International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2024: 7.101

# A Review Article on Solar Energy for Sustainable Development of Human Life on Our Mother Earth

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**Abstract:** ***The present global energy situation, led by the fossil fuels, has some serious concerns such as the impacts on regional climatic conditions, environmental degradation, depletion of fuel resources and the energy security. Nuclear power plants also have major reservations such as the associated radioactive emissions. It is thus indispensable to adopt renewable sources of energy for the global development of a sustainable electricity generation system. Solar energy is a widely distributed, sustainable, and renewable energy source. As a renewable resource, solar energy has the capability to replace the widely used fossil fuel resource in the near future. In the recent times, renewable energy sources have gained a major importance due to their worldwide social acceptance and an ability to provide sustainable energy generation to cater world electricity requirements. With a view to know the basic requirements to produce solar power like solar panels for generation of photo electrons, efficient batteries to store the solar power and to know the present status of Solar energy generated by various countries and their storage mechanisms and to know the effective utilization of solar power for sustainable growth of human development, a review on Solar energy has been undertaken and it has been observed from our world data that the total solar power produced in the world is around 1310.02 Twh (Tera watt hour). Out of which China is on the top by producing 427.72 Twh. India is in 4th place by producing 95.16 Twh only. It is observed from our world data, the energy produced by hydro power is on the top by producing above 5000Twh, it is observed from the data that, there is almost zero solar power in the year 2010, but, as the cooperation and support of the government policies, tremendous development in technology the production of solar power is increasing rapidly and achieved the above target. There is a strong hope that the majority of future energy is through solar power only to run our day to day energy requirements.***

**Keywords:** Renewable Energy, Photo voltaic Cell, Watt hour, Concentrated Solar Power, Hydropower, Wind Power, Bio energy

## 1. Introduction

Solar energy refers to technologies that convert the sun's heat or light energy to another form of energy for use [1, 2]. There are two categories of technologies that harness solar energy, Solar Photovoltaic and Solar Thermal. Solar Photovoltaic (or PV) is a technology that converts sunlight into direct current electricity by using semiconductors [3]. In contrast, Solar Thermal is a technology that utilizes the heat energy from the sun for heating or electricity production.

Since the beginning of time, people have been fascinated by the sun. Ancient civilizations personified the sun, worshipping it as a God or Goddess. Throughout history, farming and agriculture efforts have relied upon the sun's rays to grow crops and sustain populations. Only recently, however, have we developed the ability to harness the sun's awesome power. The resulting technologies have promising implications for the future of renewable energy and sustainability. The most common way of harnessing energy from the sun is through photovoltaic (PV) panels – those large, mirror-like panels seen on rooftops, handheld solar devices, and even spacecrafts. These panels operate as conductors, taking in the sun's rays, heating up, and creating energy (and electricity). On a larger scale, solar thermal power plants also harness the power of the sun to create energy. These plants utilize the sun's heat to boil water and, in turn, power steam turbines. These plants can supply power to thousands of people.

Just like wind power, solar power is a virtually unlimited and inexhaustible resource (unlike power produced from expendable fossil fuels). As technologies improve and the materials used in PV panels become "greener," the carbon footprint of solar power becomes smaller and smaller and the technique becomes more accessible to the masses.

**Figure 1:** Solar Panels occupying huge land

In geographical areas lacking in sunlight, or areas that frequently experience cloudy weather, may have difficulty for utilizing solar power effectively. Additionally, solar power technologies often require a large amount of land as shown figure 1, and they can be extremely costly. Scientists are hard at work to find an affordable, efficient solution for harnessing solar power.

## 2. Facts about Solar Power

Every hour, the sun beats down with enough power to provide global energy for an entire year. It takes an average of eight minutes for a light energy to travel from sun to Earth. Scientists have used solar energy to power spaceships since 1958. Most solar panels used today have an average life expectancy of between 20-40 years. To produce huge amount of solar power, below concepts are most useful [3, 4].

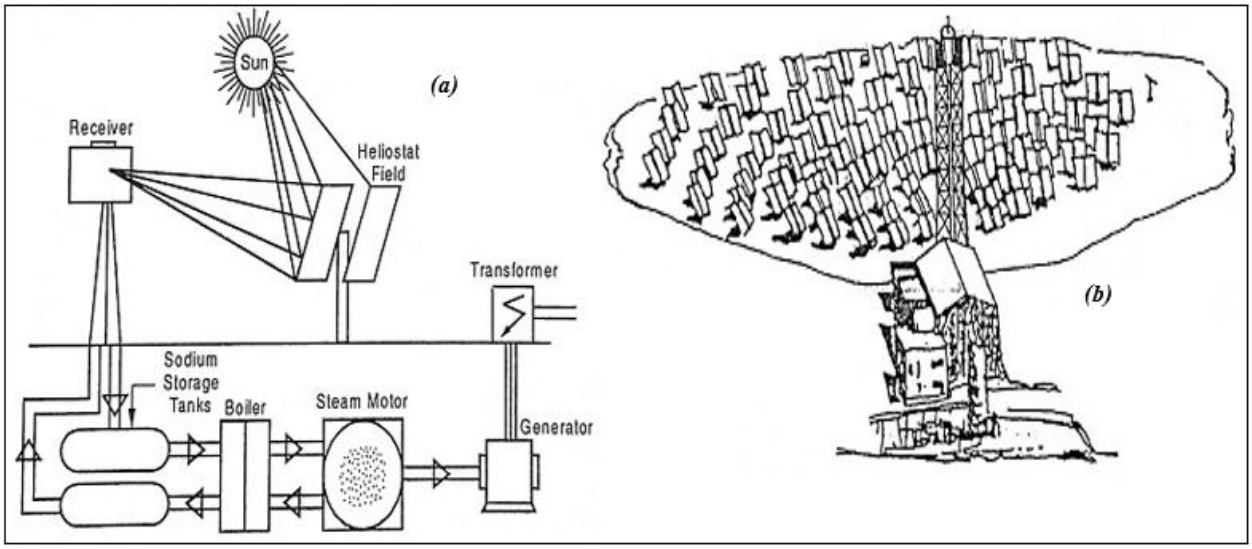


**Figure 2:** (a) Solar Tower Power Plant (b) Solar Tower System

**The solar tower:** It consists of a central receiver on a tower and a whole field of tracking as shown in Fig.2a

**The solar farm:** It consists of a whole field covered with parabolic trough concentrators as shown in Fig.2b.

With both systems (`solar farm' and 'solar tower'), a heat transfer fluid of gas is passed through the point or line of insolation concentration to collect the heat and transfer it to the point of use. Such heat can be used either directly in industrial or commercial processes or indirectly in electricity production via. steam turbine.

## 3. A Solar Power Plant

A solar power plant is mainly concerned with diminishing electricity costs by imparting energy. In the process of doing so, small and large solar systems are involved. The engaged components absorb and transmit sunlight to electricity from DC to AC. A solar energy conversion entails batteries and more accessories. [5, 6]

The working of a solar plant comprises three main elements as shown in Figure 3.

1) **Solar Panels:** Solar panels are the heart of a power plant. They are built by a number of solar cells and are solely responsible for the success of a plant. The panels are positioned on the roof of a building at a tilted angle to maximize sunlight.
2) **Battery Controller:** A battery charge controller ensures consistent power to the batteries, which is utilitarian on days of less sunshine or at night. This takes care of the battery and makes sure the battery does not get discharged or overcharged.
3) **Solar Power disconnects:** A solar power disconnect cuts off the DC power output from the solar panel. It also looks into problems with the solar system. This component should be strong enough to control the power on a bright sunny day.
4) **Solar cells:** Solar cells are majorly responsible for the flow of electricity. The energy-generating unit is fabricated with p-type and n-type silicon semiconductors. The solar cells absorb the energy from the sunlight and create electrical charges, which move in response to an internal electric field.

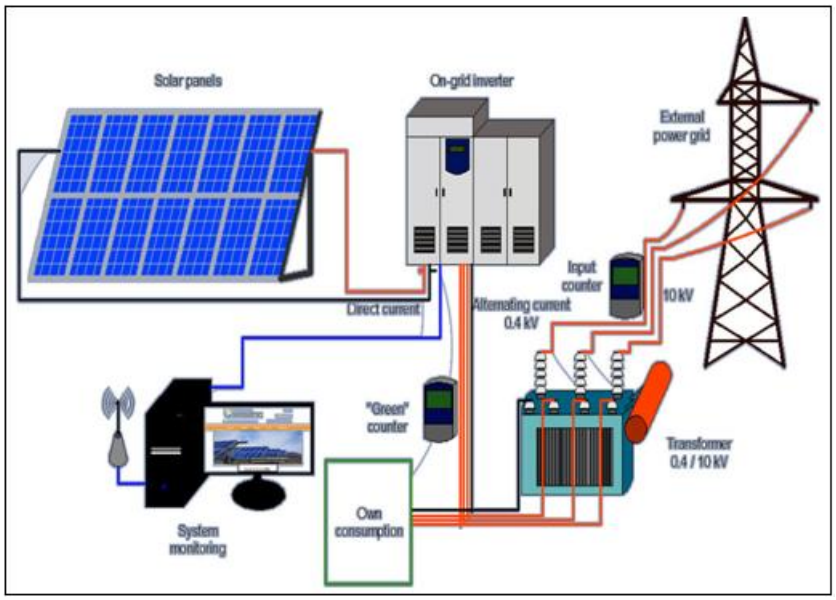


**Figure 1:** Schematic diagram of Solar Power Plant

5) **Deep cycle battery storage:** The solar system requires deep cycle battery storage in order to store the energy generated by solar panels. They are robust and are responsible for charging and discharging cycles.
6) **Solar power system metering:** Having a solar power system metre is an optional component but can help immensely maximise the solar system's efficiency.

### 3.1. Working of Solar Panels

The solar panels are built with silicon cells, metal frames and special wiring. When these panels are grouped and placed on the rooftop, they absorb sunlight and get activated. The solar cells are made up of a positively charged and negatively charged layer. Once the energy strikes a solar cell, it causes electrons and creates an electric current.

Solar panels work on converting sunlight efficiently into electricity. However, the generated electricity is in the DC form, which gets converted into AC easily. The converted electricity will then power all the appliances. The energy will run through the electric panels and distribute to the utilities. A smart electric metre will work on measuring usage and energy generation. The component will quantify the surplus power and send it back when required.

## 4. The Types of Solar Power Plants

The solar power generation process will be in two ways, they are photovoltaic and solar thermal technology.

**Photovoltaic Solar Power Plant:** Also known as PV, the working of a photovoltaic solar power plant involves photovoltaic cells. These panels are made with silicon alloys and are available in different forms. They store the energy in the batteries and can generously convert it from DC to AC. The PV panels produce free electrons once the sunlight hits the semiconductor material. This process is known as the photoelectric effect and is converted to AC from DC with an inverter. The PV panels differ from the solar thermal plant. The solar photovoltaic system working does not focus on energy but instead converts photons into energy.

**Solar Thermal Power Plant:** A solar thermal power plant generates electricity and heat by focusing on the sun's energy. This process builds steam and thereby produces electricity. Solar thermal power plants are subdivided into three types – parabolic trough, linear and solar dish power plant. The heat generated from the solar thermal power plant can be available at commercial and residential properties. Once the heat is absorbed from the sunlight, it is transferred to a fluid that involves air, antifreeze and water. It acts as a great, dependable source within a restricted area. Solar energy is one of the cleanest sources of energy. Renewable energy does not produce any noise pollution or waste and therefore does not impact the environment in any way. The cost of energy production is practically negligible as it does not need any outside supply. Besides the investment to set up a solar power plant, there are no additional costs involved. There is no loss of energy in its distribution. This keeps the performance at its peak. The installation of a solar power plant is easy and versatile. It can be set up almost anywhere. The flexibility of a solar system makes it easy to generate electricity even in remote areas. The energy production is maximum during the day hours, resulting in reduced electricity prices. With one time investment, expect free power for life. Get a return on investment in only three years. It is a most eco-friendly technique for power production.

## 5. Applications & Development of Solar Energy in India

Some major applications of solar energy include[7]:Solar water heating, solar distillation, Solar heating of buildings, Solar pumping, Solar furnaces, Solar greenhouses, Solar cooking, Solar electric power generation, The world's current solar energy capacity is 850.2 GW (giga watts). This is the maximum amount of energy that all global solar installations combined can produce at any one time. This figure has increased every year for the last decade and is more than ten times higher than it was in 2011, according to the latest data from IRENA and Ember[8].

However, it is estimated that up to 173,000 TW (terawatts) of solar energy can hit the Earth at any given moment. So we are still only using a tiny fraction of the energy available to us, which is far more than we are ever likely to need.

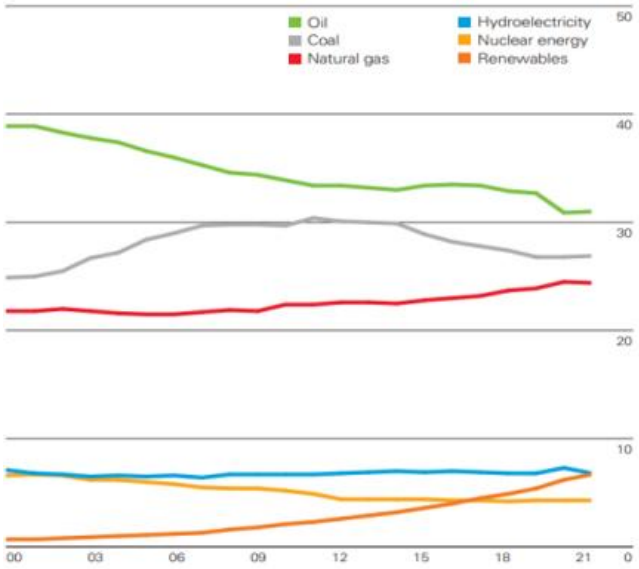


**Figure 2:** Shares of global primary energy (%) world wide

The wide spread solar radiation in India which is about 3,000 hours of sunshine [9]. In FY 2023-24, India is planning to issue 40GW tenders for solar and hybrid projects [10]. India has established nearly 42 solar parks to make land available to the promoters of solar plants[11, 12]. Solar energy is expected to grow to 60 GW by 2030. Going by the succeeding predictions, the solar sector is a lucrative career in India. The international solar alliance (ISA) proposed by India as a founder member and it put forward the concept of "One Sun One World One Grid" and "World Solar bank to harness abundant solar power on a global Scale [13 -15]. Figure 4 shows the progress of primary energies from the year 2000 to 2021. It is observed from the figure that renewable energies are increasing rapidly than other energies.

## 6. Progress of Solar Energy World Wide

Out of total global energy, 4.4% of energy comes from solar power. China generates more solar energy (308.5 GW) than any other country; The US relies on solar for 3.9% of its energy, although this share is increasing rapidly every year.

3.2 million US homes have solar panels installed. 3,975,096 people are employed in the solar industry worldwide, and 263,883 of these are in the United States [16]. The solar energy industry created more new jobs in the US than any other energy subsector last year. It would take around 18.5 billion solar panels to produce enough energy to power the entire US.

The IEA measures China's current capacity at 308.5 GW. The US is next with 123 GW of solar capacity. Japan has 78.2GW. China also installed the most additional solar in 2021, increasing its cumulative capacity by 54.9 GW. This was more than twice the amount added in the US (26.9GW). Although it remains the world's largest emitter of greenhouse gases, this shows that China is clearly taking steps toward satisfying some of its huge energy needs with renewables. The solar energy production figures have also risen over the last decade, in line with capacity. Production is now more than ten times what it was in 2011 as observed in Figure 5 & Figure 6.

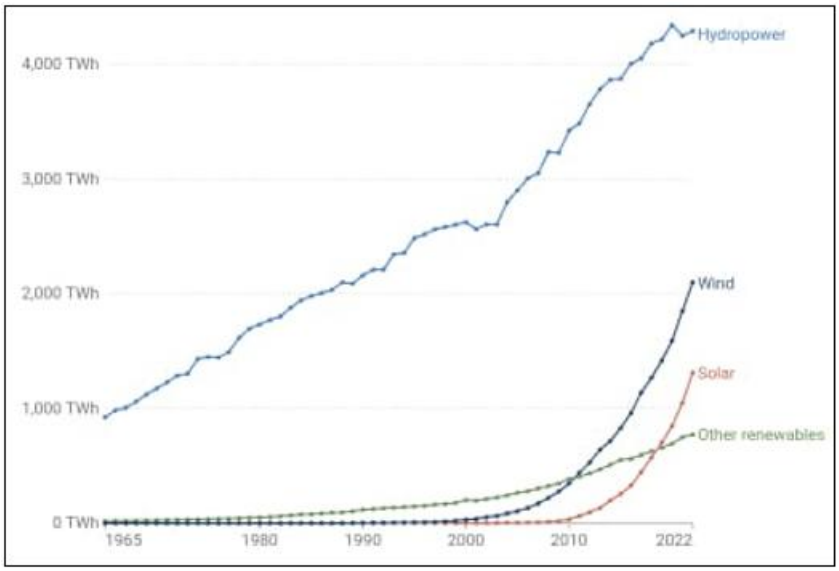


**Figure 3:** Renewable energy Generation World wide

The growth in global power generation was pulled by China (+3.7%), India (+9.7%) and the United States (+3.2%), with significant increases in Indonesia (+7.9%) and Saudi Arabia (+5.9%). The power sector accounts for 58%. This includes growth of renewable power consumption related to electrification (notably electric vehicles and heat pumps). This type of renewables deployment could also be attributed to the end use sectors. In terms of total renewables deployment, the key role of bioenergy (32% incl. district heating) and wind (24%) deserves special attention [17].

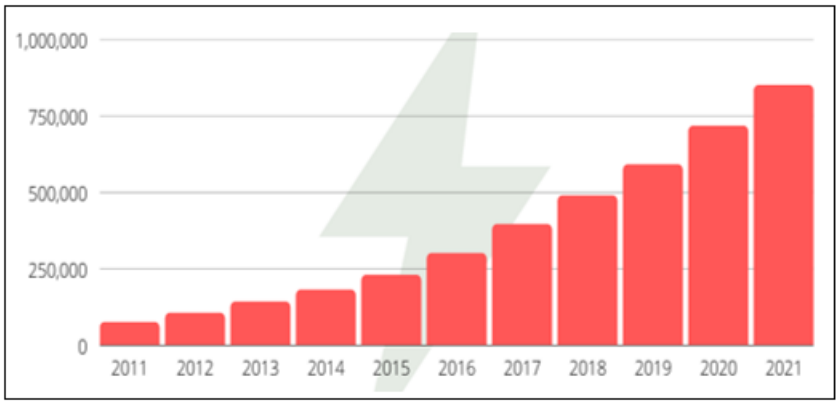


**Figure 4:** Production of Solar Power world wide

Saudi Arabia, Turkmenistan, Hong Kong, Qatar, Oman, Libya, Kuwait, and Bahrain are some of the countries that do not yet use solar power in 2024. Solar PV infrastructure can be expensive to install and has certain logistical considerations. It requires space, connectivity, and enough sunlight to make it a worthwhile investment. However, some countries that don't use solar are not bound by these constraints, yet still continue to source all of their electricity from fossil fuels. Iceland is at 100% renewable power in 2024 and Paraguay, Costa Rica, and Norway are at virtually 100%, using only minute quantities of fossil fuels. These countries get most of their renewable energy from hydro and geothermal. Figure 8 shows the percentage of various types of energy productions sources world wide. It is observed from the figure that Solar energy has occupied 15% of the total energy [18].

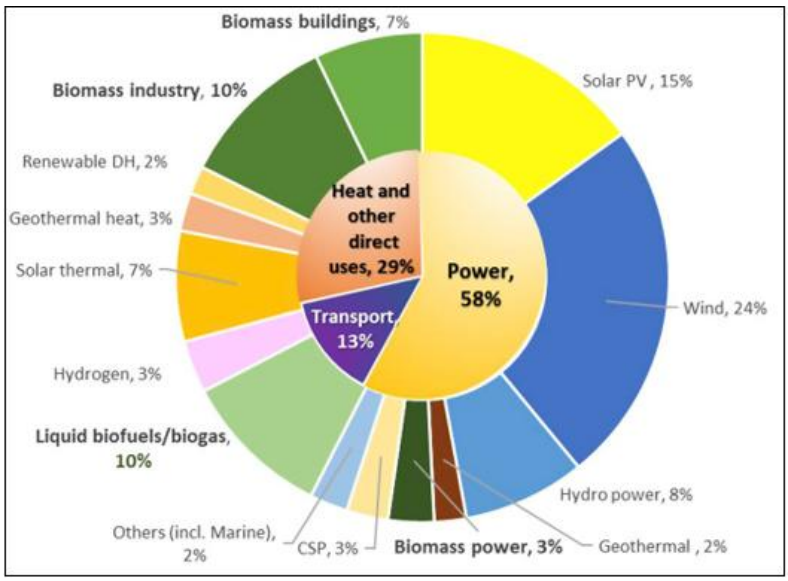


**Figure 8** Percentage of contribution of energies world wide

Bhadla Solar Park in Rajasthan, India is considered to be the world's largest solar plant in 2024 with an estimated installed capacity of 2.25 GW. Huanghe Hydropower Hainan Solar Park in China (2.2 GW) and Pavagada Solar Park in India (2.05 GW) are among the world's top most Solar plant sites, their details were given in Table 1. It is difficult to produce accurate comparisons between the world's biggest solar plants, due to ever-evolving technology and fluctuating capacities, so the list should be considered dynamic.

**Table 1:** The Biggest Solar Power Plants in the World

| Rank | Name | Country | Capacity (GW) |
|---|---|---|---|
| 1 | Bhadla Solar Park | India | 2.25 |
| 2 | Huanghe Hydropower Hainan Solar Park | China | 2.2 |
| 3 | Shakti Sthala Solar Project | India | 2.05 |
| 4 | Benban Solar Park | Egypt | 1.65 |
| 5 | Tengger Desert Solar Park | China | 1.55 |

It is observed from figure 9, that the annual carbon emissions data associated with solar energy are significantly less than those of fossil fuels. According to the latest 2021 Ember Climate data, Coal emitted 8204.6 MT of CO2e, and gas emitted 2973.52 MT. By comparison, solar energy emitted just 49 MT $CO_2$ emissions globally [19]. Renewables have the potential to fulfill all of our energy needs, and the installed capacity of solar and wind is growing year on year. However, fossil fuels remain the largest source of energy globally and that needs to change by 2030 if we are to reach net zero. Solar power is far more efficient than fossil fuels, in terms of the amount of energy it can produce compared to the amount of energy needed to manufacture and construct solar installations. Research published in the journal Nature Energy measures the EROI (Energy Return on Investment) of all major sources of power generation. This data shows how much energy is offset in the manufacture and installation/construction as a percentage of the total energy it can generate over its lifetime. Solar PV installations require

just 4% of their total capacity to produce and install. In other words, for every unit of energy "invested" in solar installations, they can return 26 units. In contrast, a coal-fired power station has an 11% energy offset, even before you factor in the ongoing emissions of actually using it [20].

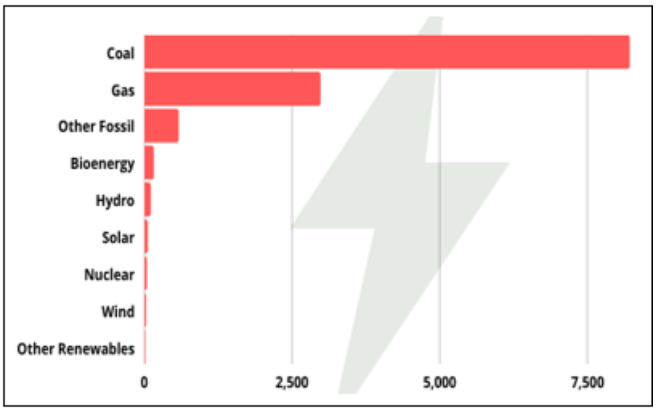


**Figure 9:** $CO_2$ emission in Mega Tonnes (MT)

China is the country with the highest number of solar industry jobs, accounting for 58% of the global total, according to the IRENA database. This is no surprise considering that China is the world's largest solar panel manufacturer, and also has the world's largest solar energy capacity. The United States, Japan, India, and Vietnam offer the next highest number of solar industry employment opportunities.10.3% of workers in the United States solar industry are unionized, which is higher than the national average of 7.4%. This is likely due to the fact that solar installation is a skilled trade that requires training and certification. Solar industry workers enjoy similar or higher wages than workers in similar jobs in other industries. Most jobs in the solar energy sector are related to installation and construction, to satisfy the rising industrial and consumer demand for new solar PV installations as detailed in the statistics above. The employment breakdown is as follows. Installation & Construction - 67%, Manufacturing - 14%, Sales & Distribuition - 11%, Operations & Maintenence - 4%, Other - 4%.

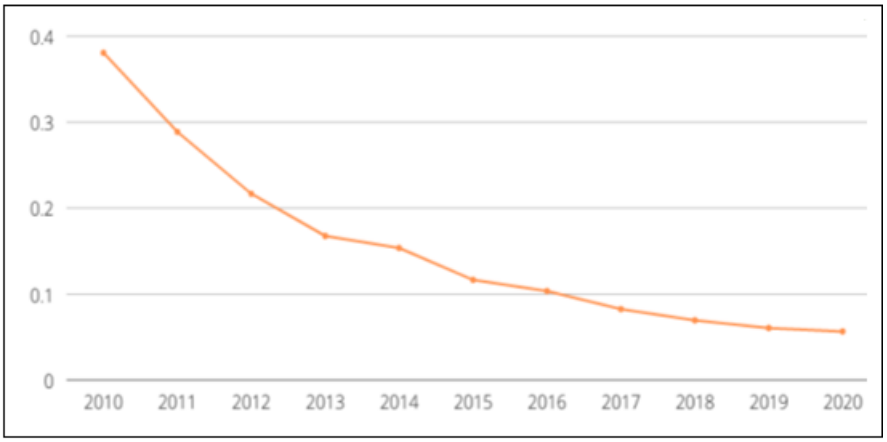


**Figure 10:** Production cost of Solar Power per kWH (in USD)

Under the IEA net-zero scenario, solar PV would need to contribute:

A capacity of 6970 TWh by 2030, Then, a further 630 GW annual capacity additions between 2030 and 2050

Leading to at least 240 million households with rooftop solar PV qnd an overall 88% of global electricity from renewable energy by 2050.

It is still possible that clean energy can power the world by 2050, and if we get there, solar will become the single largest source of electricity globally. However, we would need to spend a lot more money to achieve this. The IEA net zero scenario estimates a worldwide investment of around $4 trillion by 2030 will be required. As well as the obvious environmental benefit, this investment would stimulate economic growth and create new jobs for millions of people. To appreciate the scale of what is required, the IEA estimates that the amount of solar PV we need to add is equivalent to the number of panels in the world's largest solar park - every day. It is observed from figure 10 that the solar energy is now 7 times cheaper to produce than it was just 12 years ago [21].

The price of photovoltaic (PV) modules is a major factor in the cost of solar power. These are generally measured in cost per kWh (kilowatt hour). The LCOE (Levelized Cost of Energy/Electricity) metric is a way to measure different sources of electricity generation, taking into account installation, operating and maintenance costs over a lifetime.

The IRENA database LCOE data clearly shows that the cost of solar is falling rapidly. Those 2010 costs were estimated at $0.381 per kWh, and this had dropped to $0.057 per kWh by 2020, the most recent year for which data is available. Recurring expenses include tracking systems to follow the sun, anti-reflective coating on panels, and electrical components to tie together PV arrays. Solar power is becoming an increasingly popular option for home and business owners due to its many benefits. With solar panels, it is possible to reduce energy costs, make the environment clean, and even make money by selling excess power back to the grid. As solar technology continues to improve and prices drop, these numbers are only going to continue to grow.

## 7. Conclusions

The solar cells absorb the energy from the sunlight and create an electrical energy. Solar energy is one of the cleanest sources of renewable energy which does not produce any noise pollution or waste and therefore does not impact the environment.

It is estimated that up to 173,000 TW (terawatts) of solar energy can hit the Earth at any given moment. So, we are still only using a tiny fraction (850.2 GW (Giga watts)) of the energy available to us.

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**Acknowledgments**
The first author would like to express her sincere thanks to the principal Prof. Chandra Mukherji madam for the kind cooperation and support to taken up this project. The Second author would like to express his sincere thanks to Prof. P. Bala Baskar Sir, Joint Director of Higher Education, Telangana State for his continuous support and encouragement to taken up research activities in Government Degree Colleges. He also expresses his sincere thanks to Prof. K. Padmavathi madam, Principal, Government City College for her encouragement and support to carry out the above project in Physics Department. Both the authors are also expressing their sincere thanks to their Colleagues and family members for their support.

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