International Journal of Advanced Multidisciplinary Research
ISSN: 2393-8870
www.ijarm.com
(A Peer Reviewed, Referred, Indexed and Open Access Journal)
DOI: 10.22192/ijamr Volume 10, Issue 5 -2023

Research Article

DOI: http://dx.doi.org/10.22192/ijamr.2023.10.05.007

Development of Solar Power in India: A Comparative Analysis Across Indian States

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Keywords

Energy,
Solar power,
Sustainable
Development goals.

Abstract

Energy plays an essential role in a country's economic development. Solar, Wind, Hydro, and biomass are the primary renewable energy sources. Among the four main energy sources, solar and biomass energy have a comparatively low cost of production. Solar energy meets the demand in many sectors like industries, households, transportation, etc. Solar energy not only meets the energy demand of the people but also, solar energy has a significant impact on the country's socio-economic development. Many developing countries are now trying to use solar energy as an alternative energy source.

India has excellent potential for solar energy due to the favourable atmosphere for solar power. However, the availability of solar power is widely dispersed. In some States like New Delhi and West Bengal, the use of solar energy is insignificant. Solar power is used in various sectors in other states like Gujarat, Rajasthan, Tamil Nadu, Karnataka, etc.

Sustainable Development Goal (SDG 7) ensures access to affordable, reliable, sustainable, and modern energy for all. Under the circumstances, this paper looks into the disparity in the use of solar energy across States in India and tries to understand the reasons behind such an anomaly.

Various studies reveal that decentralized solar energy could improve the standard of living of rural households. Rural electrification through the solar photovoltaic system helps rural people to increase their income by extending the working hours in the evening. This also reduces the expenditure on LPG and Kerosene. Thus, solar power helps economic development in rural and urban areas, reducing carbon emissions and ensuring sustainable development.

In the above light, this paper attempts to study the potential of solar energy across various States in India and the utilization of such potential. It then seeks answers to the disparity in the use of solar energy across States. Also, it attempts to analyse the effectiveness of the policies promulgated by both the Centre and the State. The paper would help to make policy decisions for the greater use of solar energy in the States, thereby leading to more sustainable development for the country.

1. Introduction

In the current global warming situation, as the temperature rises drastically, it provides more devastating power to cyclones and other natural calamities like floods. The requirement for a small and independent solar system will persist in those circumstances. Moreover, renewable energy has the power to reduce carbon emissions. It can also eradicate greenhouse gas emissions, mitigating climate change and providing a clean environment and energy for all future generations (Owusu & Asumadu Sarkodie, 2016). Solar energy will be an excellent opportunity for India to achieve an environment-friendly atmosphere, reduce energy demand on coal, oil, etc., and meet the future energy crisis.

In the above light, this paper attempts to study the potential of solar energy across various States in India and the utilization of such potential. It then seeks answers to the disparity in the use of solar energy across States. Also, it attempts to analyse the effectiveness of the policies promulgated by both the Centre and the State. The paper would help make policy decisions for the greater use of solar energy in the States, thereby leading to more sustainable development for the country.

2. Statement of the Problem

Energy security is one of the vital issues or challenges due to the prevailing energy crisis; energy security depends on the difference between the sources of energy production and energy consumption. Coal contributes more to the creation of thermal electricity. Out of the total thermal output in India, 87.81% comes from coal production, which is an exhaustible resource **(**CEA report Jan 2017**)**. Estimated coal reserves were 315.14 billion tonnes in India in 2017, whereas the addition of coal reserves was 6.34 billion tonnes over the next year **(**Energy Statistics 2018). Total coal production in India rose from 639.23 million tonnes in 2015-16 to 662.79 million tonnes in 2016-17, which increased by about 3.79% from the previous year **(**Indian Bureau of Mines, March 2018). The consumption of coal in India has also increased over the period. Coal consumption in India in 2016-17 was 841.56 million tonnes **(**Energy Statistics 2018**)**. In the above context, fossil fuel availability is gradually diminishing due to increasing demands and a limited supply of fossil fuel in the power-based sector, which creates a gap between energy demands and energy production **(**Kumar Manoj et al., 2018**)**. The dependency on coal or fossil fuels has decreased from the energy mix over the years from a global perspective. The estimated share of the renewable energy mix in total final consumption was 19.3%. In contrast, fossil fuels have 78.4%, and nuclear power has a 2.3% contribution in the shares of total consumption (Renewable Energy Statistics 2017).

Another alarming situation is that per capita energy consumption (PEC) from thermal electricity increased from 631 kWh in 2005-06 to 1,208 kWh in 2019-20. Per capita, energy consumption is the ratio of total energy consumption during a particular year to the estimated mid-year population. As the population increases, per capita energy consumption also increases. In recent decades, an increasing trend of per capita electricity consumption. From 2011-12 to 2019-2020, there was a steady growth in per capita electricity consumption, an increase of 36% in respect of 2011-12.

To overcome the problem of the energy crisis in the future, solar energy will be an additional energy source. In an area without electricity, decentralized solar energy will be a valuable source for rural people. Renewable energy can meet the energy mix policy through the grid network.

3. Relevance of solar energy installation in India

Solar energy can be easily adopted in India as compared to other forms of alternative energy sources, due to various reasons as described below: -

a. Potentiality of solar energy in India

India has excellent potential for solar energy installation due to the favourable atmosphere for solar power installation. The availability of solar energy sources is widely dispersed. In some states, solar energy used is insignificant (for example, Delhi), whereas other States use solar energy at a larger scale. The only constraint of solar power installation is the need for huge space for solar power storage, particularly during the monsoon period.

b. Cost of solar energy

Solar power installation has recently had the highest cost compared to other alternative energy sources. The solar mission aims to reduce costs through technological innovation. However, solar energy has the lowest operation and maintenance costs after installation.

c. Environmental Impact of solar energy

Solar power is environmentally friendly and has zero carbon emissions.

d. Inexhaustibility of solar energy

Solar power is more reliable than other sources for the characteristics of inexhaustible features. Due to the limited supply of coal in the future, there will be an energy supply shortage. Even there will be the chances of import of coal from other countries than internal trade between the countries. This practice will be the possibility of a price hike of coal. In this situation, solar power will be the most alternative in desirable places where solar energy has great potential.

4. Review of Literature

The study covered the current status, prospects, and barriers to adopting solar energy in underdeveloped and developing countries. Som and Pathak (2015) highlight the economic and environmental costs of generating electricity from conventional and non - conventional energy sources with a detailed study and conclusions drawn on the future role of non –conventional energy resources in the Indian energy scenario. The study showed that the costs relating to set up, operating price, and electricity price of conventional energy resources is increasing due to various factors. In contrast, renewable energy resources and the inherent positive impact on environmental and resource conservation issues may be cost-effective. Within another 15 to 30 years, the share of renewable or non –conventional energy delivery systems would rise to become comparable to that of conventional power systems**.** Jain et al. (2016) found that many government policies promote solar energy. However, a gap still exists between the policy measures and the actual scenarios in Chhattisgarh.

Many studies have focused on the current status and political and economic barriers to the mass use of solar power and emphasize suitable policy measures so that solar energy becomes an economically attractive electricity option. (e.g., Sisodia 2015: Manju 2017)

5. Objectives of the Study

The objective of this study is to analyse the potential of solar energy across various States in India and the utilization of such potential as also to look at the projection of growth of solar power in the next ten years in respect of the growth of the previous ten years and to do comparative analysis across the Indian States for the development of solar energy over the years and assess the policy effectiveness of government initiatives across the Indian states and also to look at the targets and achievements of the solar development program in India through the national solar mission by the Government of India in terms of State -wise total installed capacity.

6. Methodology

This study is based on secondary data related to renewable energy sources. It comprises a literature survey of peer-reviewed articles, research papers, government-published documents, the Ministry of New & Renewable

Energy (MNRE), the Central Electricity Authority of India (CEA), etc. These data were collected from secondary sources based on research needs to fulfill the objectives. Excel sheets and suitable charts and diagrams followed from the data set; simple statistical techniques have been used to justify the research objectives. We will interpret the data concisely and most straightforwardly on the ground of tables and diagrams to fulfill the research objectives and find the conclusions executed from the continuous data series over the period.

7. Analysis of Data

7.1. Renewable Energy in India

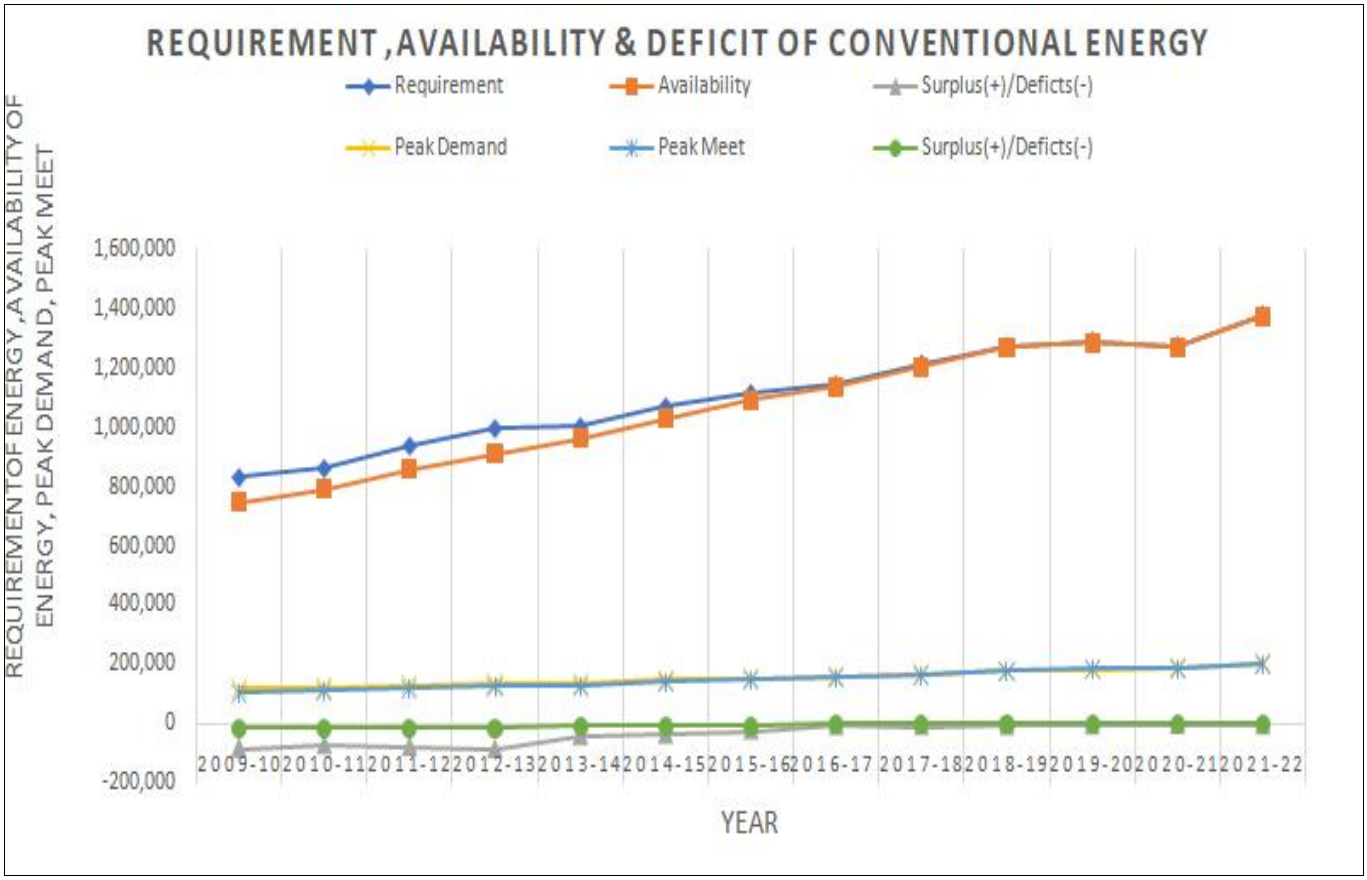
Table 1 indicates the energy and peak, giving the details of energy requirement, energy availability, and power not supplied in a million units (MU) as well as the percentage and peak demand, peak met and not met both in megawatt and percentage. The energy requirement is more than the supply of energy from power stations from 2009-10 to 2021-2022. From 2016-2017 onwards, the requirement of power and supply of power moved on the same path, which means surplus production is diminishing. There is a crude deficit in the production of energy. Peak still needs to fulfil the peak demand also.

Table 1. The power supply position in the country during 2009-10 to 2022-23

	Energy				Peak			
Year	Requirement	Availability	Surplus (+)/Deficits (-)		Peak Demand	Peak Meet	Surplus (+)/Deficits (-)	
(MU)	(MU)	(MU)	MU	%	(MW)	(MW)	MW	%
2009-10	8,30,594	7,46,644	-83,950	-10.1	1,19,166	1,04,009	-15,157	-12.7
2010-11	8,61,591	7,88,355	-73,236	-8.5	1,22,287	1,10,256	-12,031	-9.8
2011-12	9,37,199	8,57,886	-79,313	-8.5	1,30,006	1,16,191	-13,815	-10.6
2012-13	9,95,557	9,08,652	-86,905	-8.7	1,35,453	1,23,294	-12,159	-9
2013-14	10,02,257	9,59,829	-42,428	-4.2	1,35,918	1,29,815	-6,103	-4.5
2014-15	10,68,923	10,30,785	-38,138	-3.6	1,48,166	1,41,160	-7,006	-4.7
2015-16	11,14,408	10,90,850	-23,558	-2.1	1,53,366	1,48,463	-4,903	-3.2
2016-17	11,42,929	11,35,334	-7,595	-0.7	1,59,542	1,56,934	-2,608	-1.6
2017-18	12,13,326	12,04,697	-8,629	-0.7	1,64,066	1,60,752	-3,314	-2
2018-19	12,74,595	12,67,526	-7,070	-0.6	1,77,022	1,75,528	-1,494	-0.8
2019-20	12,91,010	12,84,444	-6,566	-0.5	1,83,804	1,82,533	-1,271	-0.7
2020-21	12,75,534	12,70,663	-4,871	-0.4	1,90,198	1,89,395	-802	-0.4
2021-22	13,79,812	13,74,024	-5,787	-0.4	2,03,014	2,00,539	-2,475	-1.2

Source: CEA (Central Electricity Authority of India)

Fig.1: Requirement, Availability and Deficit of Conventional Energy



Source: CEA (Central Electricity Authority of India)

7.2 Role of Renewable Energy in India

Fig 2 shows the source–wise non-conventional energy resources installed in India in MW between 2016 to 2020. Based on five years (2016 to 2020), the progress of solar power in installed capacity has shown an increasing trend. Solar power in India has been rising mainly since the year 2016. The contribution of wind power to total renewable energy has been continuously decreasing in India. It is noticeable that in 2020 the contribution of wind energy in total renewable energy has been reduced to 34% compared to 2016, with a 57% contribution of wind energy in absolute renewable power. Hydropower is used in hill areas where the turbine generates electricity. Biomass and waste of energy still now have limited use in our country. However, these two are very useful in reducing carbon emissions. Waste to power is the modern concept of energy use by industrial waste, or a substantial waste of municipalities procured to produce electricity.

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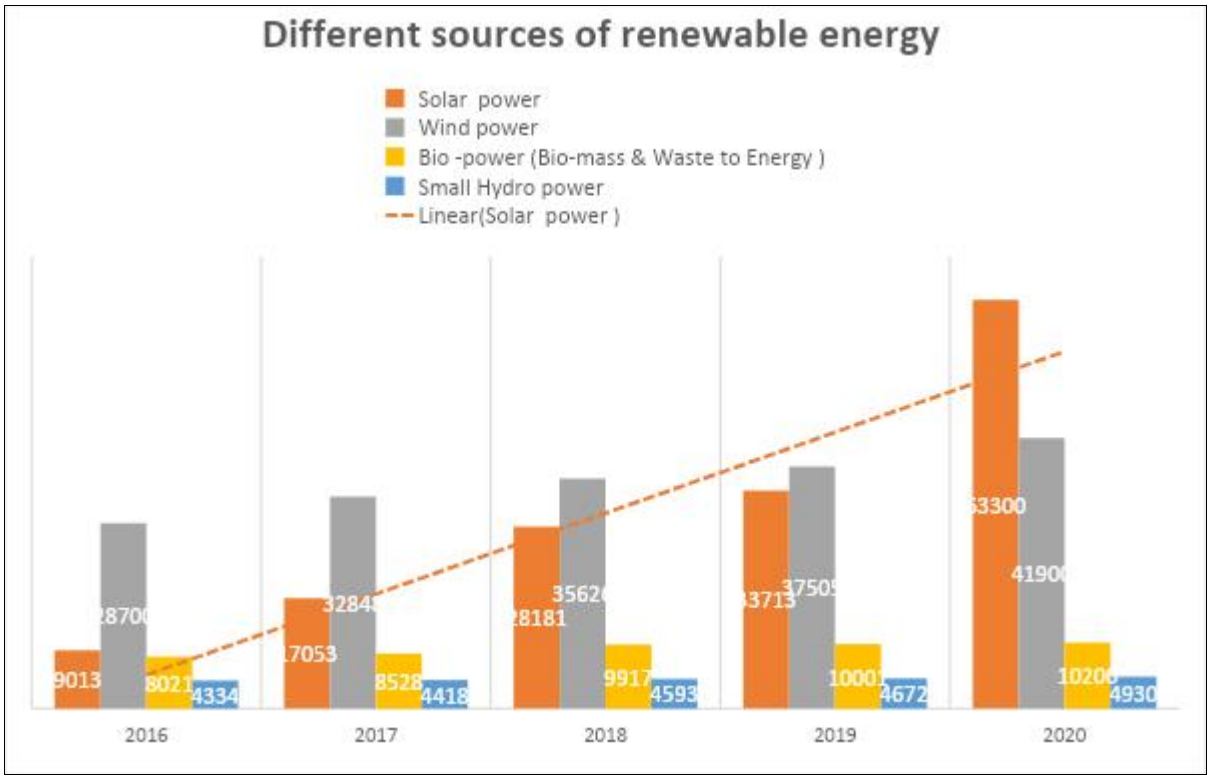
Fig 2: Source–wise installed capacity in India between 2016 to 2020



Source: MNRE (Ministry of New & Renewable Energy) different annual report

7.3 Projection of Growth of Solar Power in 2033 based on the previous 15 years' growth of solar power in India:

Table 2 gives the result of forecasting the growth of solar power in India in 2033. The forecasting for solar development in 2033 will be 85,944 MW. In 2015 the government set the target for solar growth to 100,000 MW. Later in 2019, the government revised the target for solar capacity growth to 300,000 MW. The result indicates that this is far from the target. There is a disparity in solar installation between the states, and many states still need to install solar power regarding the potentiality of solar energy.

Table 2. Projection of Growth of Solar Power in 2033 based on the previous 15 years' growth of solar power in India:

	Year	Solar capacity
	2008	2
	2009	2
	2010	6
	2011	32
	2012	941
	2013	1686
	2014	2632
	2015	4879
	2016	6763
	2017	16612
	2018	21651
	2019	28181
	2020	30175
	2021	35148
	2022	53302
	2023	66780
Forecast:	**2033**	**85944**

Source: MNRE (Ministry of New & Renewable Energy)

7.4. Target & Achievements from solar and Renewable Energy as of December 2022 (in MW):

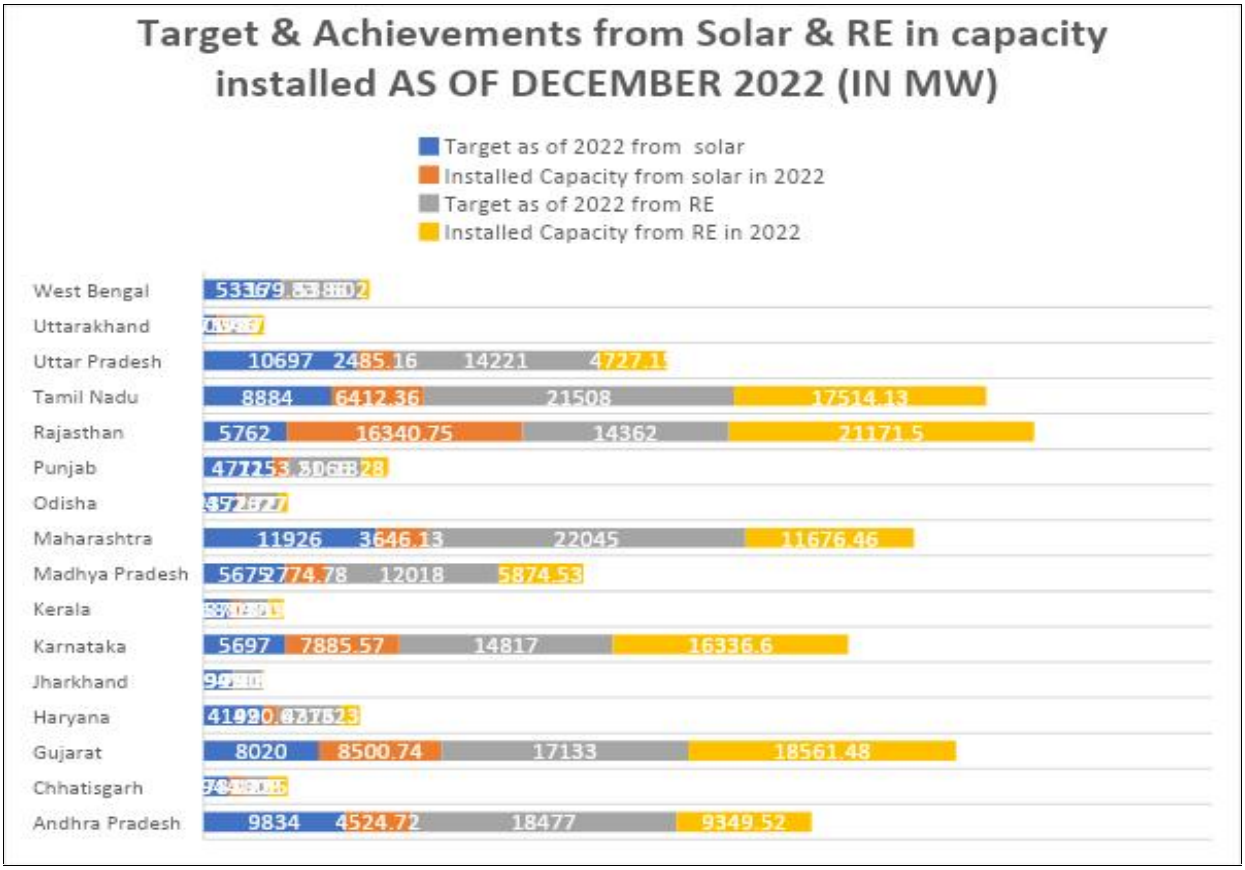
Achievements exceed the target in Rajasthan, Karnataka, and Gujarat in solar and total renewable energy generation. Rajasthan and Gujarat contribute the highest to India's entire renewable energy generation. Rajasthan and Gujarat led India's renewable power generation capacity growth in 2022. Rajasthan has a 77.18 % share of solar energy in the total renewable energy installed capacity as of December 2022. Gujarat has a 45.80% share of solar in total renewable energy installed capacity in the same period. Karnataka also meets the target for solar and renewable energy development. Rajasthan, Gujarat, Tamil Nadu, Uttar Pradesh, Andhra Pradesh, Karnataka, Maharashtra, and Madhya Pradesh concentrate more on solar and renewable energy development than the other states as of December 2022.

Table 3. State-wise Percentage of the progress of Solar power against Targets as of 2022 (in MW)

State	Target from solar 2022	Installed Capacity from solar 2022	% of Progress	Rank
Andhra Pradesh	9834	4524.72	46.01	8
Chhattisgarh	1783	944.22	52.96	6
Gujarat	8020	8500.74	105.99	3
Haryana	4142	990.67	23.92	12
Jharkhand	1995	94.91	4.76	15
Karnataka	5697	7885.57	138.42	2
Kerala	1870	688.35	36.81	9
Madhya Pradesh	5675	2774.78	48.89	7
Maharashtra	11926	3646.13	30.57	10
Odisha	2377	452.72	19.05	14
Punjab	4772	1153.21	24.17	11
Rajasthan	5762	16340.75	283.60	1
Tamil Nadu	8884	6412.36	72.18	4
Uttar Pradesh	10697	2485.16	23.23	13
Uttarakhand	900	575.46	63.94	5
West Bengal	5336	179.83	3.37	16

Source: MNRE

Fig 3. Target & Achievements from solar and Renewable Energy in capacity installed as of December 2022

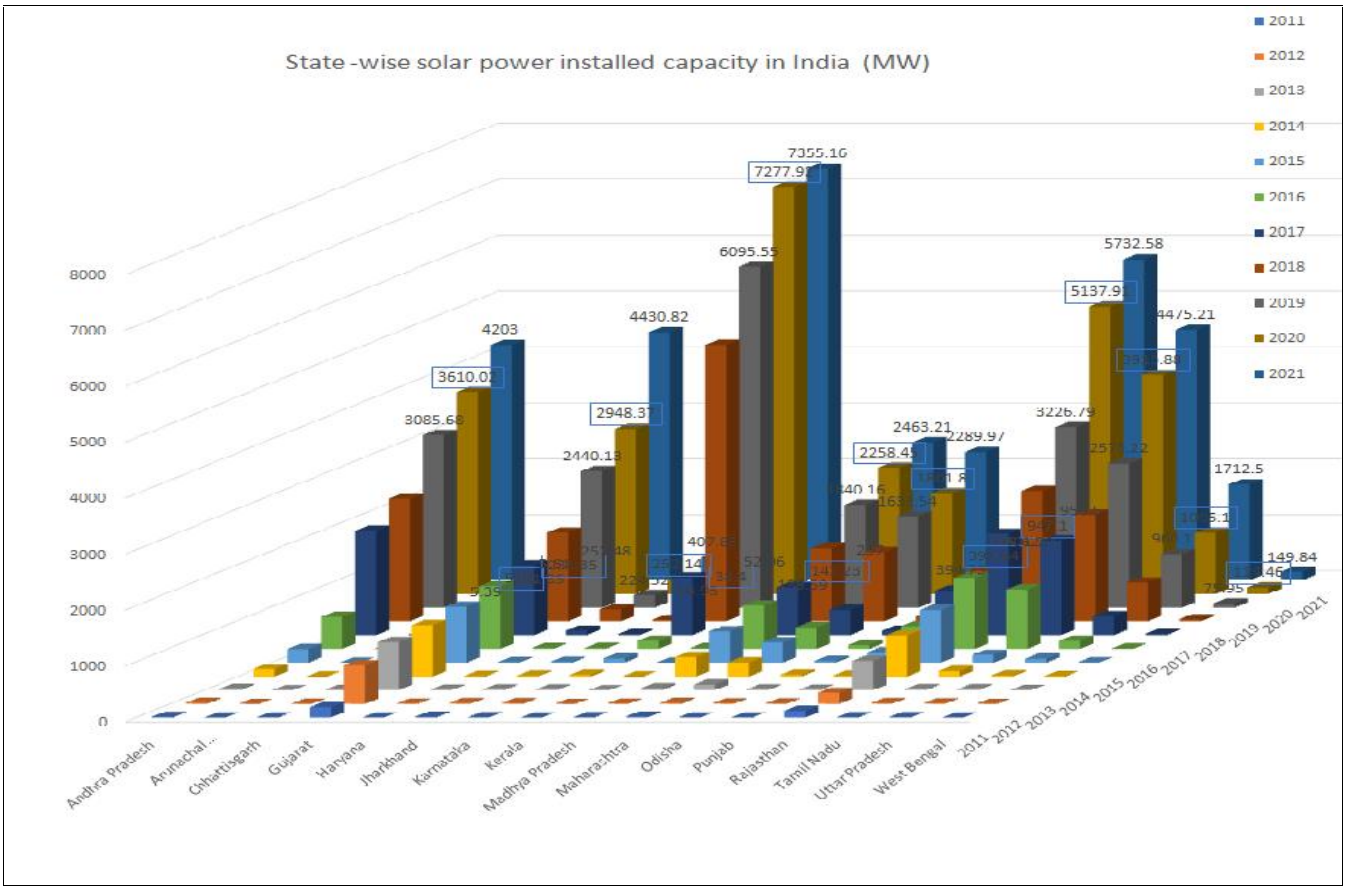


Source: MNRE

8. Comparative analysis of Indian States for solar energy

Fig. 4 shows that Andhra Pradesh had the highest capacity for solar power installation than other states in 2017. Rajasthan had the second-highest ability for solar power installation for that particular year. West Bengal failed to reach the top 10 states for solar energy installation. West Bengal had a negligible contribution compared to other states in solar installed capacity. Every year, the addition of solar energy is a low amount in West Bengal up to 2016, but after 20l6, solar energy installation improved. Rajasthan and Gujarat are ahead in solar power installation after a grid-connected national solar mission announced in 2010 to develop 20,000 MW solar capacity generations through grid appliances within 2022. States like Gujarat, Andhra Pradesh, Rajasthan, Karnataka, and Tamil Nadu have policies to promote solar energy generation from rooftops of residential, commercial, and industrial buildings. Rajasthan and Gujarat are ahead in solar power installation after a grid-connected national solar mission announced in 2010 to develop 20,000 MW solar capacity generations through grid appliances within 2022. In this circumstance, the State Government of Gujarat took the initiative to increase grid-based solar power installation as the state is rich in sunshine and started the project of grid-connected rooftop solar power projects and large-scale projects with the help of the Gujarat Energy Development Agency (GEDA)**,** which is state nodal energy to promote renewable energy.

Fig. 4. State–wise solar power installed capacity in India from 2011 to 2021



Source: MNRE

9. Policy effectiveness of solar energy usage

Rajasthan reached the country's top regarding renewable energy installed capacity in recent years. Rajasthan is a potential solar state in India due to maximum sunshine, dry climate, and deficient average rainfall. The government of Rajasthan formed policies to concentrate on solar and renewable energy power by investing in the largest solar park in the country, encouraging stakeholders to invest in renewable energy development and proposal for several Ultra Mega Renewable Power Projects (UMREPP). The State Government of Gujarat has taken the initiative to increase grid-based solar power installation as the state is rich in sunshine and started the project of grid-connected rooftop solar power projects and large-scale projects with the help of the Gujarat Energy Development Agency (GEDA)**,** which is the state's nodal energy agency to promote renewable energy. Gujarat could be the global hub for the renewable energy sector in the recent 3 to 5 years. The present renewable energy installed capacity is 18561.48 MW. Renewable energy will grow above 38,000 MW by 2025 and over 61,000 MW by 2030—these estimations on the project proposals approved by the Government of India. States like Gujarat, Andhra Pradesh, Rajasthan, Karnataka, and Tamil Nadu have policies to promote solar energy generation from rooftops of residential, commercial, and industrial buildings.

10. State-wise Targets and achievements of the solar development program in India

Prime Minister Dr Manmohan Singh propelled the Jawaharlal Nehru National Solar Mission on the eleventh of January 2010. The mission has set the goal-oriented objective of extending 20,000 MW of grid-connected solar power by 2022 and targets diminishing the expense of sun-based energy in the nation through:

a. long-term policy.
b. The broader scope of arrangement.
c. Progression through further research and development.
d. Domestic creation of necessary crude materials, parts, and items.

It has considered accomplishing grid equality parity by 2022. The grid-connected national solar mission is a great initiative of the Government of India to develop renewable energy. The Jawaharlal Nehru National Solar Mission, established in 2010, helped the state and national initiatives and has led to significant successes in solar power development at both state and federal levels. The mission considers three phases to fulfil the goal of 20,000 MW of grid-connected solar power within 2022. The Jawaharlal Nehru national solar mission (JNNSM) objective is to establish India as the best solar energy practice by creating the policy conditions for its expansion across the country**.** Each Phase is through differing key policies and targets. The progress of solar power in India started after the national solar policy was implemented in India. First Phase (2010-2013), Second Phase (2013-2017), and Third Phase (2017 -2022) in the three phases' targets and achievements set for the development of solar power—the target set for utility grid power, off-grid solar energy, and through solar thermal collectors' applications. After implementing this solar mission, every state, according to the solar potential of the state, set the target to develop solar power, and the state government, with the approval of the Government of India, sanctioned different projects and implemented them according to budget allocation for the states.

Table 4. Grid & Off-grid-connected national solar mission:

Phases	Period	Target (MW)		Achievements (MW)	
		Utility grid	Off-grid	Utility grid	Off-grid
Phase-I	2010-2013	1,000	200	1,044.50	223
Phase-II	2013-2017	10,000	1000	10,604.16	1000
Phase-III	2017-2022	20,000	2,000		

Source: MNRE

Table 4 shows India's state–wise connected national solar mission in Phase –I between 2010 and 2013, Phase –II between 2013 and 2017 and Phase III between 2017 and 2022. The achievements from the solar power installation exceed the target from the solar power installation. In phase 1, the state of Gujarat, Rajasthan, is leading in solar power installation. States like Madhya Pradesh, Haryana, Uttarakhand, West Bengal, Tamil Nadu, Uttar Pradesh, Delhi, and Maharashtra did not significantly affect solar power installation. Table 5 shows India's state–wise grid-connected national solar mission in Phase I. Table 6 shows the State-wise Grid Connected Solar Power Installed Capacity under Phase II (April 2013 to March 2017) (In Megawatts) in India.

Table 5. State –wise grid connected the national solar mission in India in Phase –I (2010-2013)

Sl. No.	State/UT	Installed Capacity (MW)
1	Gujarat	690
2	Rajasthan	198.7
3	Andhra Pradesh	21.8
4	Maharashtra	20
5	Jharkhand	16
6	Tamil Nadu	15.1
7	Karnataka	14
8	Odisha	13
9	Uttar Pradesh	12.4
10	Punjab	9.3
11	Haryana	7.8
12	Madhya Pradesh	7.4
13	Uttarakhand	5.1
14	Others	4.4
15	Chhattisgarh	4
16	Delhi	2.5
17	West Bengal	2.1
18	Lakshadweep	0.8
19	Andaman & Nicobar	0.1
	Total	**1044.5**

Source: MNRE

We observe from Table 5 and Table 6 that there is a difference in the State-wise grid connecting the national solar mission in India in Phase I and Phase II. During Phase I, from 2010 to 2013, Gujarat was leading in solar energy installation, followed by Rajasthan and Andhra Pradesh. However, in Phase II, from 2013 to 2017, the Southern states of Andhra Pradesh, Tamil Nadu, Telangana and Karnataka did exceptionally well in Solar Power Installed Capacity.

Table 6: State-wise grid-connected national solar mission in India in Phase -II (2013-17)

State-wise Grid Connected Solar Power Installed Capacity under Phase II in India (April 2013 to March 2017) (In Megawatt)					
States/UTs	**2013-2014**	**2014-2015**	**2015-2016**	**2016-2017**	**Total**
Andhra Pradesh	108.69	126.77	435.11	1294.26	1964.83
Tamil Nadu	81.76	54.12	919.24	630.01	1685.13
Rajasthan	178.95	228.85	327.83	543	1278.63
Telangana	0	61.25	360.8	759.13	1181.18
Karnataka	17	46.22	68.24	882.38	1013.84
Madhya Pradesh	309.85	205	217.79	80.67	813.31
Punjab	7.52	168.75	219.79	388.89	784.95
Gujarat	58.5	83.65	119.12	130.19	391.46
Maharashtra	149.25	82.23	25.01	66.61	323.1
Uttar Pradesh	3.7	42.16	72.24	193.24	311.34
Uttarakhand	0	0	36.15	192.35	228.5
Chhattisgarh	3.1	0.5	85.98	35.28	124.86
Bihar	0	0	5.1	103.42	108.52
Kerala	0	0	13.02	61.15	74.17
Haryana	2.5	2.5	2.59	66.01	73.6
Odisha	17.5	2.26	35.16	12.5	67.42
Other/MoR/PSU	0	0	58.31	0	58.31
Delhi	2.14	0.32	8.82	25.99	37.27
West Bengal	5	0	0.56	18.37	23.93
Chandigarh	2	2.5	2.31	10.52	17.33
Assam	0	0	0	11.78	11.78
Daman and Diu	0	0	4	6.46	10.46
Jharkhand	0	0	0.19	7.08	7.27
Tripura	0	5	0	0.09	5.09
Dadra and Nagar Haveli	0	0	0	2.97	2.97
Andaman and Nicobar Islands	0	0	0	1.46	1.46
Jammu and Kashmir	0	0	1	0.36	1.36
Himachal Pradesh	0	0	0.2	0.53	0.73
Goa	0	0	0	0.71	0.71
Nagaland	0	0	0	0.5	0.5
Arunachal Pradesh	0	0	0.24	0	0.24
Mizoram	0	0	0.1	0	0.1
Pondicherry	0	0	0	0.05	0.05
Manipur	0	0	0	0.03	0.03
Meghalaya	0	0	0	0.01	0.01
Lakshadweep	0	0	0	0	0
Sikkim	0	0	0	0	0
India	947.46	1112.07	3018.88	5525.75	10604.16

Source: MNRE Annual Report

11. Conclusion

Renewable energy is the best alternative for future generations as fossil fuel reserve decreases and the impact of climate change becomes severe. Through renewable energy, mainly grid-based solar development energy mix to the grid will increase. The renewable purchase obligation (RPO) throughout the country will develop to generate demand for renewable energy. The State Electricity Regulatory Commission (SERCs) is indebted to purchase a certain percentage of power from renewable energy sources. This process will help to overcome the transition phase of a coal-based power system. An off-grid solar system will also be the best alternative for rural areas for drinking, as an energy source, and for agricultural purposes.

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Quick Response Code	Subject: Management
DOI:10.22192/ijamr.2023.10.05.007	

How to cite this article:
Moumita Ghosh and Achiransu Acharyya. (2023). Development of Solar Power in India: A Comparative Analysis Across Indian States. Int. J. Adv. Multidiscip. Res. 10(5): 63-75.
DOI: http://dx.doi.org/10.22192/ijamr.2023.10.05.007