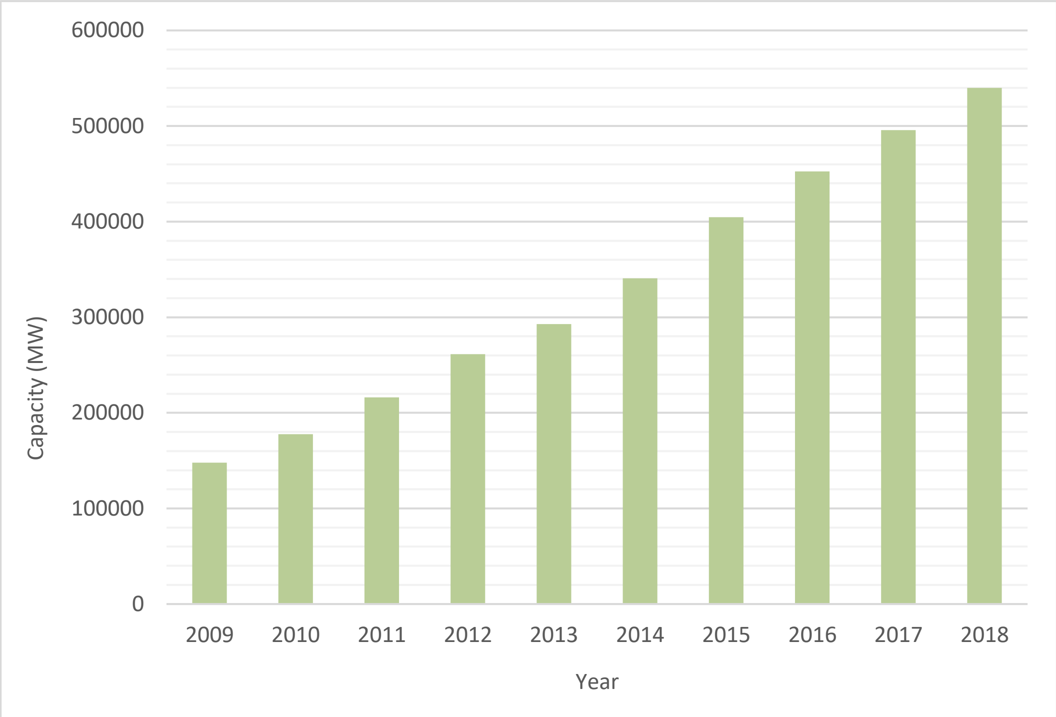

Figure 13. Worldwide onshore wind power installed capacity [2]

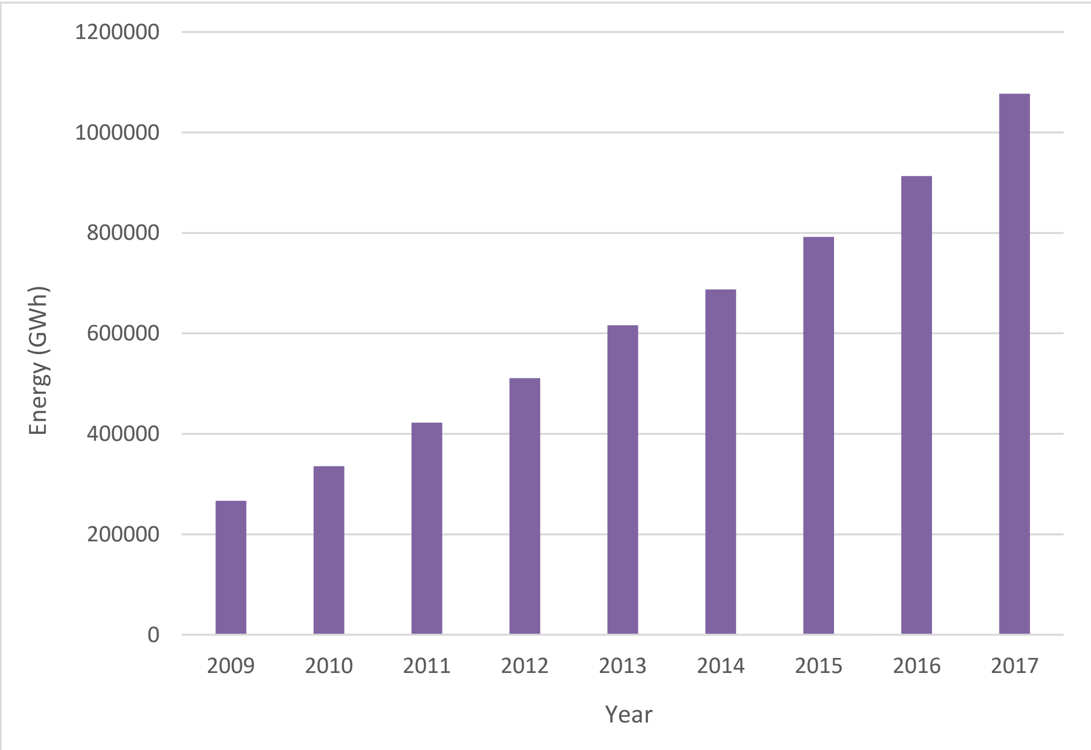

Figure 14. *Global onshore wind power production [2]*

Offshore wind power plants are the least available wind power technology worldwide compared to the onshore plants. Offshore windfarms require certain kinds of constraint like area, environment and etc. Moreover, it requires quite huge amount of investment compared to the onshore farms which is one of the major reasons of less offshore wind farm in the world. However, the installation of global offshore wind farm is increasing year after year. The increase of installation of offshore wind farm was less than 1000 MW per year from 2009 to till 2014. But from the year 2015, its started to rise significantly, reaching around 11717 MW in 2015 compared to 8492 MW in 2014. After the year 2015, the growth rate was more than 4000 MW per year between 2015 to 2018. The installation capacity was almost double compared in 2018 contrasted with 2015, reaching the highest megawatt of 23706 in 2018, while this was around 18891 MW in 2017. This was nearly 5000 MW increase in a year.[2] (Figure 15) The energy production of global offshore wind power is illustrated in Figure 16, where the maximum production of offshore wind power documented in 2017 about 57331 GWh. The production curve followed the global installation curve, which easily shows that the amount of production was in line with the capacity of installation. The production was recorded more than 20000 GWh in 2014, while its been dramatically rose to 36215 GWh in 2015. An increase of more than 12000 GWh in one year, although the year 2016 passed through steady development of production. [2]

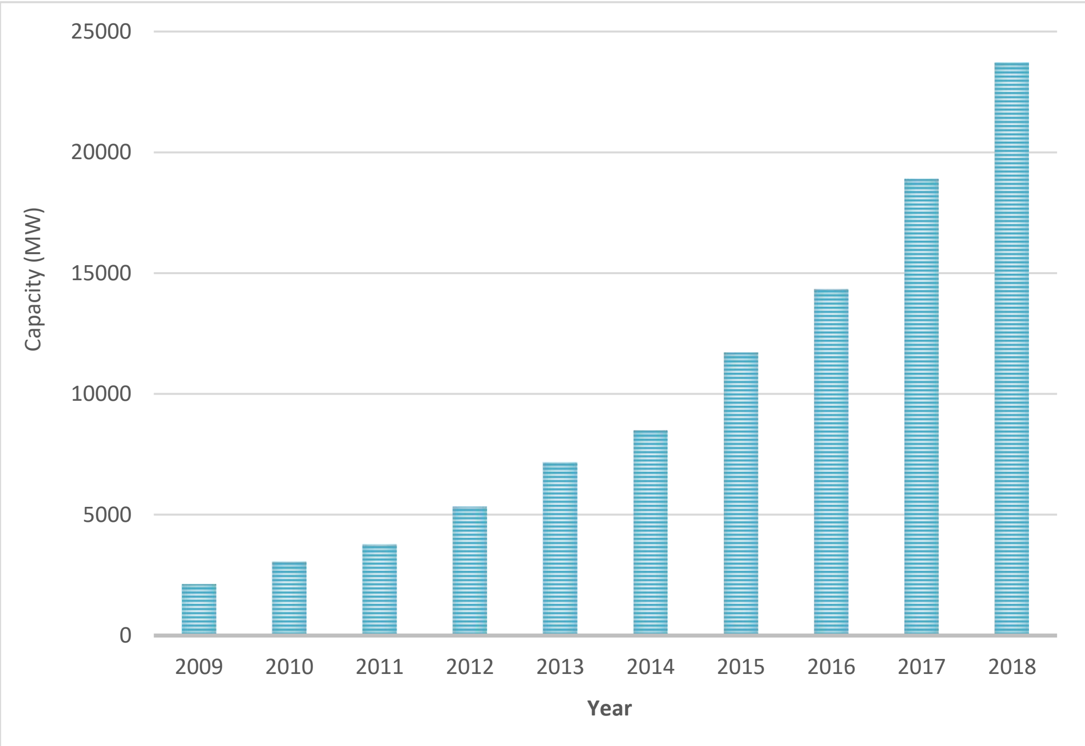

Figure 15. *Worldwide annual offshore wind power installed capacity [2]*

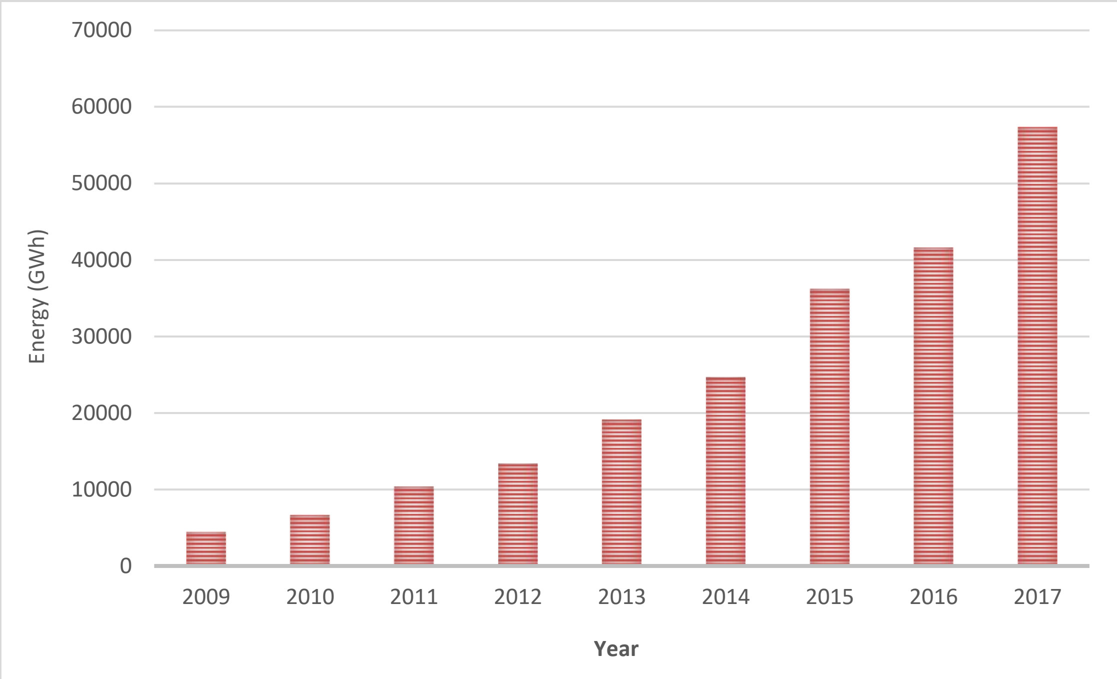

Figure 16. *Global offshore wind power production from 2009-2017 [2]*

The huge numbers of wind farm installation and the popularity of wind electricity generation was possible due to the lower costs, considering the average lifetime and sustainability compared to the other fossil fuel-based technology. Enhancements in technology and production processes, competitive supply chains and regional manufacturing facilities are all supporting to maintain pressure on turbine prices. [33] The total installation cost of onshore and offshore wind power from the period of 2010 to 2018 is illustrated in Figure 17. It indicates that the weighted-average overall installed cost of onshore wind farms fallen by 6 percent in 2018, a decline from 1600.5 USD/kW in 2017 to 1498.5 USD/kW in 2018. In 2010, the price of cumulative onshore wind power was calculated around 1915 USD/kW which was declined year-on-year to 1611 USD/kW in 2016, with the help of continuous fall of wind turbine prices. The overall installation costs of offshore wind farms have fallen fairly since 2010. The worldwide weighted-average installed costs of offshore wind dropped around 5% between the year 2010 to 2018, from 4572 USD/kW in 2010 to 4353 USD/kW in 2018. Meanwhile, the newly commissioned offshore wind farms had a significant amount of year-on-year volatility on the overall installed prices. It is notable to mention that the price suddenly decreased to 3764 USD/kW in 2016 from the price of 5086 USD/kW in 2015, then climbed by 4642 USD/kW in 2017. [33]

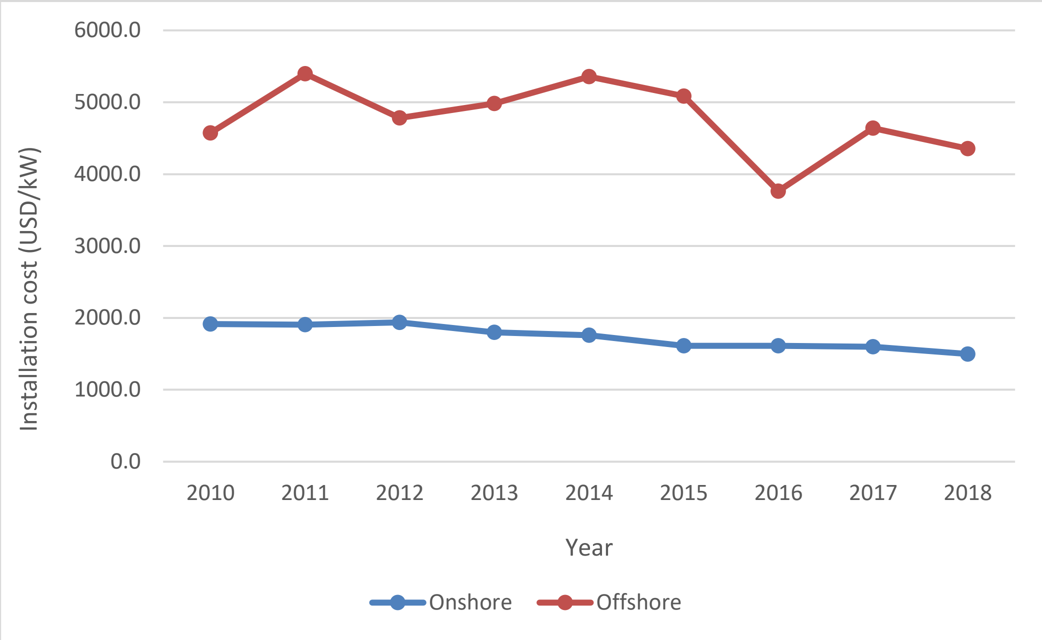

Figure 17. *Cost of global onshore and offshore wind power installation [33]*

The global weighted average levelized cost of electricity of onshore wind projects commissioned in 2018, around 0.055 USD/kWh, which was 13% lower compared to 2017. Between the period from 2010-2018, the weighted average LCOE decreased 35% in 2018, based on the data, it was 0.084 USD/kWh in 2010 to 0.055 USD/kWh in 2018. (Figure 18) The weighted average LCOE of offshore wind power experienced ups and down at their global measurement.

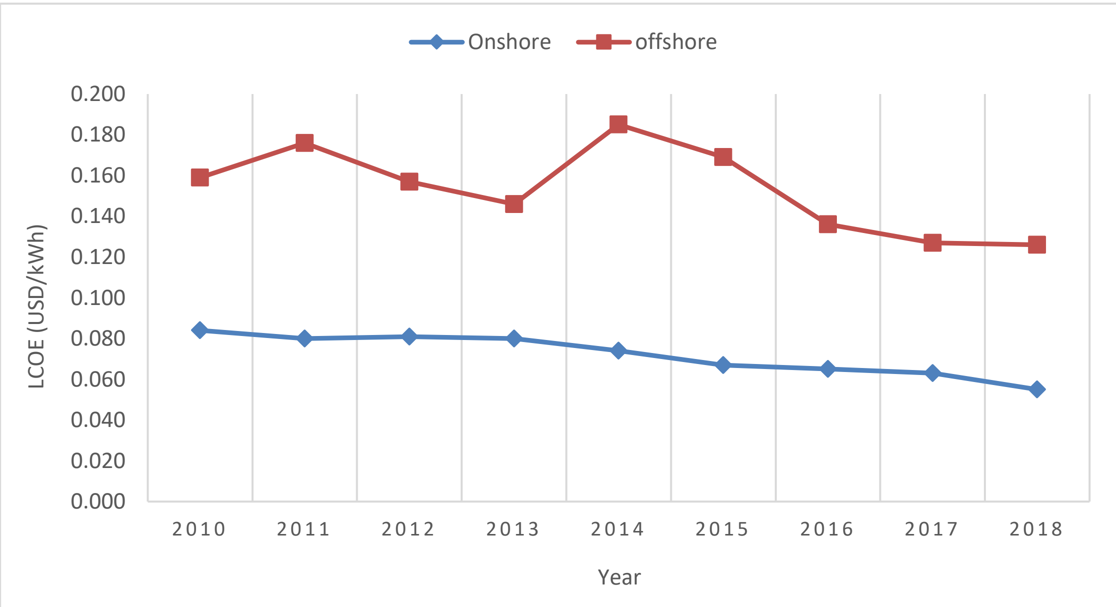

Figure 18. *Levelized cost (LCOE) of global onshore and offshore wind power [33]*

The exception of the chart happened in 2014, when the costs increased to 0.185 USD/kWh from the lower cost trends of 0.146 USD/kWh in 2013. Nevertheless, the overall LCOE of offshore wind power from 2010 to 2018 had declined to 20%, hence the LCOE dropped from 0.159 USD/kWh to 0.126 USD/kWh. (Figure 18) [33]

3.3 Hydropower

Hydropower is the highest producer of world renewable energy, contributing much of the renewable energy demand for long time. The worldwide hydropower market in 2018 seem to be quite similar to the previous year considering the capacity increase and concentration of activity. Around 21484 MW was enhanced to reach a total installed capacity of about 1295317 MW in 2018. The growth of hydropower installation never climbed all of sudden, rathe it was following a steady trend by increasing a certain amount of installation capacity. The global hydropower installation capacity from 2009 to 2017 was increasing quite first on average more than 30000 MW per year. Though there was an increase in 2018, but it was quite less than those of previous year, yet the installation reached to 1295317 MW in 2018 from 990877 MW in 2009. (Figure 19) This was mostly contributed by China representing more than 35% of new hydropower capacity installations, followed by Brazil 3866 MW, and Pakistan 2487 MW in 2018. However, the production of hydropower reached the highest record around 4163728 GWh in 2016, while the production dropped to 4158175 GWh in 2017, although the installed capacity was increased. This is mainly due to more than half of all hydropower resources worldwide have either already undergone, or will soon require, upgrades and modernisation. [1] The year 2015 was also a tougher year for the global hydropower production where approximately 4864 GWh generation declined compared to the year 2014, notably 3991419 GWh and 3996283 GWh. Moreover, the period from 2009 to 2014 was more favourable for hydropower, where it showed the rising trend of production, the highest giga-watt hours of production recorded in 2010, about 3531243 GWh compared to 3348943 GWh in 2009. Overall, the production increased about 809232 GWh between 2009 and 2017.[2] (Figure 20)

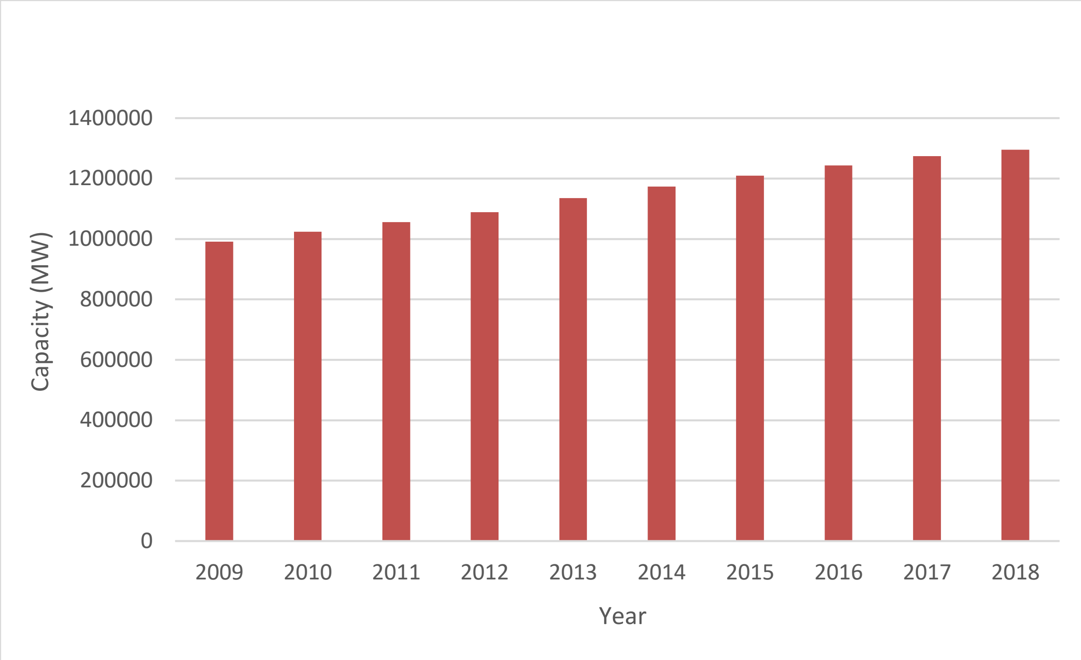

Figure 19. *Worldwide hydropower installed capacity by year [2]*

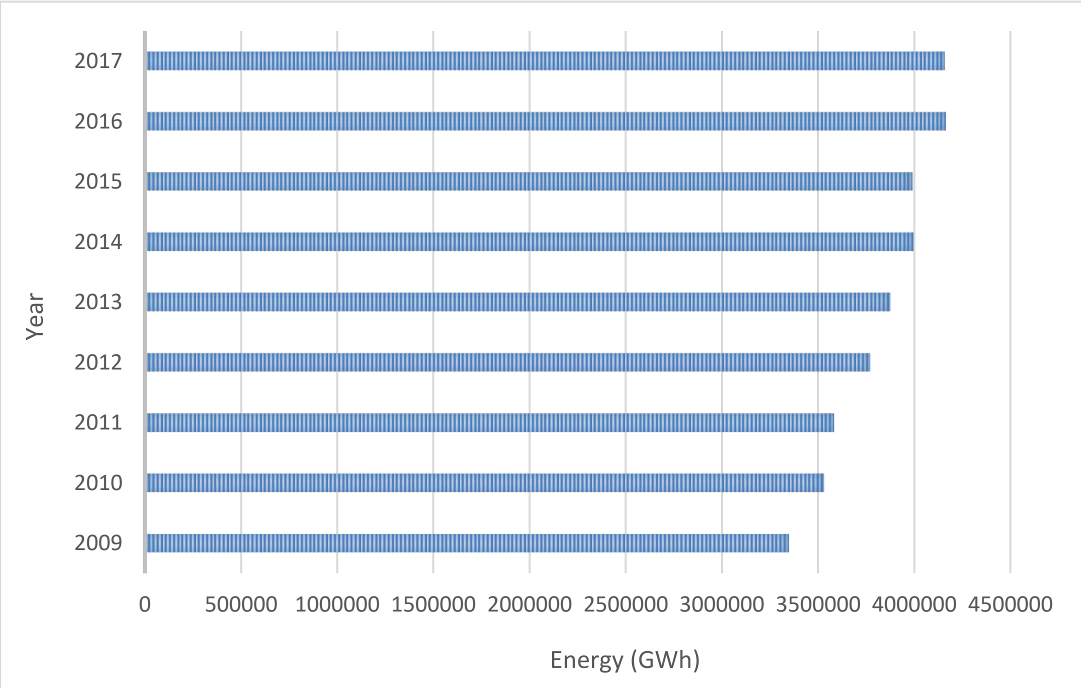

Figure 20. *Worldwide hydropower production between 2009-2017 [2]*

Hydropower with the combination of run-of-river plant, storage plant and basic plant can be defined as hydropower with mixed plants which contributes the majority of the new capacity installation and energy production. The highest amount of hydropower is generated from such medium worldwide due to the scalable technology and comparative to low running cost. Figure 21 and Figure 22 explained the total volume of installation and production of hydropower (including mixed plants) where the installation of global renewable hydropower was slightly rise year by year, while the power production experienced ups and down in different consecutive year. The total installed capacity increased around 21299 MW in 2018 compared to 2017, notably 1174968 MW and 1153669 MW. The installation capacity increased around 32% from 2009 to 2018, followed by the numbers 890108 MW in 2009 and 1174968 MW in 2018.[2] (Figure 21)

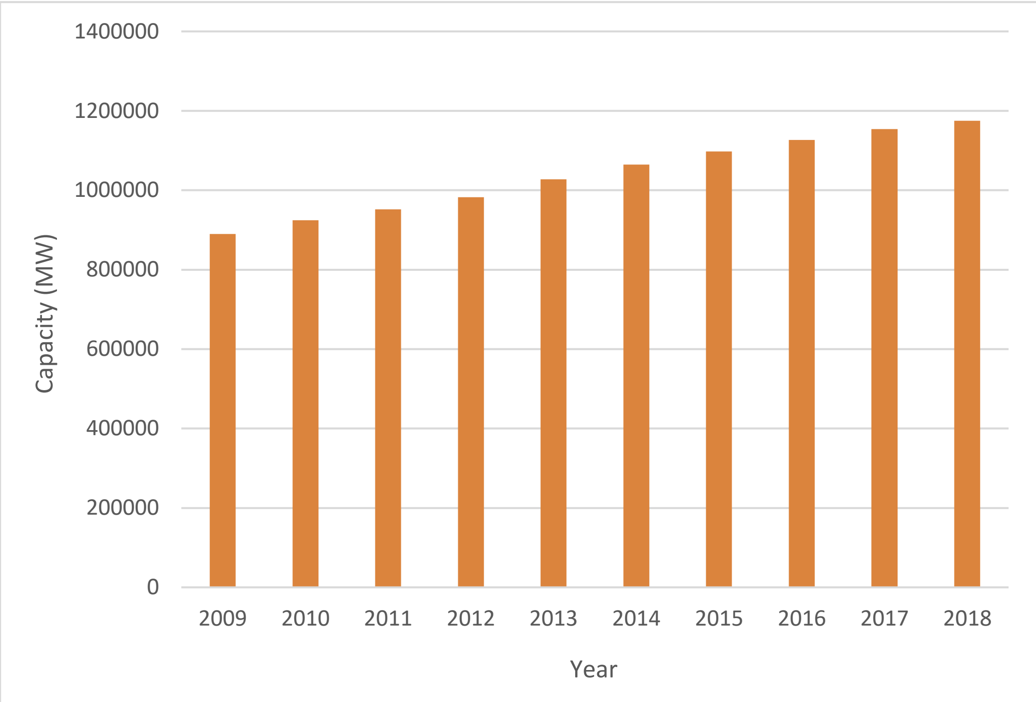

Figure 21. *Worldwide hydropower including mixed plants installed capacity [2]*

The production of renewable hydropower decreased around 11947 GWh in 2017 compared to the previous year, while this was enhanced by 151485 GWh in 2016 in contrast with 2015. Though, it was less than 6554 GWh production of renewable hydropower in 2015 compared to 2014, notably 3903811 GWh in 2014 and 3897257 GWh in 2015. From the period of 2009 to 2014, the global production rate increased about 19% that has risen by total 4036795 GWh in 2017.[2] (Figure 22)

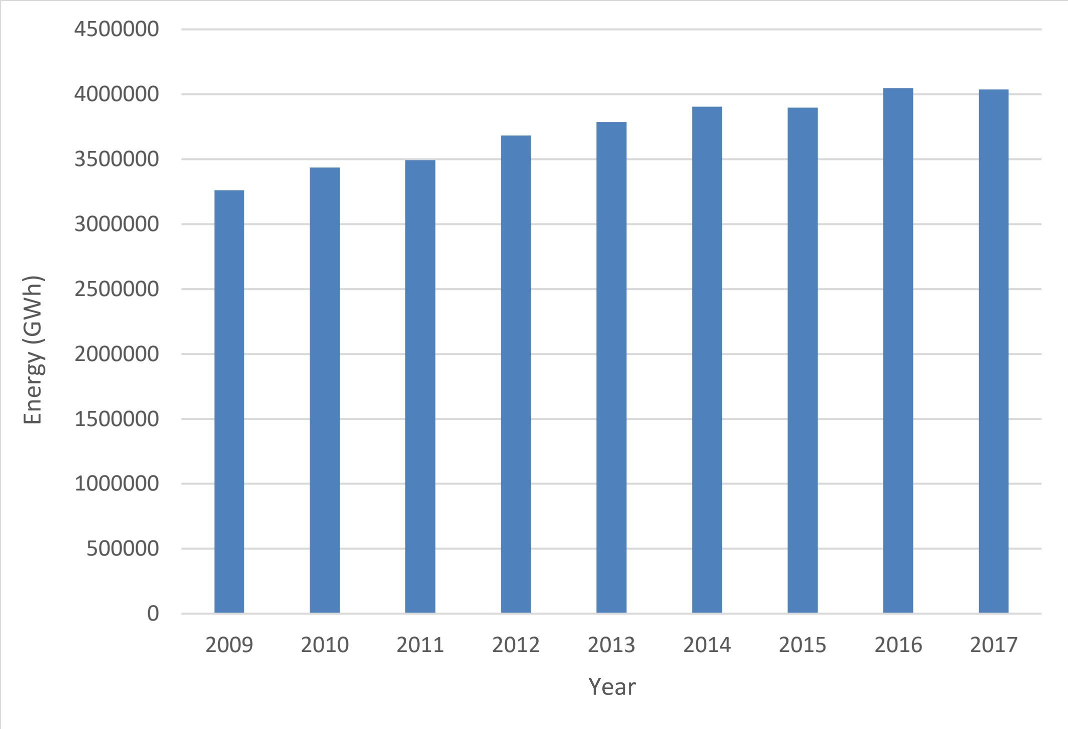

Figure 22. *Global renewable hydropower including mixed plants production [2]*

The pure pumped storage hydropower shows different trend in either installation or also for production. The installation experienced initial falls in their cumulative installation and generation. It will be worth to mention that the total installation declined around 478 MW in 2010 compared to the year 2009, the overall installation capacity in 2009 was 10079 MW and 100291 MW in 2010. In 2018, globally the installation improved by only 185 MW in contrast with the previous year, notably 120349 MW and 120164 MW in 2017. (Figure 23) The generation of pure pumped storage hydropower increased about 6393 gigawatt-hours in 2017 than the earlier year, the data followed as 121380 GWh in 2017 and 114987 GWh in 2016. However, the production dropped after 2010 to till 2014, where the highest production of electrical energy from pure pumped storage hydropower recorded around 93871 GWh in 2010, while it was about 92472 GWh in 2014. On the other hand, the production boosted in 2015, by adding only 291 GWh compared to the year 2010.[2] (Figure 24)

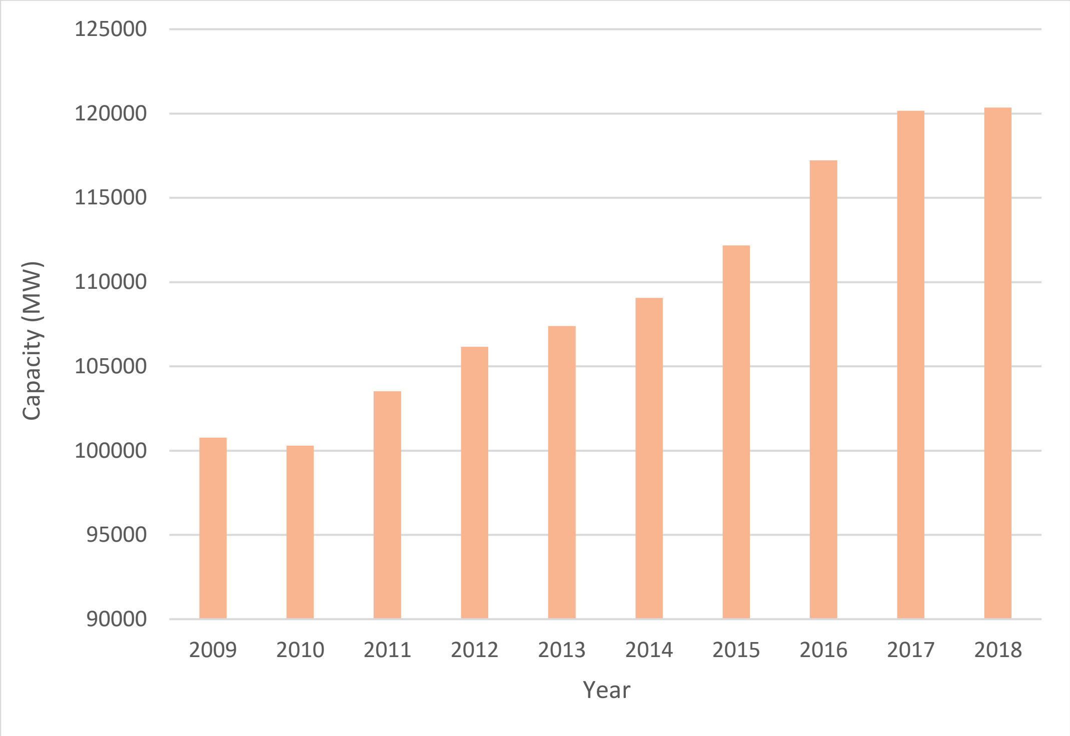

Figure 23. *Global pure pumped storage hydropower installed capacity [2]*

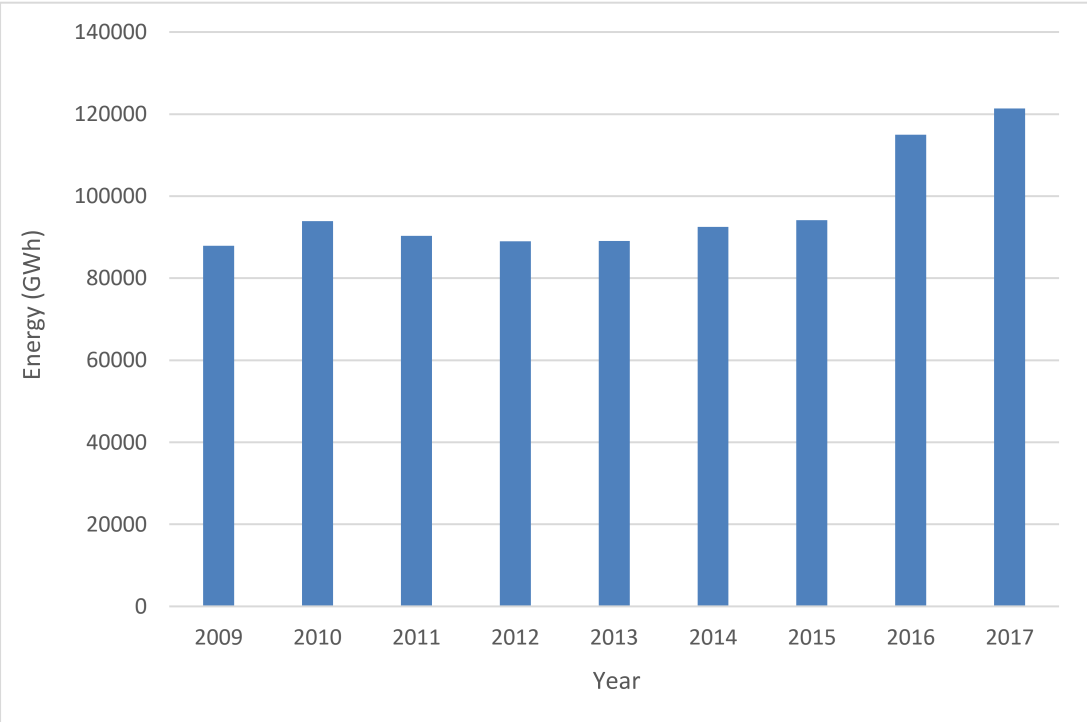

Figure 24. *Global pure pumped storage hydropower production annually [2]*

Hydropower is particularly a renowned renewable energy technology, because of the low-cost energy it delivers, and the flexibility it can offer to the grid. The global weighted-average levelized cost of hydropower was 0.048 USD/kWh in 2018. It was around 11% less compared to 2017, but from the year 2010 to 2018, it was about 29% higher than in 2010, notably from 0.041 USD/kWh to 0.048 USD/kWh.[33] In the period from 2010 to 2013, the worldwide weighted-average LCOE of hydropower was comparatively balanced, before beginning to soar up from 2014 onwards. This can be due to its extremely location specific technology, with every project planned for a certain location within an allotted river basin, however, the precise reasons for this price expansion are difficult to figure out. Meanwhile, the global weighted-average installed cost of hydropower projects was dropped to 1492 USD/kW in 2018, around 16 percent declined compared to 1768 USD/kW in 2017. This was quite similar to the price in 2016, notably 1753 USD/kW. The overall weighted-average installation cost of hydropower increased around 260 USD/kW between 2010 and 2018. The average total installation costs mostly rely on the locations of where the forthcoming hydropower projects will be authorized. [33] The Figure 25 below explained the total weighted average levelized cost of production and weighted-average installation costs of global hydropower.

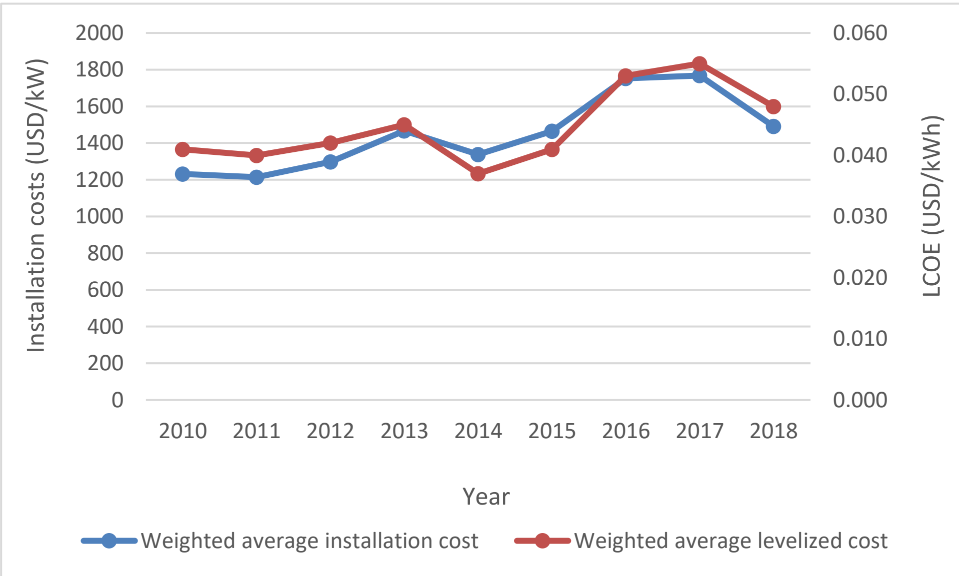

Figure 25. *Global hydropower installation and production costs [33]*

The worldwide total hydropower weighted-average capacity factors between 2010 and 2018 for projects assigned differed from 44 percent in 2010 compared to 51 percent on 2015, and finally settle down at 47% for assigned projects in 2018. [33]

3.4 Bioenergy

Bioenergy is one of the popular sources of renewable electricity in the world. It accounts for around 8 percent of the total global renewable power production in 2018. [1] The installation of bioenergy was always increasing slightly year by year. In 2018, the highest installation of bioenergy was recorded about 117828 MW, an increase of about 6163 MW compared to the previous year, notably 111665 MW in 2017 which was a 12% increase in contrast with 2016. Between the period from 2009 and 2018, the total bioenergy installation increased about 13 percent, marking from 61774 MW in 2009 to 117828 MW in 2018. (Figure 26) At the same time, the production of bioenergy was in the uprising trend. To begin with the year 2009, where the data showed that the generation of bioelectricity was about 277060 GWh, which was then achieved to 466470 GWh in 2015, a sum of record 9% of global renewable energy generation based on the International Energy Agency (IEA). The production of bioenergy then enhanced to around 485014 GWh in 2016, and again risen to about 495395 GWh in 2017. (Figure 27) Although, it was an increase of around 10381 GWh, but it failed to climb up the overall renewable energy production competition and decline to eight percent. [2] This can be due to the growing influence of other renewable technologies like solar PV, wind power etc.

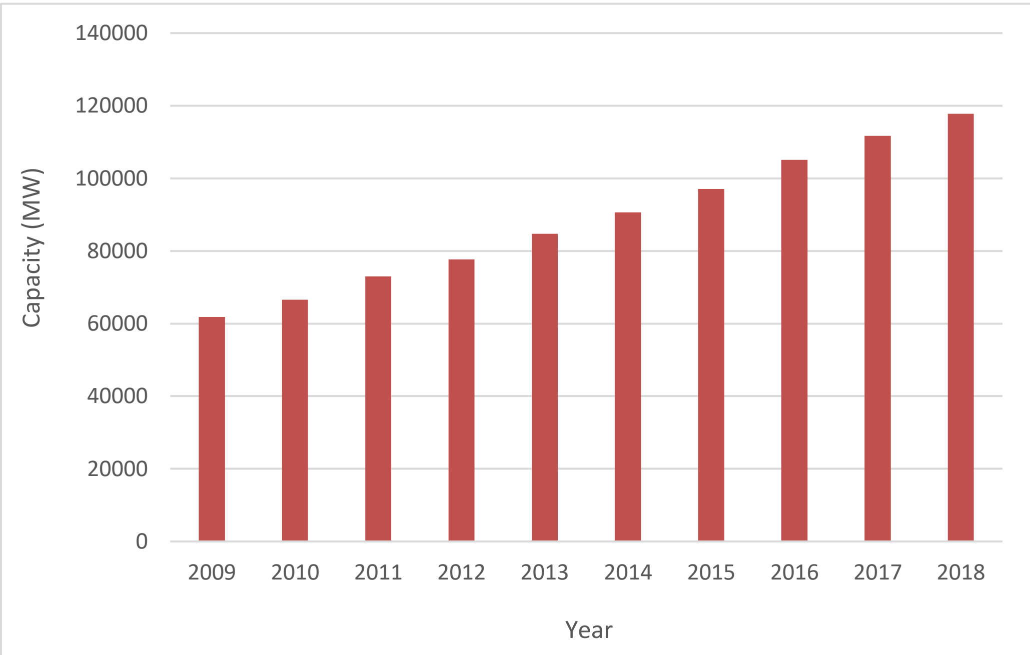

Figure 26. *Global bioenergy installed capacity [2]*

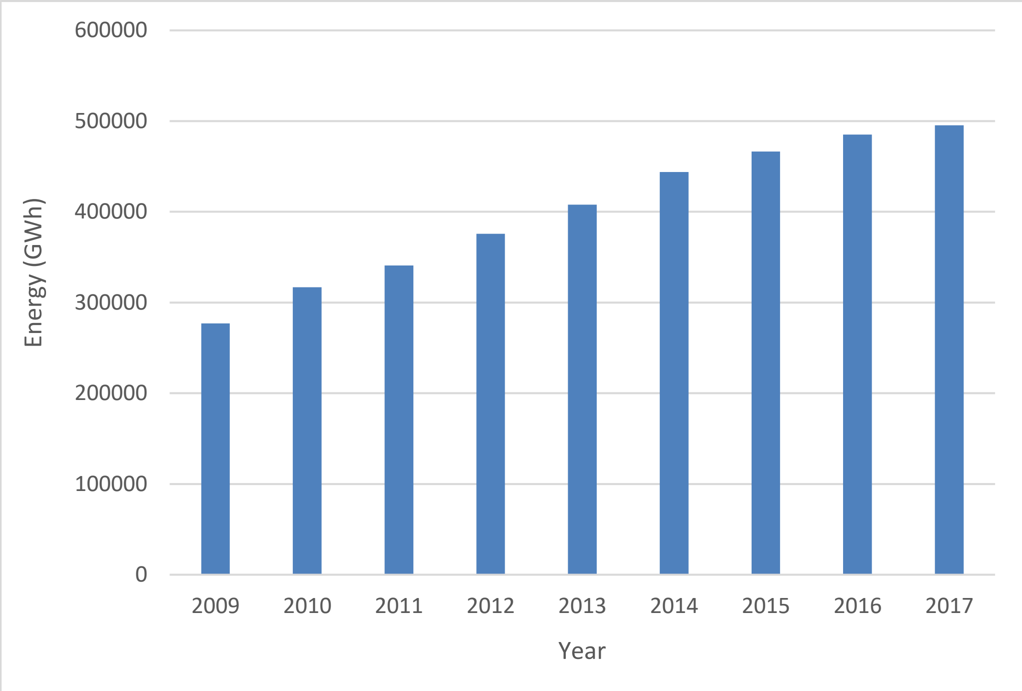

Figure 27. *Global bioenergy production from 2009-2017 [2]*

Bioenergy has several sub-technologies, which largely involved to produce the maximum amount of bioelectricity. Among them, combinedly solid biofuels and renewable waste is a major sources of bioelectricity production. The number of solid biofuels and renewable waste installation capacity is rising continuously, where the highest volume of installation capacity achieved in 2018, about 96464 MW, which was an increase of 5257 MW higher than in 2017. There was an average increase between 2009 to 2013, more than 8% increase was noticed in these periods. Overall, the installation capacity increased to 44667 MW from 2009 to 2018, notably 51797 MW to 96464 MW. (Figure 28) However, the production also followed rising trends and the maximum production recorded 400956 GWh in 2017, an increase of only 9253 GWh compared to 2016. The production of solid biofuels and renewable waste between 2009 to 2015 was steady, on average more than 2500 GWh production increased yearly. The production increased nearly double in 2017 around 400956 GWh, in contrast with 2009 about 232394 GWh.[2] (Figure 28)

To talk about the installation and production of renewable municipal waste alone, the total number of renewable municipal waste achieved 12597 megawatts in 2018, around 14% higher than in 2017. Overall, from 2009 to 2018, the installation capacity raised double in nine years, remarkably from 5375 MW to 12597 MW in 2018. The production of renewable municipal waste risen in accordance with the installation. It was increased to 39659 GWh in 2010 compared to 28704 GWh in 2009. Then between 2010 to till 2012, the production was almost similar but from 2013 onwards, it started to climb and reached to 57129 GWh in 2017.[2] (Figure 29)

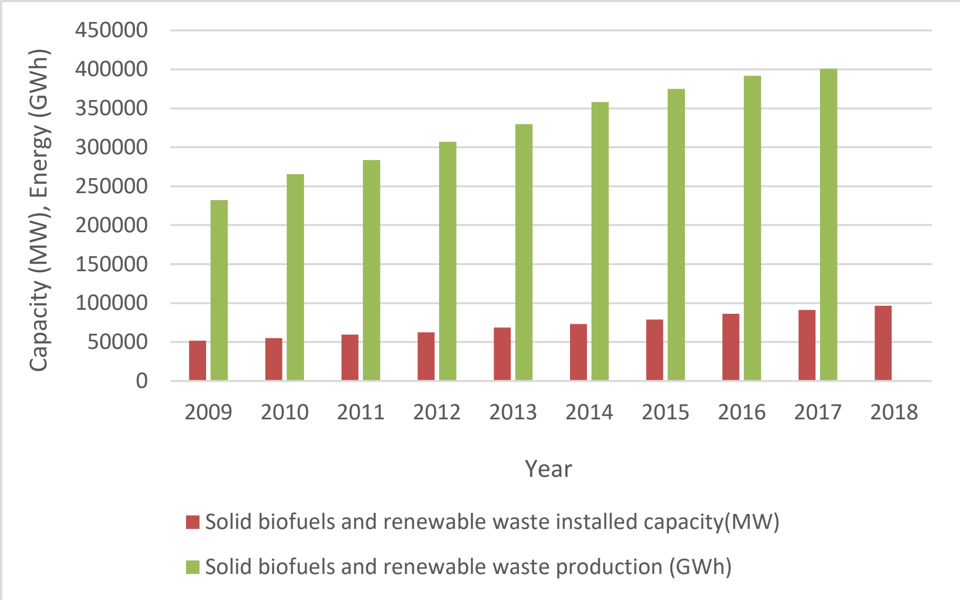

Figure 28. *Global solid biofuels and renewable waste installation capacity and production [2]*

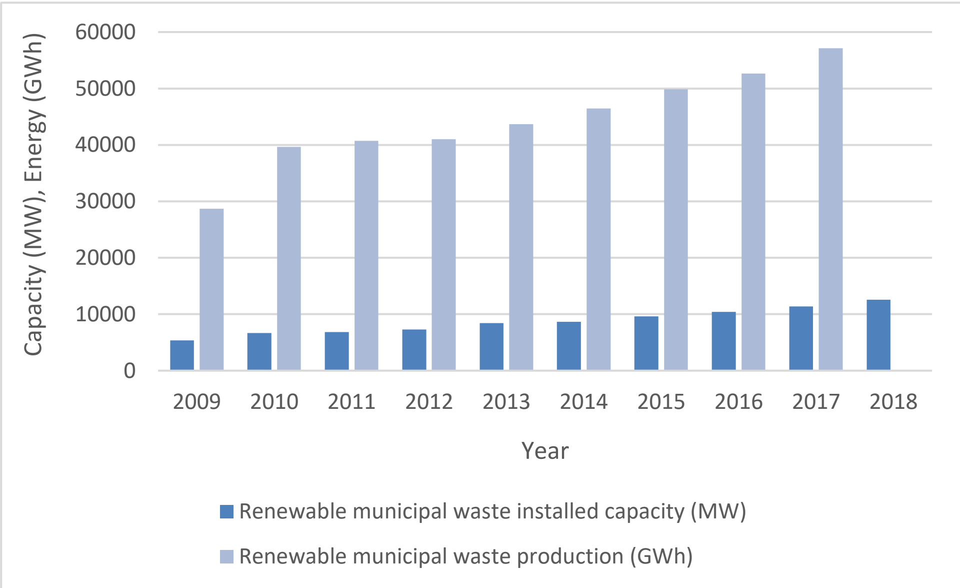

Figure 29. *Global renewable municipal waste installation capacity and production [2]*

Bagasse is another source of renewable bioenergy production. The overall installation capacity from 2009 to 2018, followed a steady rise where the highest installation reached to 18678 MW in 2018, in contrast it was about 413 MW higher than in 2017. From the year 2015 to 2018, the installation capacity was quite steady while the installation from

2009 to till 2015, increased by on average 1200 MW year by year, remarkably 8276 MW to 17053 MW. Meanwhile, the production of bagasse represented an uprising trend while there was an exception in 2011 when the production declined around 252 GWh compared to 2010, particularly 33209 GWh in 2010 and 32957 GWh in 2011. The decline of the production is maybe due to the insufficient supplies of the raw materials that caused the least productions. The rest of the year went well by enhancing the maximum production recorded in 2017, around 53936 GWh. [2] (Figure 30)

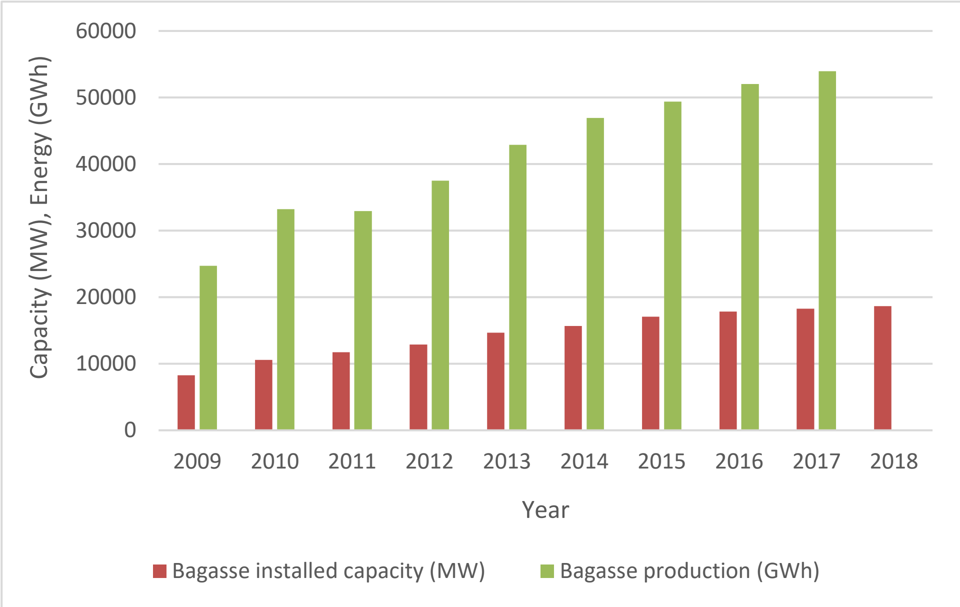

Figure 30. *Global bagasse installation capacity and production [2]*

Other solid biofuels particularly one of the renowned sources of renewable bioenergy in most of the countries in the world. The installation of other solid biofuels was enhanced quite well between the period of 2009 to 2018, where the maximum installation occurred in 2018, approximately 65156 MW, while it was about 38146 MW in 2009. The installation capacity was quite steady in contrast with the year 2011 and 2012, remarkably 41117 MW and 42331 MW. However, after that it was rising about 3000 MW annually till 2018. (Figure 31) On the other hand, the production was very impressive which was accounted about 289787 GWh in 2017, an increase of roughly 2863 GWh compared with 286924 GWh in 2016.[2] It would be worth to mention that among all the renewable energies, EU countries particularly preferred other solid biofuels and wood combinedly as their primary renewable energy source and produced around 42% of renewable energy in 2017 from this source. [34] There was a fairly increase of production between 2009 to 2015, where on average approximately more than 16000 GWh energy production increased year by year.[2] (Figure 31)

Figure 31. *Worldwide other solid biofuels installation capacity and production [2]*

Liquid biofuels are one of the biggest contributors of matching global renewable transport oil demand and supplied 4% of the global road transport fuel in 2016. The worldwide liquid biofuel installation indicates a different trend from the period of 2009 to 2018. The sum of installation was equal in both 2017 and 2018, accounting for 2867 MW, while it was decreased to 1961 MW in 2016 compared with 2066 MW in 2015. It was also decreased in both 2013 and 2014 contrasted with 2012, notably 2066 MW in 2012 while 2041 MW and 1968 MW in 2013 and 2014.[2] At the same time, the production of liquid biofuels also reveals both ups and down trends, where the highest production achieved in 2015, notably 5878 GWh, where the second largest production was recorded in 2016, about 5551 GWh. Nevertheless, it was decreasing in 2017, 2012 and 2011, where a kind of disasters in the production of biofuels happened in 2011 when the production declined around 1644 GWh compared to 5296 GWh in 2010. The produced biofuels were even higher in 2010 in contrast with 2017.[2] (Figure 32)

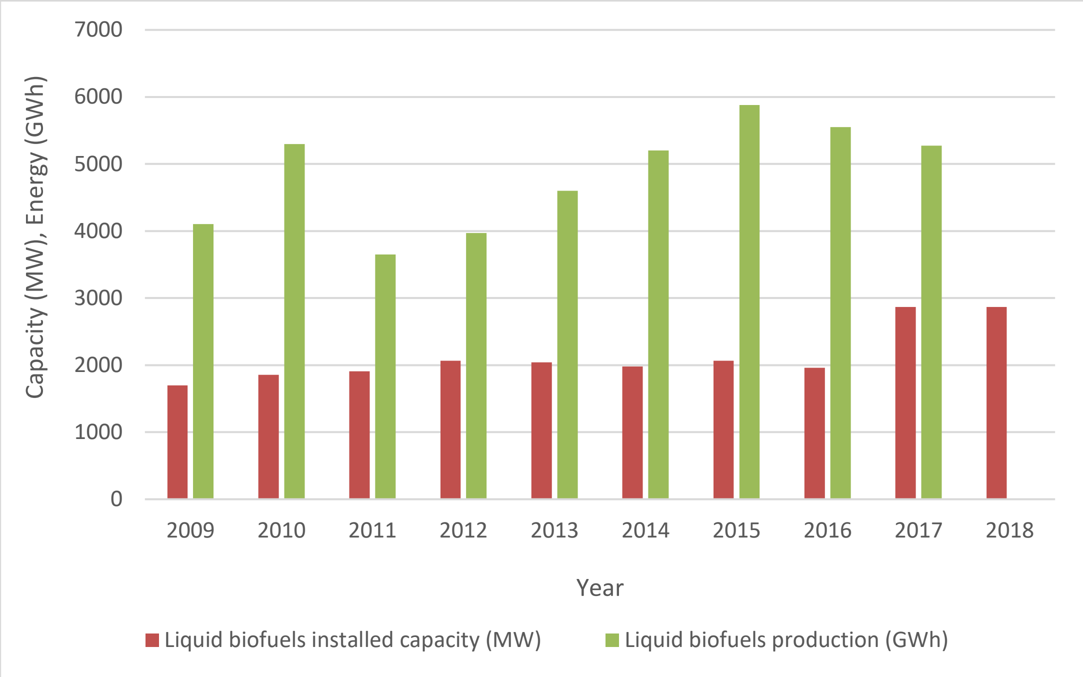

Figure 32. *Worldwide liquid biofuels installation capacity and production rate [2]*

Biogas is also a renowned source of global bioenergy productions particularly in the rural areas of the developing countries in the world. The number of biogas plants installation are rising day by day. The highest amount of biogas projects commissioned was 18126 MW in 2018, an increase of 906 MW than in 2017. Between 2014 to 2018, it was rising almost more than 900 MW per year, while the major capacity increased in 2011, around 1907 MW compared to 2010, remarkably 9518 MW to 11425 MW. [2] On the other hand, the production of biogas was increased always, though the amount of increase was quite less in between 2015 to 2017, where on average 1600 GWh expanded globally. But the period from 2009 to 2014 was more favourable for the growth, where on average more than 10000 GWh biogas production increased each year and the maximum production achieved 80062 GWh in 2014, which was then enhanced to 87932 GWh in 2017.[2] (Figure 33)

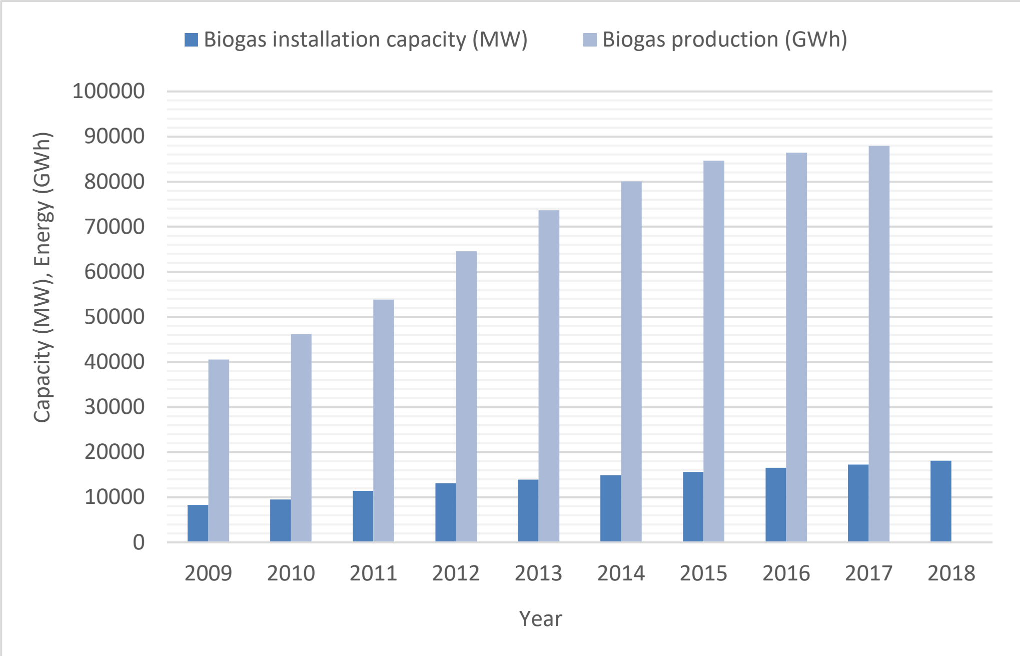

Figure 33. *Worldwide biogas installation capacity and production [2]*

Bioenergy can provide competitive electricity where low-price feedstocks are obtainable as by-products from farming or forestry processes. The worldwide weighted-average overall installation costs of bioenergy projects dropped to around 2105 USD/kW in 2018, down from around 2847 USD/kW in 2017. The installation cost in 2010 was quite high, around 2555 USD/kW fell to almost half of around 1279 USD/kW in 2011. Then it started to increase until 2013 about 2978 USD/kW which then falls gradually.[33] (Figure 34)

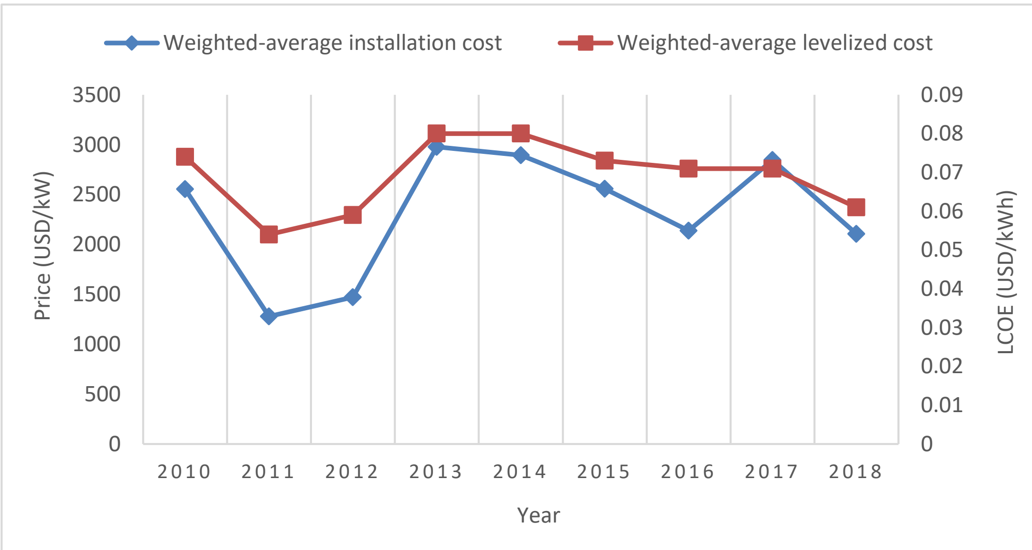

Figure 34. *Global bioenergy installation and production costs from 2010-2018 [33]*

On the other hand, the global weighted average levelized cost of different bioenergy power plants authorized was 0.061 USD/kWh in 2018, which was approximately 14% lower compared to 2017. The weighted-average LCOE in both 2016 and 2017 was equal around 0.071 USD/kWh and it was 0.08 USD/kWh in both 2013 and 2014. (Figure 34) According to the IRENA renewable cost database, the global weighted-average capacity factor decreased to 78% in 2018 while it was about 86% in 2017. Among the countries in the world, the lowest capacity factor was achieved by China 64%, while it was highest in North America about 83% in 2018. [33]

3.5 Geothermal Energy

The geothermal energy is particularly used as a source of renewable energy since long time. The installation and production of geothermal energy is increasing quite sharply where the total installation capacity achieved around 13277 MW in 2018, an enhancement of about 577 MW compared with 12700 MW in 2017. The overall installation capacity between 2009 to 2018 increased about 3508 MW, reaching from 9769 MW to 13277 MW. The lowest amount of capacity rose about 90 MW from 2010 to 2011, remarkably 9993 MW to 10083 MW while the rest of the year went well where on average more than 400 MW capacity installed yearly.[2] (Figure 35) On the other hand, the production curve followed the uprising trend during the period from 2009 to 2017 where the maximum production was recorded around 85978 GWh in 2017, an increase of 2866 GWh compared to 83112 GWh in 2016. The production of geothermal energy remains moderate, with the maximum production achieved around 5023 GWh in 2014 compared to 2013, particularly 77155 GWh in 2014 and 72132 GWh in 2013. The overall production increased around 18691 GWh between the period 2009 to 2017, notably 67287 GWh in 2009 to 85978 GWh in 2017. This is illustrated in Figure 36

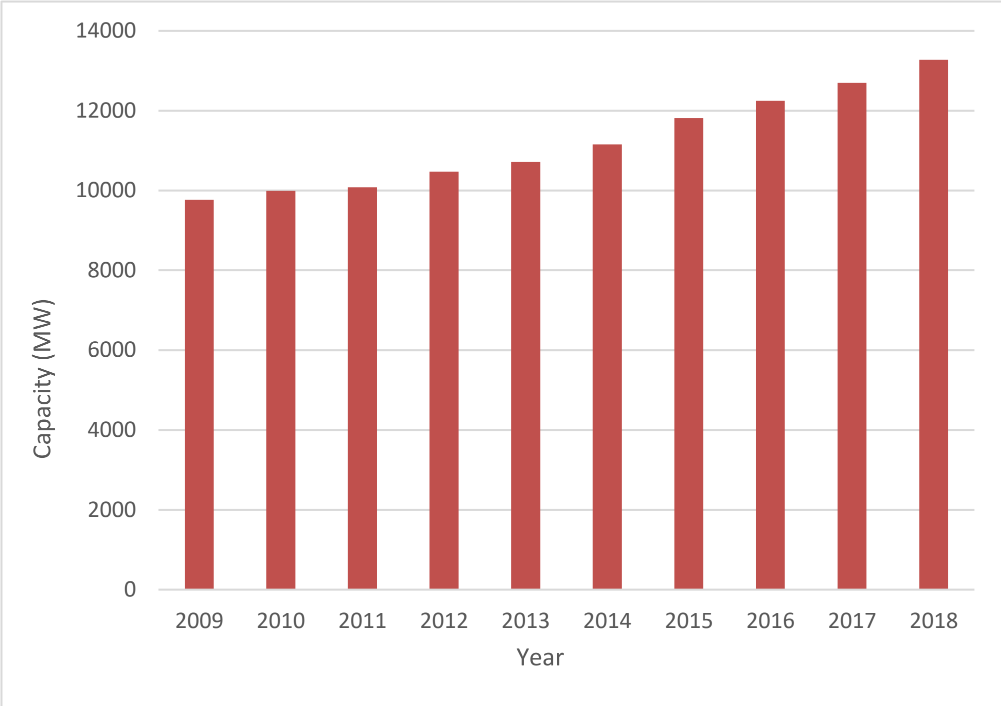

Figure 35. *Worldwide geothermal energy installation capacity [2]*

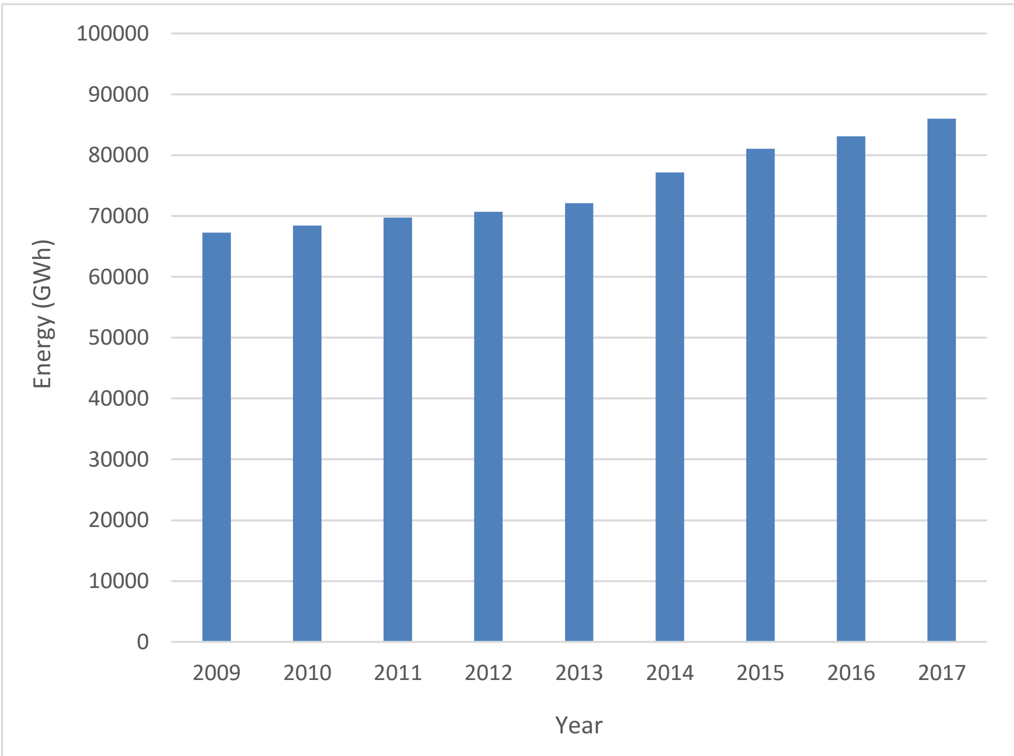

Figure 36. *Global geothermal energy production from 2009-2017 [2]*

The cost of geothermal energy projects commissioned between 2010 and 2018 experienced different trends. In the early 2010, the installation was quite less about 2543 USD/kW which then all of sudden soared to double around 5162 USD/kW in 2012. Then it fell down around 40% in 2013, particularly 3715 USD/kW which then gradually declined until 2015 and then started to soar up again. The installation cost of geothermal projects commissioned in 2018 was recorded around 3976 USD/kW, an increase of 215 USD/kW in contrast with the previous year. (Figure 37) However, the weighted average levelized cost of global geothermal plant commissioned in different year experienced both ups and down trend. The global weighted-average LCOE in 2018 of newly commissioned geothermal plants was around 0.072 USD/kWh, which was approximately 1% lower compared to 2017. The worldwide weighted-average levelized cost of overall commissioned geothermal plants in 2010, was about 0.048 USD/kWh, with the soaring trend it was 0.083 USD/kWh in 2012, where from the period from 2013 and 2018, the average costs were particularly 0.06 USD/kWh and 0.072 USD/kWh. (Figure 37) Again, the weighted average capacity factor of geothermal energy was maximum in 2015, accounting for 89% while it was around 84% in 2018. The lowest weighted average capacity factor of geothermal energy was in 2017 about 81% amongst the period of 2010 to 2018. [33]

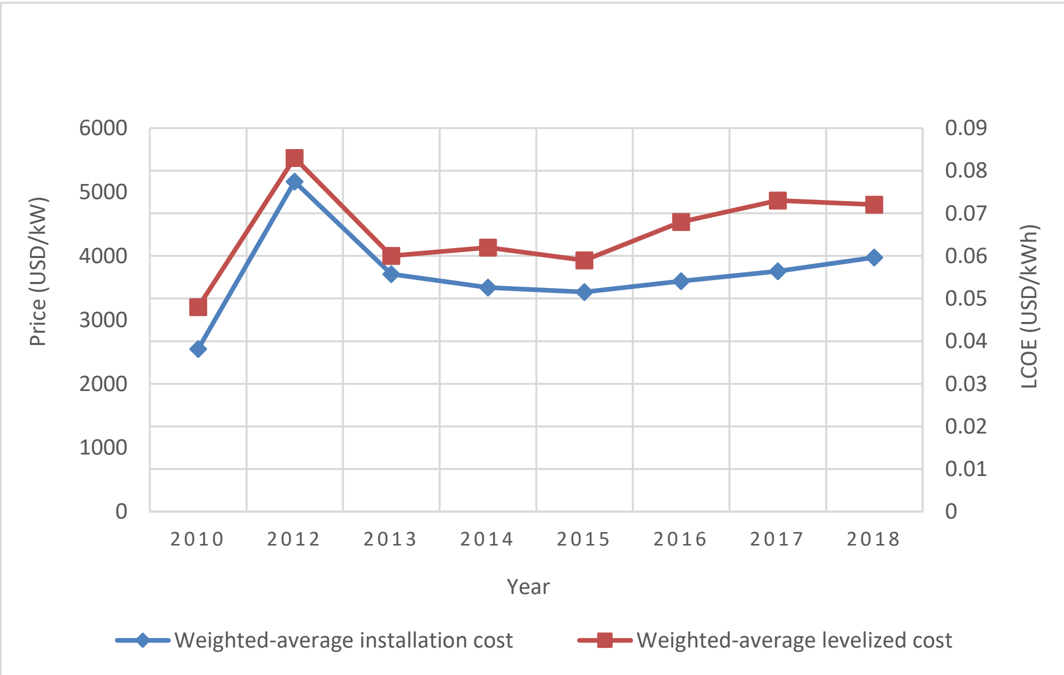

Figure 37. *Global geothermal energy installation and levelized cost [33]*

4. FORECAST FOR THE FUTURE RENEWABLE ENERGY TECHNOLOGY

The consumption of electric power has dramatically increased in the world for decades and also enhancing day by day. At the same time, the conventional fossil fuel-based energy is also decreasing and at certain time, the world will be out of fossil fuel. Besides, these unsustainable conventional fossil energies have a considerable impact on the environment causing enormous amount of greenhouse gas emissions and increasing the global temperature. On such situation, the world is looking for an alternative source of energy and of course renewable energy is the only option to replace the conventional system and to fulfil the environmental requirement. The Paris climate conference (COP21) in 2015 brought the countries in the world together where every country agreed to attain sustainability of energy production and thus, reducing the overall Carbon emissions and emphasizing to boost the renewable energy production. Moreover, they committed to keep the global temperature at below 2 degree Celsius by 2050. [38] This helped to set up energy goals by most of the countries in the world to introduce renewable energy in their annual power generations. At present, renewable energy is producing more than 26% of the global electricity in the world which easily reflects the importance of renewable energy in the global energy market. [1] This indicate the golden opportunity of renewable electricity generation in future energy market and therefore, considering the present trends of renewable power development, the forecast of future renewable power can be done with the existing statistics of renewable energy generation and installation capacity. Different regions or countries in the world have their own strategic goal to increase their renewable energy consumption where only Denmark is the single nation in the globe that have an aim of achieving 100% of its ultimate energy consumption from renewable sources. [35] Again, European union sets a target to achieve a collective 32% of renewable energy consumption by 2030. Several US cities also set a goal to achieve 100% of renewable energy generation capacity by 2050 where China, one of the largest producers of renewable electricity also aiming to fulfil 35% of its energy from renewable sources. [1] In this chapter, the production of different renewable energy till 2030 are forecasted based on current energy statistics that was described in the previous chapter.

4.1 Solar power

Solar power, especially solar photovoltaics (PV) is one of the fastest growing renewable energy technologies in the world. Solar PV alone achieved around 480 GW installation capacity in 2018, while producing approximately 425 TWh energy in 2017. (Figures 5 and 6) Global solar PV market is largely dominated by China accounting for 45% of the energy production capability. Due to the introduction of deployment quotas instead of feed-in-tariff (FITs), it is expected that the growth rate in China will be steady or can decline for about few years after 2017 which will actually be influenced on global solar PV growth rate. [36] It is noticeable that the net capacity increased in 2018 compared to 2017 although it was expected that it will decrease in 2018 (Figure 5). Therefore, it is possible to assume that the net capacity will increase yearly on average addition of more than 100 GW to over 120 GW per annum until 2030. This means that the net capacity will reach up to the mark of 1 TW in the year 2023.

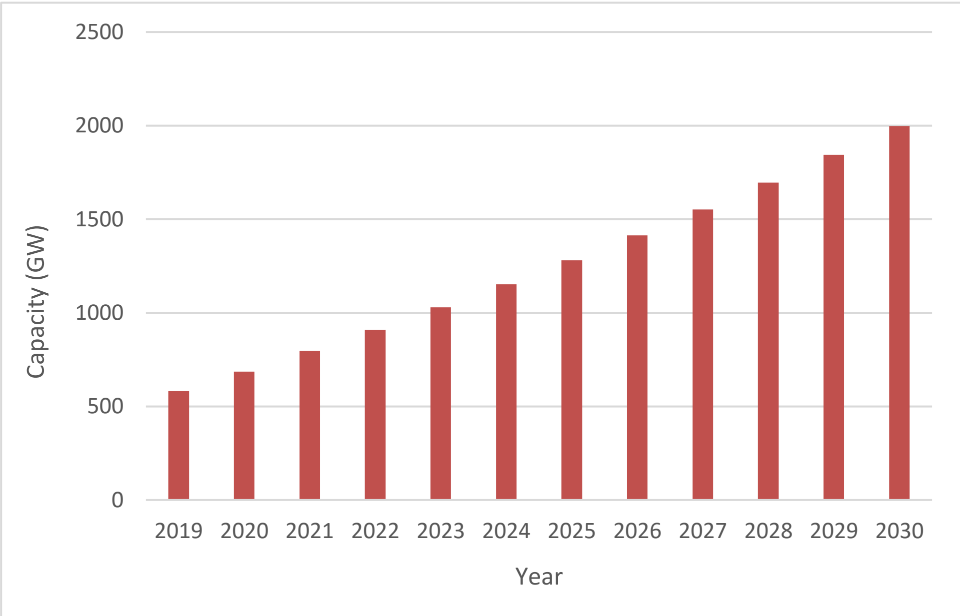

Figure 38. *Forecasted global cumulative installation capacity of solar PV between 2019-2030.*

Again, the capacity will increase to approximately 1280 GW in 2025, where it is expected that over 700 GW of new capacity will be installed at the end of 2030, the total installation capacity will reach around 2,000 GW. (Figure 38) On the other hand, the production of solar PV will rise dominantly which will reach more than 1 petawatt-hour (PWh) in 2022.

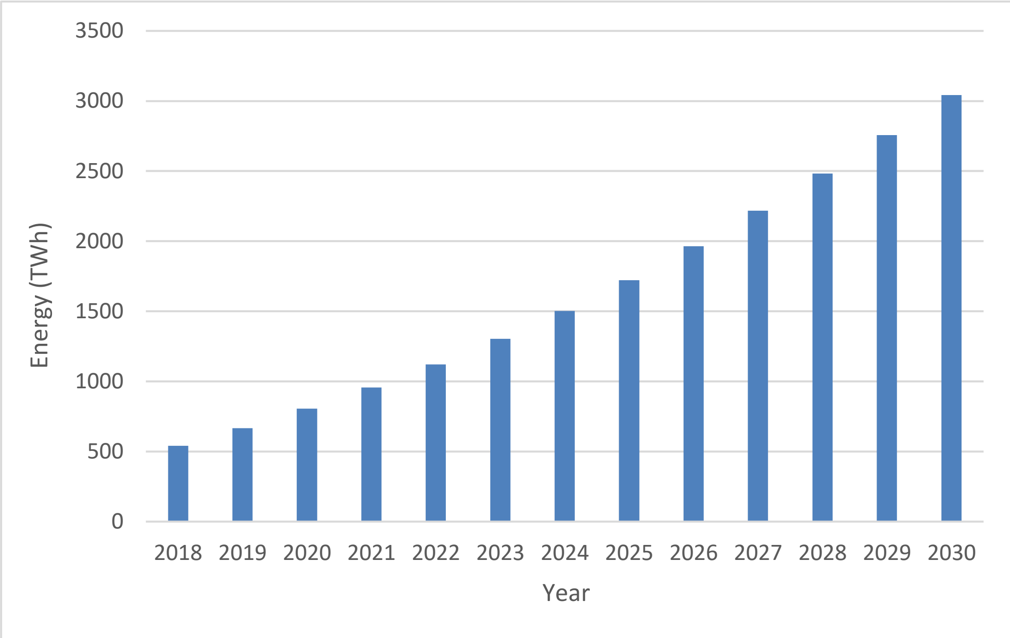

Figure 39. *Forecasted global cumulative electricity generation of solar PV between 2018-2030.*

The generation of electric energy from solar PV will be more than 1700 TWh in 2025. It is also expected that there will be a sharp rise of the production between 2025 to 2030, where the generation will be more than 1000 TWh in just few years, rising to around 3000 TWh in 2030. (Figure 39) The major contribution will be done by China, Unites States, India and Japan accounting for more than two third of the global solar PV production. The development of solar power largely depends on the stable policy and regulatory towards renewable energy by all the countries in the world. The energy will be mostly utilised to power the buildings, heating and cooling purposes and it will be also used for charging electric vehicle.[1] The reduction of levelized cost year by year will lead to the ultimate growth of solar PV. According to BloombergNEF neo report published in 2019, the levelized cost of battery storage will drop around 64% to about 67 USD/MWh by 2040, compared to the present 187 USD/MWh today which will benefit the PV system. According to SunShot 2030, they are aiming to reduce 50% of the levelized cost of solar PV between 2020 and 2030 and aiming to attain a target of USD 3 cents per kilowatt-hour in 2030. [37] Besides, the production cost of concentrated solar power (CSP) will be quite less around USD 5 cents per kilowatt-hours for base load and it will enable the increase of CSP production accordingly combined with solar photovoltaics. [37] It is expected that the market of renewable energy would attain USD 730 billion per annum in 2030. [38]

To compare this forecast with IRENA energy Remap 2030 and DNV GL forecast on renewables, power and energy 2050, Solar power Europe energy forecast 2019-2023 and IEA (International Energy Agency) forecast and market analysis between 2018 and 2023, the data found with the assumed calculation in the Figure 38 and Figure 39 represents the actual growth rate of the future solar photovoltaics (PV) development in terms of installation capacity or electricity generation. [1][32][39][40]

4.2 Wind power

Wind power is another most promising source of renewable energy technology in the world. According to a press released by Global wind energy council (GWEC), wind could power around 20% of the world renewable energy demand by 2030. [42] Again, the European union is looking to fulfil 24.4 % (Central scenario) of its electricity demand by 2030, while producing around 778 TWh of energy. [41] Meanwhile, around 563 GW of the wind power capacity was installed in 2018, where about 1134 TWh of wind energy was produced during 2017. (Figure 11 and Figure 12) This was the highest increase of both wind power installation and generation where more than 95% of wind power contributed by onshore wind source. Global wind energy market will be dominated by the onshore wind energy where it is expected that offshore wind power will increase about 22% by 2023. [42] The forecast of onshore and offshore wind power is done from the reference case described in chapter 3.2. The average growth rate year by year is accounted while considering the total increase of wind power and also the technical development of turbine technology and further the policy and regulatory initiative towards wind power technology is also considered in the study. It is expected that the global wind power capacity both onshore and offshore wind power combinedly will reach more than 2000 GW in 2030. The forecast indicates that the global wind power installation capacity will be achieved around 1 TW in 2025, where onshore wind power capacity will be more than 900 GW and offshore will be around 50 GW. It is predicted that the net capacity will increase far more after the year 2025 where more advanced turbine technology with the increase of the size of the blade will be introduced. This will further help to boost the capacity where it is assumed that the net capacity will increase approximately more than 450 GW of wind power combinedly with the onshore and offshore technology (Figure 40). On the other hand, the production of global wind power is projected to rise quite steady in the beginning to till 2023. The onshore wind energy generation is expected to produce more than 2050 TWh of energy in 2023, while the offshore wind source is estimated to produce record over 130 TWh.

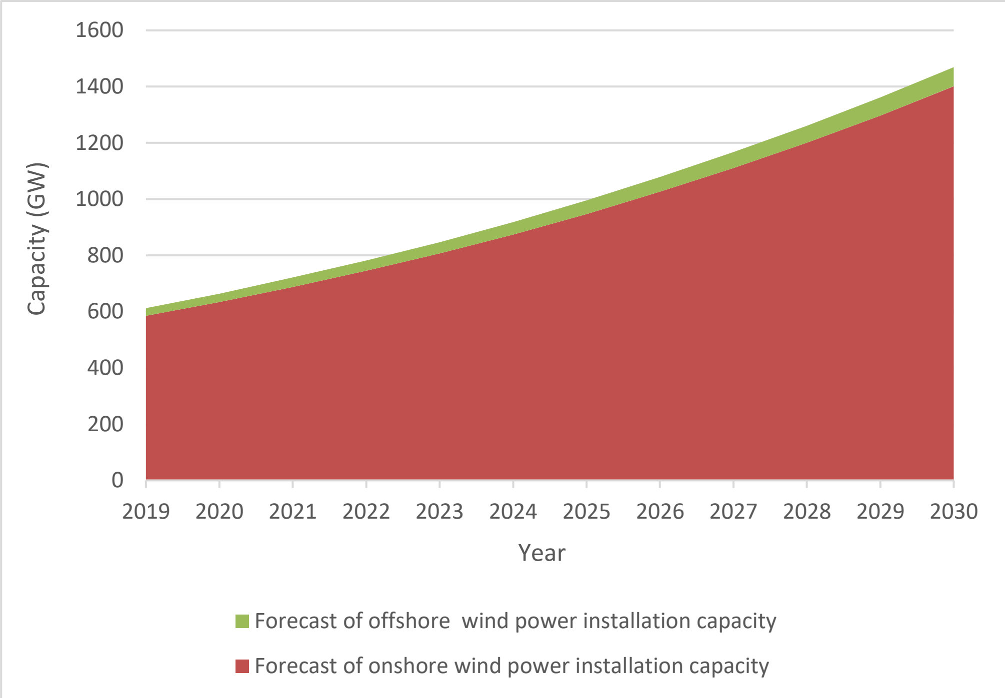

Figure 40. *Forecast of global onshore and offshore wind power installation capacity from 2019-2030.*

Moreover, the overall forecast indicates that the production of wind power combinedly from both onshore and offshore source will generate above 4000 TWh energy in 2030, notably from onshore over 3800 TWh and above 270 TWh from offshore wind technology. (Figure 41)

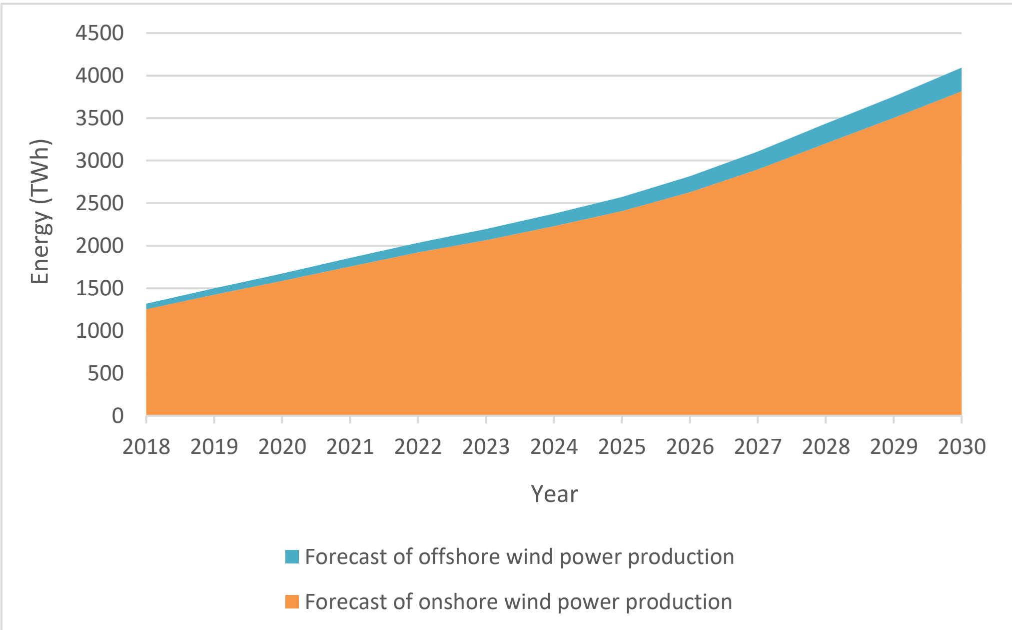

Figure 41. *Forecast of global onshore and offshore wind power production.*

According to Global Wind Energy Council (2016), wind power will fulfil around 20% of the world electricity demand which will create approximately 2.4 million new work opportunities and further it will reduce annually more than 3.3 billion tons of carbon-dioxide emissions by 2030. It is also estimated that the annual investment on wind power technology will be around USD 200 billion. [43] Besides, it is projected that the levelized cost of energy (LCOE) will follow the current falling trends and will be minimal. To achieve such goal, wind power technology advancement is inevitable. It is assumed that the development will focus on turbine technology that involve lighter, more adaptable blades, latest aerodynamic control instruments, modernization of transmission systems, advanced sensors, and of course an intelligent control system. [39]

To relate this forecast with the IRENA (International renewable energy agency) energy REmap 2030 and DNV GL forecast on renewables, power and energy 2050, Global Wind Energy Council (Market outlook 2019 to 2023) and International Energy Agency (IEA) Clean Energy Tracking Progress and forecast from 2018 to 2030 on Sustainable Development Scenario (SDS), the data found with the assumed calculation in the Figure 40 and Figure 41 signifies the actual growth rate of the future wind power development in terms of installation capacity or electricity generation. [39][40][42][44]

4.3 Hydropower

Hydropower is the leading renewable energy producers for long time, and it is accounted for around 60% of the total renewable energy generation in 2018. [1]Globally, the total hydropower excluding the pumped storage hydropower was installed around 1132 GW capacity in 2018 while producing approximately 4243 TWh of energy. [20] Therefore, the forecast is done only for the potential future hydropower installation and production. The forecast is performed considering the reference values of the past capacity and production and also further investment and policy trend towards the hydropower technology. It is expected that the installation capacity will increase around 225 GW from 2019 to 2030. The hydropower installation capacity will follow a steady rising trend, where it is assumed that the capacity will above 1270 GW by 2025, and it is estimated that the capacity will increase on average 18 GW per year till 2025. [36] The capacity is expected to rise up to about 1360 GW by 2030. (Figure 42)

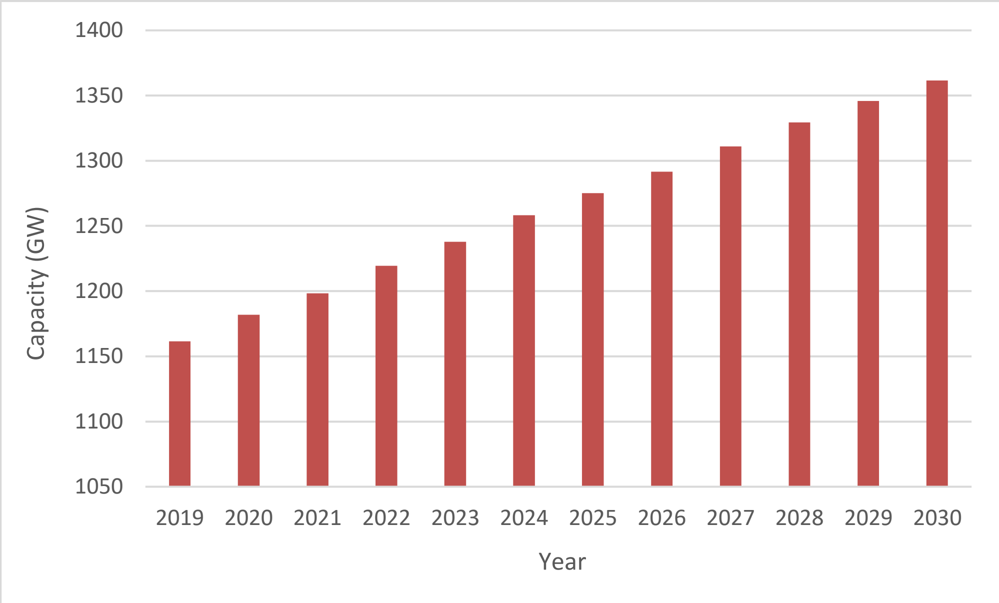

Figure 42. *Forecast of global hydropower installation capacity from 2019-2030.*

On the other hand, it is projected that the global hydropower production will rise over 5200 TWh in 2030. There will be a slight enhance of production between 2019 to 2021, accounted for around 4270 TWh and 4440 TWh. The production will increase on average more than 80 TWh per year between the period from 2021 to 2030. (Figure 43) Hydropower production is likely to grown by above 3% in 2018 due to constant recovery from drought in Latin America along with strong capacity increase and good water accessibility in China. [44]

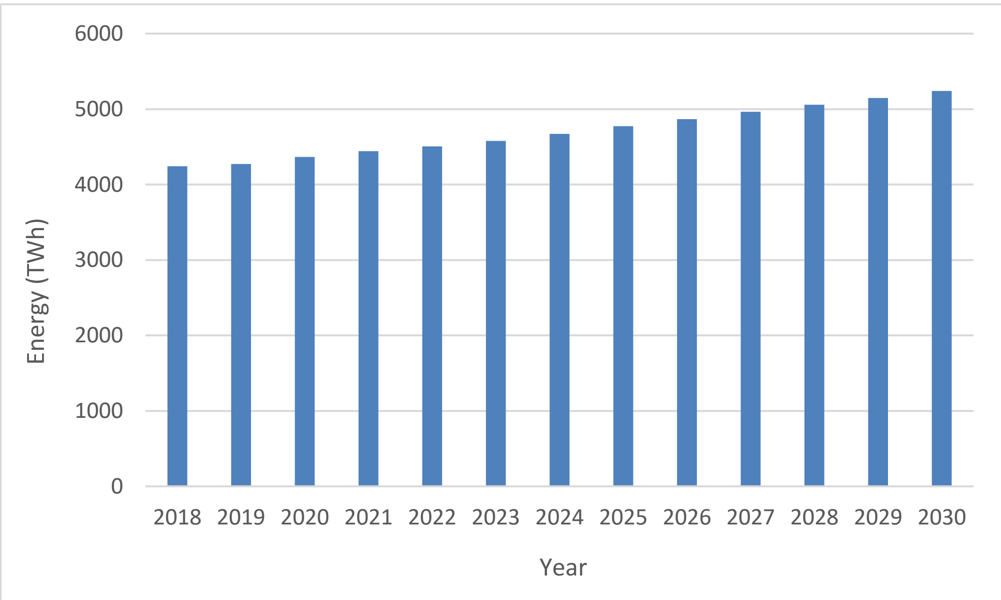

Figure 43. *Forecast of global hydropower production.*

Most of the progress in hydroelectricity production will come from big projects in evolving economies and developing countries. Large and small hydropower projects can expand access to modern power facilities and relieve poverty and will promote economic and social development especially in these countries. Although hydropower projects need very significant amount of investment, that can vary up to 10 billion USD and therefore, financing remains a crucial concern. This forecast expects for innovative funding schemes and reforms of market design to make sure adequate long-term profits flows and minimize risks for investors. The majority of the cost of electricity from hydropower plants originates from the financing cost, whereas electric apparatus has similar prices per MW in most of the countries, while the cost of labour varies depending on the regions or site. [45] The key drivers that will impact the development of hydropower are technology modernization to lower the cost, the simultaneous impact of the environmental consideration and the development of market leading condition that emphasise the extended asset life of hydropower amenities.

To compare this prediction with the International Renewable Energy Agency (IRENA) energy Remap 2030 and DNV GL forecast on renewables, power and energy 2050, IEA (International Energy Agency) Clean Energy Tracking Progress and forecast from 2018 to 2030 on Sustainable Development Scenario (SDS), the data found with the assumed calculation in the Figure 42 and Figure 43 shows the actual growth rate of the future hydropower development in terms of installation capacity or electricity production. [39][40][44]

4.4 Bioenergy

A huge extent of biological feedstocks can be transformed through a variety of techniques into thermal power, fuels for transport (biofuels) and electricity. Modern sustainable bioenergy except the conventional consumption of biomass (solid biofuels) provides roughly 50% of the overall renewable energy in final energy utilization. Moreover, bioenergy in the type of liquid biofuels or biogas and biomethane, solid fuel (biomass) can be utilized to generate heat for household places, and for cooking and heating water, whichever in conventional stoves or in modern usages notably as pellet-fed heating system boilers. [1] The use of solid biofuels can change throughout the period of time where the demand is expected to be double around 108 exajoules (EJ) which is approximately 3.7 % progress rate by 2030, whereas around 30% would be used in producing biofuels for the transport division and nearly a third of total in producing power and for district heating.[46] For the analysis, every form of bioenergy is accounted to calculate their overall estimated growth rate in terms of both installation capacity and for productions. The average percentage of increase during the period of 2009 to 2018 are taken as a reference to estimate for future growth till 2030. Bioenergy is estimated to expand by about 69 GW over 2018-2030 to attain around 186 GW. This progress is 10% lesser than the implementation throughout the period of 2012-2018. (Figure 26 and Figure 44) The worldwide new additions of bioenergy installation capacity will remain comparatively steady at around 5 GW and 6.5 GW annually during the projection period. It is assumed that the net capacity will reach more than 150 GW in 2024, while it is expected that the capacity will fairly improve to the next six years, reaching more than 180 GW in the world. (Figure.44)

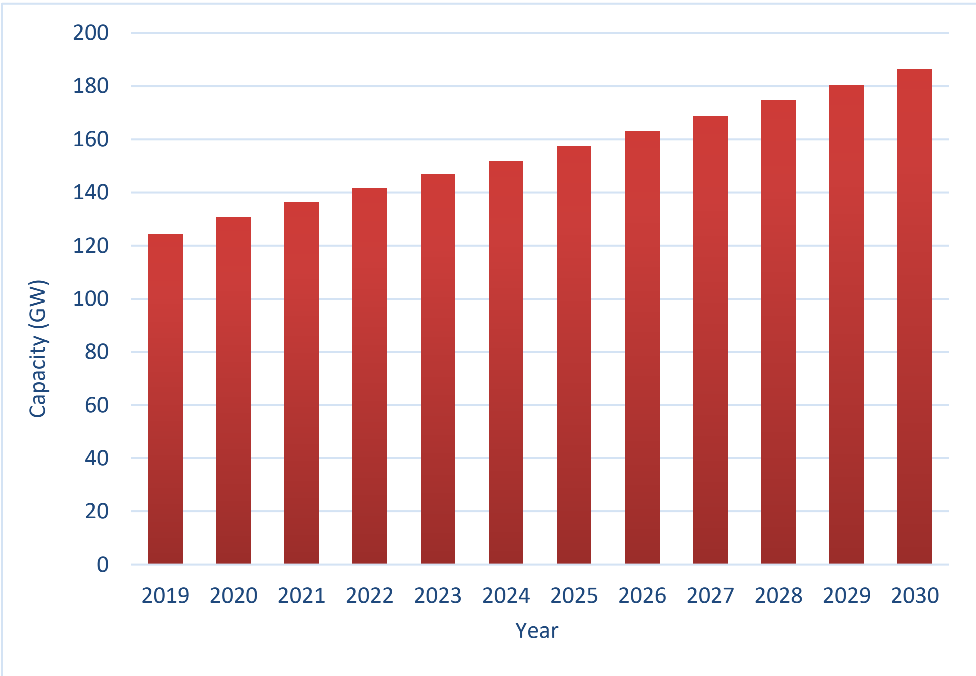

Figure 44 *Forecast of global bioenergy installed capacity per annum*

On the other hand, the production of bioenergy electricity is expected to rise quite steady, hence it's following the uprising trends since 2011, it is expected to enhance by 8% in 2018. The production is projected to reach more than 800 TWh in 2025 and by 2030 over 1100 TWh. The growth rate is expected around 6 percent per year over the periods, where air contaminant constraints are taken into consideration. (Figure 45)

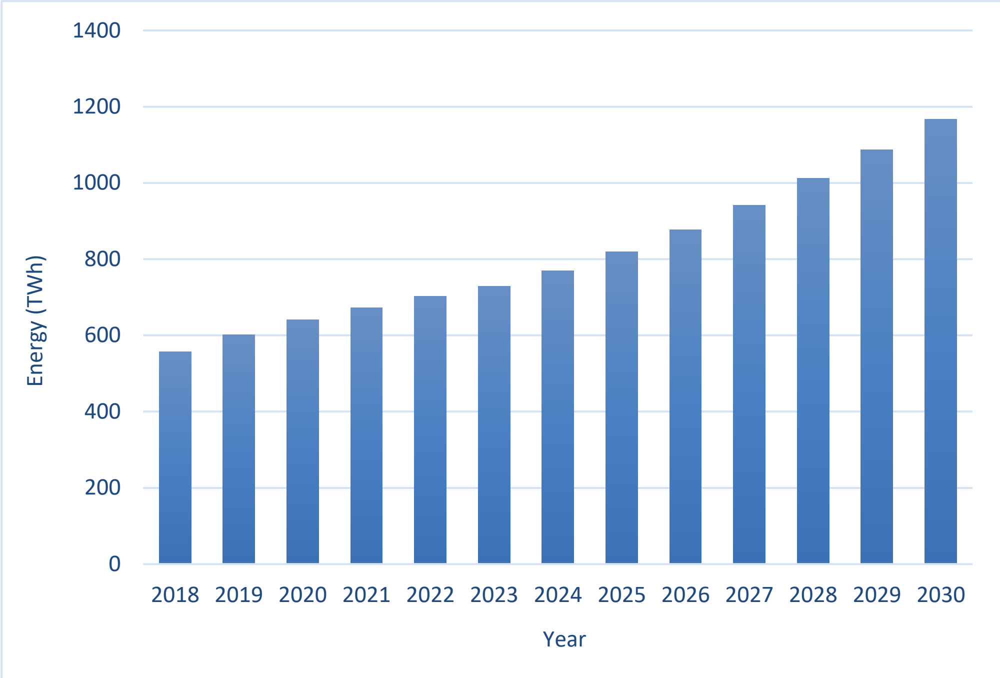

Figure 45 *Forecast of global bio-electricity production from 2018-2030*

According to IRENA roadmap 2050, the end-use of transport liquid biofuels is likely to reach 370 billion litres per year by 2030 which will fulfil around 9% of the global transport oil demand and to meet the demand the production should be triple from the current condition to the forecasted period. [38] Energy from waste deployment is also expanding strongly as rising urbanisation and economic growth leads to more municipal solid waste production. Energy from waste technology presents a solution enhanced to landfills for municipalities to handle municipal solid waste. [44] The supply costs of biomass in the domestic level is likely to vary in agricultural residues as minimum as 3 US dollar to as maximum 17 US dollar per gigajoules for the energy yields. [46] The investment is also likely to increase a considerable amount to meet the global demand.

To make a comparison of this forecast with the IRENA (International Renewable Energy Agency) bioenergy Remap 2030, International Energy Agency (IEA) Clean Energy Tracking Progress and forecast from 2018 to 2030 on Sustainable Development Scenario (SDS), the data found with the assumed calculation in the Figure 44 and Figure 45 shows the ultimate growth rate of the future bioenergy development in terms of installation capacity or electricity generation. [44][46]

4.5 Geothermal Energy

Geothermal energy is another source of renewable energy which is increasing gradually. In the recent years, majority of the energy capacity is added in just few countries notably Turkey, Indonesia and United States.[1] Geothermal energy has a well potential future in terms of heating and electric energy along with other thermal technologies. It is estimated that geothermal energy will provide around 1% of the global renewable energy by 2050. [47] The forecast of geothermal energy is done in accordance with the average rate of increase occurred between 2010 and 2018, and further considering the policy initiative and tendency to invest on geothermal power. Geothermal energy installation capacity is projected to expand about 28% per year to attain just over 16 GW by 2023. It is assumed that the installation capacity will rise very steadily and will reach more than 21 GW by 2030. The development is projected to take place mostly in the developing countries and in emerging economies around 70% of the total by 2030. [48]

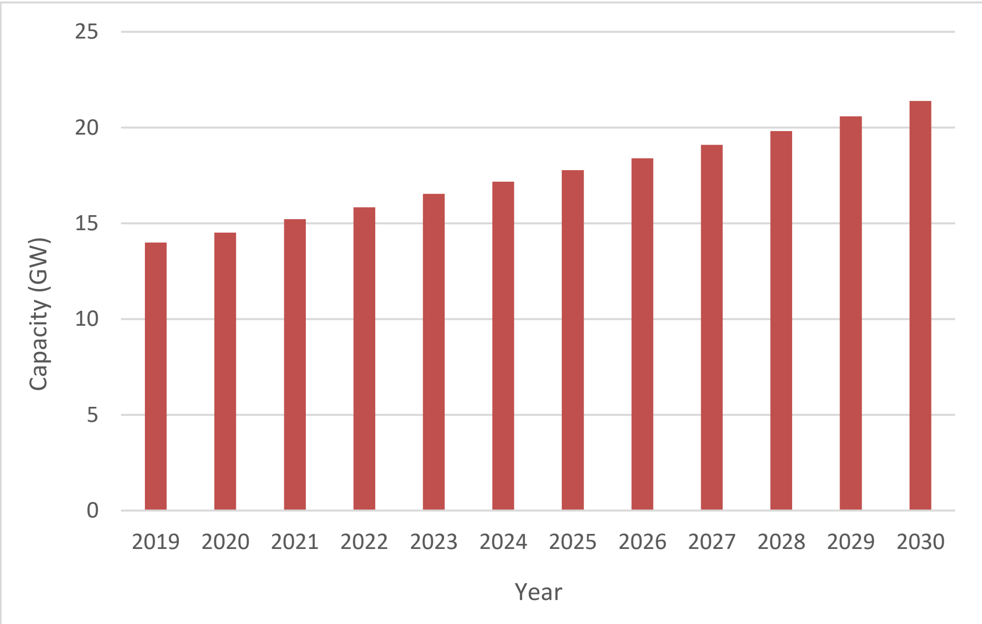

Figure 46 *Forecast of global geothermal energy installation capacity*

On the other hand, the production of geothermal energy is also contributing in global renewable electricity generation. Geothermal energy production was projected at around 630 petajoules, with approximately half of this around 90.7 TWh in the form of electricity and rest as heat. [1] It is assumed that the production will rise about 6% in 2018 compared to the average progress rate in past 5 years, and further it is also estimated that the production will reach more than 100 TWh by 2022. The production of geothermal power is projected to expand on average 5.5 percent per year until 2030, reaching more than 144 TWh. (Figure 47) This will be mostly harnessed for the production of electrical energy and for different thermal uses which includes both industrial heat input and space heating.

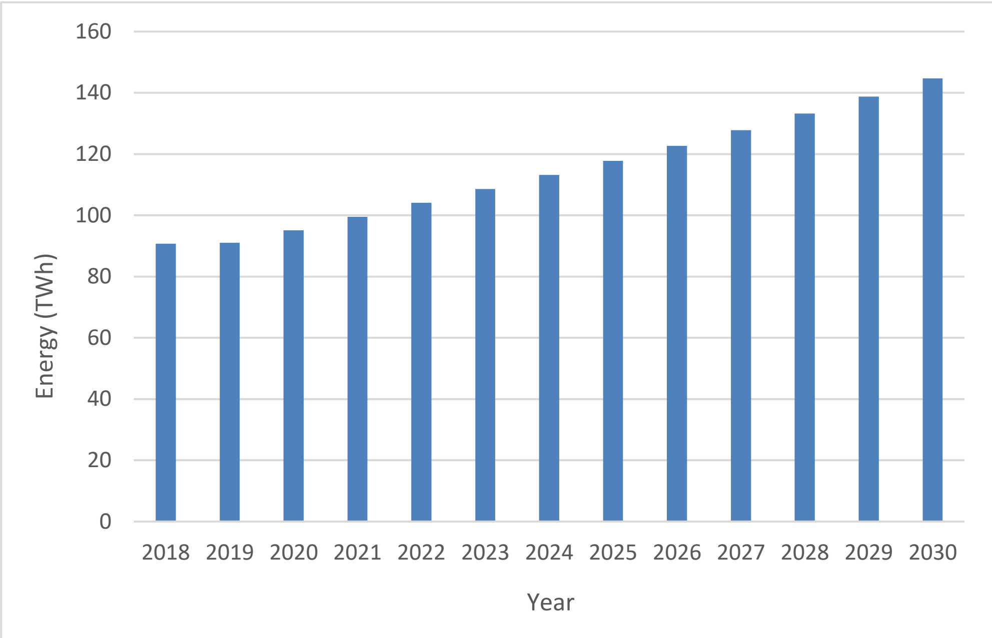

***Figure 47** Forecast of global geothermal energy production*

Though there is a significant potential of geothermal energy, the enormous amount of drilling cost makes harder to invest on such power technology. It is accounted that only drilling take on average 40-70% of the overall capital costs of a geothermal energy projects. [44] Research and development are necessary to figure out a solution of design and cost reductions of geothermal energy and to make it more feasible for the growth.

To compare this forecast with the International Energy Agency (IEA) Clean Energy Tracking Progress and forecast from 2018 to 2030 on Sustainable Development Scenario (SDS), and DNV GL (Renewables, power and energy use forecast to 2050), the data found with the assumed calculation in the Figure 46 and Figure 47 shows the similarity of the growth rate of the future geothermal power development in terms of installation capacity or electricity production. [39][44]

5. CONCLUSIONS

The impact of fossil fuel-based technology in the environment and their short-period of life further remind the importance of alternative sustainable renewable energy source that can replace the existing system. The aim of the study was to find out the future of the emerging renewable energy technology, while analysing their current situation both in the market and consumer level. The study generally focused on key renewable energy technologies notably, solar power, wind power, hydropower, bioenergy and geothermal energy. The results of the studied technology illustrate that there will be a major influence in the future energy market from these renewable sources. Moreover, it is also indicated that the prospects of large investment towards renewable power and their future in the upcoming decades.

The investment towards fossil fuels and coal power significantly decreases, while the data found by utilising all of renewable energy sources determined the enhancement of the spending towards the new sustainable renewable energy technology. The solar photovoltaic and wind power are the most promising source of renewable power technology, where the data showed that these two renewable technologies will likely to expand most while contributing maximum share of global renewable energy in the future. The new capacity is also increasing in highest numbers, the enhancement of PV technology and wind turbine technology offering the maximum efficiency in production. Besides, hydropower seems to rise quite steady due to lots of factor related to the hydropower technology regarding locations and investment etc. The data indicate that still hydropower will be the dominant renewable power provider in 2030. Bioenergy on the other hand will be most popular especially for meeting the oil demand in transport sectors, domestic power supply in emerging economies, and providing heat energy. It is assumed that there will be proper policy of collecting waste in most of the countries where it is expected that the consumption of bioenergy will be double by 2030 compared to present. Lastly, the forecasted data represent that the utilisation of earth geothermal energy will increase quite slowly as because of the huge investment cost related to the power technology. It is still expected that it will further help to meet the global heating and electricity demand in most of the countries.

The selected study was conducted to determine the importance of the renewable energy technology and to estimate their future market condition. Again, it is also aimed to make more feasible for the present market and to enhance more awareness about the potential of such renewable energies at present and future market. Therefore, the present situation and their estimated future are also described considering their present growth rate.

To sum up, for a clean, emissions free nature and a sustainable future, renewable energy is must to save the ecosystem.

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