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Solar Power Sector in India: Recent Advancement, Challenges, Policies and Future Prospects

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ABSTRACT :

In recent era, the global pursuit of the renewable energy sources has become crucial in order to prevent climatic changes and to ensure sustainable growth. However, India has been observed as one of the leading countries in the use of solar power technologies due to its plentiful sunshine resources and currently achieved remarkable growth driven by the positive market conditions and ambitious government schemes. The solar capacity of India has been exponentially improved achieving considerable goal in both, distributed solar installation as well as utility-scale. Although Indian solar energy system has reflected remarkable progress, but additionally facing few challenging issues such as policy uncertainties, financial constraints, land acquisition hurdles etc. The government's continuous efforts in the field of technological advancements, increasing interests of investors for this sector's growth, declining costs of photovoltaic (PV) solar cells and panels leads promising future of Indian solar power sector. By leveraging its huge solar potential and overcoming challenges, India can be emerged as a global leader in contributing environmental sustainability and economically growth at national as well as global scale. This abstract offer a thorough overview of variation in installation capacity in past years of various states of India and the Indian solar energy market emphasizing the solar sector's growth trajectory, regulatory environment, various policies, emerging challenges and future opportunities.

Keywords: Renewable energy, Solar Power, Environment, Photovoltaic Cell etc.

1. Introduction :

Solar energy can perform an imported role in issue of fossils fuels depletion and global warming [1]. People opinion and analyse using survey studies and determine the present and future prospects related to renewable energy [2]. The aim of this paper is to study about need of solar energy and problem faces in installed solar energy and efficiency of solar energy technology, describes about different-different policies and schemes and data of installed capacity in same states. With the goal of supplying electricity to the nation's population in an economical and effective manner, the Ministry of authority created The National Power Programme, at en-year action plan [3]. In 2022, India produced 175 GW of renewable energy, in which 100 GW received from solar energy [4] which have more installed other than renewable energy. A variety of strategies might be used to lower carbon emissions, which would improve the use of solar energy and spur technical advancement. Three main factors are driving the development of solar energy technologies: reduced CO_2 emissions, economic benefits, and energy security. The total amount of renewable energy in 2017 will reach 100 MW. Seventy-five percent of global CO_2 emissions are attributed to the power system energy production sectors [5]. To promote and improve energy production sources, the Indian government formed the Ministry of New and Renewable Energy (MNRE) [6]. India Every year, 900 GW of renewable energy are generated from a variety of sources, including small hydro (2.2%), wind (12%), solar (83%), and bio-fuel (3%). [7].

In February, 2020 India has total solar energy capacity was 87.67%; in which these states include Tamil Nadu, Gujarat, and Karnataka, among others, include Maharashtra, Rajasthan, and Andhra Pradesh. However, due to a lack of programmes, policies, and regulations to promote renewable energy, a small number of states produce less renewable energy than the rest of the nation. However, due to a lack of programmes, policies, and regulations to promote renewable energy, a small number of states produce less renewable energy than the rest of the nation. Installing solar panels over plants or crops can reduce the heating effect of the panels by maintaining humidity, in addition to giving the plants indirect sunshine and other solar energy benefits [8]. The US has further lowered the cost of electricity in the solar power sector; nevertheless, there are drawbacks to solar technology as well, including effects on buildings, aesthetics, regular and unintentional chemical releases, etc. In past five years, there has been a remarkable surge in the solar photovoltaic business.

2. Growth Trajectory and Solar Energy Market Trends

The market for solar energy is expected to develop at a compound annual growth rate (CAGR) of 28.82% from 1.84 thousand gigawatt in 2024 to 5.08 thousand gigawatt by 2029, based on installed base estimations. Of all renewable technologies, this had the highest absolute generation growth and overtook wind power for the first time in 2022. More than 45% of all investments made in the production of electricity worldwide in 2022 came from solar photovoltaic. The International Energy Agency (IEA) forecasts that the demand for solar PV would increase from 261 GW in 2022 to 800 GW by 2030, assuming that solar PV reaches the Net-Zero Scenario level. India increased its solar PV installations by 40% from 2021 to 18GW in 2022. Due

to a new goal of increasing PV capacity auctioned to 40GW yearly and the rapid expansion of the nearby supply chain, there could be another acceleration of PV growth soon [9]. By 2022, the Jawaharlal Nehru National Solar Mission hopes to have developed and implemented solar energy technology in the nation that will bring it into line with grid electricity rates. The state and federal governments of India have made a major effort to solve the problem of ecologically friendly growth. India's energy security problem, India would also be playing a significant role in the international effort to address the problems brought on by climate change. The National Solar Mission seeks to develop the legal framework required for solar energy's quick adoption across the country, positioning India as a global leader in the field. In the event that anticipated cost reductions do not occur or occur more quickly than anticipated, the goal would be to shield the government from having to pay subsidies. The main target of the mission is to focus on developing a favorable environment for the country's adoption of solar technology, both centrally and decentralically.

The National Solar Mission's primary characteristics are:

1. Make solar energy and the mission of India a global leader envisions installing solar power 20,000 MW by 2022, 1.000 MW by 2030, and 2,000 MW by 2050 is the projected capacity.
2. A total of between Rs.85,000 crore and Rs.105,000 crore is anticipated to be invested during the course of the 30-year timeframe.
3. The goal is to reach installed capacity of 20 gigawatts (GW) by 2020 and tariff parity with conventional grid power between 2017 and 2020.
4. A solar production capacity of 4-5GW deployed by 2017.

For the next five years, solar photovoltaic (PV) is predicted to contribute significantly more yearly capacity to renewable energy sources than wind and hydropower combined. The IEA reports that in 2022, solar PV production by 270 TWh, or 26%, to reach about 1,300 TWh. Of all renewable energy sources, this had the greatest total generation growth and overtook turbines for the first time in 2022. In addition, the world's need for electricity is rising steadily as a result of urbanisation, population expansion, and the electrification of numerous industries, including transportation. To satisfy this rising energy demand, solar PV systems provide a scalable and decentralised alternative, especially in areas with sparse or unstable grid infrastructure. In 2022 saw a record-breaking growth in global solar PV capacity expansion investments of over 20%, topping USD 320 billion. In 2022, solar photovoltaics (PV) accountedforover45% of all global investments in power generation, which is quadruple the amount spent on all fossil fuel technologies put together. PV investment is anticipated to increaseintheupcomingyearsasaresultofaggressivegovernmentgoals,supportive policies, and rising competitiveness. Some significant markets, such as the Chinese market, grew with 100 GW installed PV capacity in 2022, representing about 60% more than in 2021 [10].

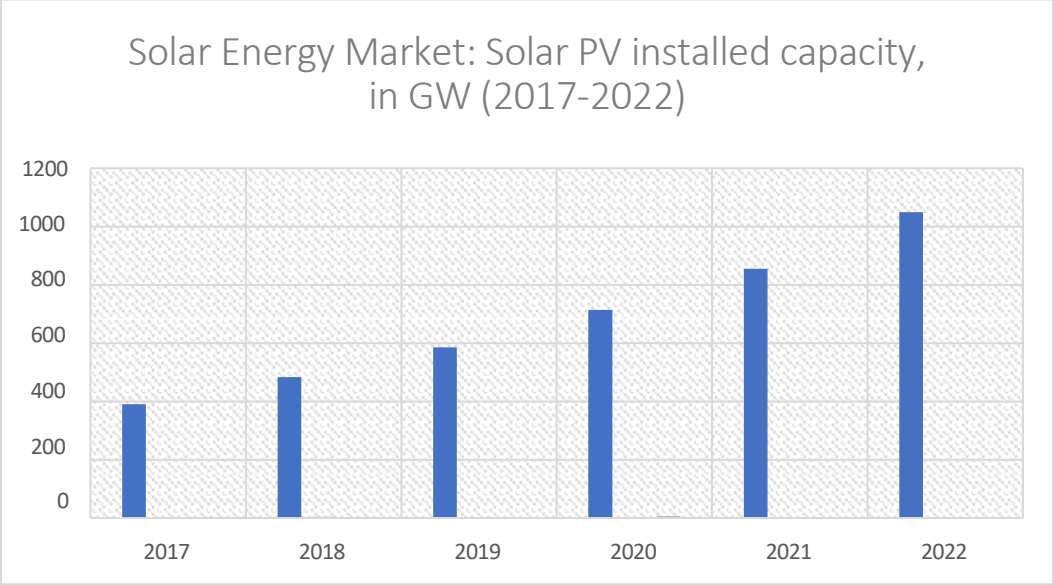

Fig.1. Year-wise (2017-2022) solar power installed capacity (GW) in India.

State-wise Analysis of Different Types of Solar Power Production

In the table 1, Data of some states solar power production in which Rajasthan has the leading ground state 11.82 (GW) and total solar power production is 25% and other states like Gujarat has 14%, Karnataka has 13%, Tamil Nadu has 10%, Telangana has 8%, Andhra Pradesh has 8%, Maharashtra has 5%, Madhya Pradesh has 5%, Uttar Pradesh has 4%, Rest of India has 9% solar power production.

Table 1 - State-wise analysis of different types of solar power production

State	Ground	Roof Top	Solar in Hybrid	Off Grid	Solar Power Total	
	(GW)	**(GW)**			**(GW)**	%
Rajasthan	11.82	0.81	1.38	0.44	14.45	25
Gujarat	5.91	1.92	0.00	0.04	7.87	14
Karnataka	7.28	0.37	0.00	0.03	7.68	13
TamiNadu	5.26	0.37	0.00	0.06	5.69	10
Telangana	4.36	0.26	0.00	0.01	4.62	8
Andhra Pradesh	4.24	0.15	0.00	0.09	4.48	8
Maharashtra	1.74	0.98	0.00	0.05	2.77	5
Madhya Pradesh	2.46	0.21	0.00	0.08	2.75	5
Uttar Pradesh	1.85	0.26	0.00	0.13	2.24	4
Rest of India	2.84	1.75	0.00	0.81	5.40	9
Total	**47.77**	**7.08**	**1.38**	**1.74**	**57.97**	**100**

Year-wise capacity installation of some leading states

The largest state in India, Rajasthan, makes up roughly 10.4% of the country's total land area. There are limits to conventional energy sources like coal. Only two perennial rivers—the Mahi and Chambal—have nearly all of their hydropower potential utilised. There are about 208, 110 square kilometres of desert in Rajasthan. Rajasthan receives the second-highest amount of sun radiation worldwide, according to the US Department of Energy. In India, the State of Rajasthan experiences the highest levels of solar radiation and the lowest average rainfall. It also boasts an abundance of cheap, under utilised desert land. It receives approximately 6-7 kWh/m2/day of solar energy and more than 300–325 bright days annually. Rajasthan has the most potential for solar energy production, however the results are not up to par. In Rajasthan State, there is also a significant discrepancy between supply and demand for solar energy used in agriculture. Therefore, law maker sought to enact such a law to encourage farmers and rural residents to participate in the solar energy programme more quickly [11].

Nowadays the use of electricity is increasing very fast and the demand for it is also increasing very fast. The easiest way to meet our electricity needs is solar energy. Solar energy is also cheaper than other countries. Due to more use of solar energy, it is becoming cheaper and more accessible. And the thing is also that both the state government and central government are giving subsidy due to which solar system in Gujarat more likes the process of getting subsidy on solar panels in Gujarat is going to be very easy [12]. Gujarat government has started a scheme in 2022, the name of the scheme is Surya Shakti Kisan Yojana, Gujarat government allows farmers to install solar panels on their fields and establish their farms. Due to this, farmers get 60% profit on cost [13]. TamilNadu leads in terms of solar power capacity with 1368 MW as of 22 August 2016. The TamilNadu government has decided that work on upto 900 MW will be started by 2023. Out of which the target is to get 40% from Tamil Nadu state, solar power plant on the roof. Yes, this policy is applicable to both utility and consumer [14]. More and more households are benefiting from subsidies for solar panels in Tamil Nadu, taking the country closer to setting its solar target [15]. Government of India is preparing solar panel subsidy only scheme to achieve the target by 2024 in Madhya Pradesh and other state. Its mission is to promote solar energy among all the people living in the state. Madhya Pradesh is moving rapidly in the direction of clean energy.

With government and public cooperation, Madhya Pradesh will emerge as a major center of solar energy in the country in the coming days. The government has prepared the complete roadmap by preparing the Renewable Energy Policy 2022. The government is also exploring the possibilities of installing solar energy in government offices of Madhya Pradesh. MP government has made a plan that the farmers of the state will get free solar pumps. The state electricity distribution corporation had to arrange electricity for those groups or those sections where there was no source of electricity and the MP government had to provide electricity for the production of electricity. One good thing about electricity connection is that in the year 2023, this priority will be given to such farmers where electricity is at least 300 meters away from the farm [16].

Materials & Types of Solar Power

- Monocrystalline-Panel
- Polycrystalline-Panel
- Thin-film Solar Cell

- Amorphous Silicon-Solar Cell
- Biohybrid-Solar Cell
- Cadmium telluride- Solar Cell
- Concentrated PV cell.

Monocrystalline Solar Panel

Solar panel with monocrystalline structure first-generation solar panels is another name for these panels. A monocrystalline solar panel is what it's known as due to the fact that silicon is a monocrystalline material. It looked to be a uniform black colour with rounded white edges. Because it is composed of the purest form of crystalline silicon, it will have a better efficiency than other kinds of solar panels.

- Efficiencyrate-20%
- Greater effectiveness
- Space efficient
- Extended lifespan
- Lower installation cost
- Applications

5.2. Polycrystalline Solar Panel

First-generation solar panels are another name for these panels. A polycrystalline solar panel is what it's known as. due to the fact that it is composed of poly silicon or monocrystalline silicon. It looked to be square solar wafers with a speckled blue appearance. It is made by melting unprocessed silicon, which is a speedier and less expensive process. in order for the efficiency to be less than that of monocrystalline solar panels. It is useful for owners of huge areas because it takes up a lot of room. Typically, polycrystalline photovoltaic components consist of many precious stones connected within a single cell. The battery is manufactured with a very high assembly efficiency by utilising the cooling and hardening technology of the protruding candy cane [17]. With 48% of the world's solar cell manufacturing in 2008, these batteries were the most widely used type, with a performance increase of roughly 12–14%. One example of a poly silicon solar cell that resembles glass is ribbon-shaped silicon [18].

- Rate of efficiency15%
- Less efficient than solar panels using monocrystalline crystals
- Take up a lot of room;
- Have a shorter lifespan;
- Have benefits
- Affordable

5.3. Thin-film Solar Cell

It is primarily utilised in smaller solar power plants and belongs to the second generation of solar panels. You can purchase this solar panel for a very low price if you believe that other solar panels are very costly. However, its primary drawback is that it will yield minimal efficiency. Additionally, there are other benefits like superior flexibility and tolerance to high temperature.

- Efficiency: 7–10%

5.4. Amorphous Silicon Solar-Cell

These solar panel types are primarily seen in pocket calculators. Triple-layered technique is employed, whereby is a great tool for thin-film diversity.

- Rate of efficiency:7–10%
- Affordable
- Composed of inexpensive, readily accessible materials.

5.5. Biohybrid Solar Cell

It is still being researched after being found by the Vanderbilt University expert team. Emulating the natural process of photosynthesis is the primary goal of this research endeavour. The fact that there won't be any power loss during the process of converting solar energy into electrical energy is another fantastic benefit. This solar panel has an extremely short lifespan (a few weeks to nine months).

5.6. Cadmium Telluride Solar Cell

The process uses cadmium telluride to generate cells at a very cheap cost with a pay back time of less than a year, hence the term "cadmium telluride solar cell." more than a year. Its production process uses practically the minimum quantity of water. One significant drawback is that it is poisonous. It is not advised to use for this reason alone.

- Efficiency : 22.1%
- Low cost

- Less water needed for production.

5.7. Concentrated PV Cell

Its efficiency is approximately 41% higher than that of other solar panels. Its mirror surfaces are curved, and lenses that make room for increased effectiveness.

- Rate of efficiency: About 41%
- Extremely high performance;
- Increased efficiency

6. Challenges :

Land Scarcity

Individually, availability of land is a scarce resource in India. Other needs based on land may have to make way for the exclusive use of a particular region of land for the installation of solar cells. The amount of land needed for utility-scale solar power installations, which now require 1 km^2 of land for every 20–60 MW generated, may put an impact on India's land supply.

6.2. Government Support

The Indian government is promoting the usage of solar energy through several projects. . A budget of Rs. 10 billion has been announced by the government for the Jawaharlal Nehru National Solar Mission and the creation of a Clean Energy Fund in the 2010-11 budget plan. Additionally, the budget has boosted private solar enterprises by excising excise duty on solar photovoltaic panels and decreasing customs charge on solar panels by 5%. This is anticipated to result in a 15–20% decrease in the installation of solar panels on roofs [19].

6.3. Environment Related Problem

While solar energy is considered clean and renewable, large-scale solar projects can have environmental impacts such as land degradation and habitat disruption. Proper planning and environmental assessments are necessary to mitigate these impacts.

7. Future Prospects of Solar Energy in India :

This is because solar radiation causes India, a tropical country, to receive 3,000 hours of sunshine annually. The majority of people reside in rural areas, which present numerous opportunities for the advancement of solar energy. India has seen the proposal of numerous large-scale projects, the greatest of which is a solar power plant situated in the country's Thar Desert, capable of producing between 700 and 2,100GW. The Jawaharlal Nehru National Solar Mission (JNNSM) of the Centre aims to produce 20,000 MW of solar energy by 2022. Apart from the previously mentioned, about 66 MW is deployed in rural regions for street lights, lanterns, and solar water pumps, among other applications. The highest potential for solar energy is in Rajasthan. Due to its plentiful solar radiation resources and the existence of the vast and desolate Thar desert, Rajasthan has a potential of approximately 142 GW. More than 60 GW of solar electricity might be generated in Madhya Pradesh; significant amounts of waste land are also available in Maharashtra, Jammu &Kashmir, and other states. Gujarat, the leading Indian state has an estimated 36 GW of potential solar power, making it the highest-capable state in India in terms of installed solar power. Large tracts of marshland can be found throughout the state, however these places also serve as habitat for a wide variety of species. Gujarat has begun developing utility-scale solar power installations on water canals, with an installed capacity of approximately 900 MW. The goal established by the Indian government is to expand solar power capacity by five times. The government now intends to install 100 GW of solar power production by 2022, as opposed to 22 GW.

8. Conclusion :

Annual growth of solar energy in market is 28.82% from 1.84 thousand GW in 2024 to 5.08 thousand GW by 2029. Demand of solar energy increase 261 GW in 2020 to 800 GW by 2030, assuming the solar PV reaches the net zero scenario level. A budget of Rs. 10 billion has announced by the government for the Jawahar Lal Nehru Solar Mission and clean energy fund in 2010-11. In this paper, comparison of distinct types of solar panel has been analyzed. Monocrystalline solar panel is very high efficiency-20%, low cost, higher life span and both use of residential and commercial solar installation. Concentrated PV cell is higher efficient approx 41% but due to higher efficiency a cooling system and solar tracker are absolutely necessary. The JawaharLal Nehru Solar Mission aims to achieve 20,000 MW of solar energy generation by 2022. Compared to India's overall solar capacity of 750 GW, this comprises 20 GW of ultra mega solar power plants distributed across 12 states, each with an installed capacity of 500 MW or more. Rajasthan is one of the major places in India for solar energy production. The role of Rajasthan and its age in this field can be emphasized. However, Gujarat government has done a lot of development in solar energy which can make Gujarat's solar policies successful and bright. Tamil Nadu has also done a lot of development in solar energy. And it is a good sign that the demand for solar power is increasing in Tamil Nadu. Madhya Pradesh has a potential for about 61 GW of solar energy, which the state government is attempting to utilise through significant initiatives and regulations.

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