INTERNATIONAL JOURNAL OF RESEARCH AND SCIENTIFIC INNOVATION (IJRSI)
ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VI June 2026

Solar Energy Deployment and India's Sustainable Energy Transition: A Technical Assessment

Kajal[1], Sonia[2] and Dr. Rajesh[3]

[1,2]Research Scholar, Department of Economics, MDU Rohtak

[3]Associate Professor, Department of Economics, MDU Rohtak

DOI: https://doi.org/10.51244/IJRSI.2026.1306000328

Received: 21 June 2026; Accepted: 26 June 2026; Published: 09 July 2026

ABSTRACT

Solar energy has emerged as one of the most important renewable resources for achieving sustainable development. Solar energy offers a clean, abundant, and environmentally responsible solution to growing global energy demands. This shows increasing importance of solar energy in sustainable development strategies. Among the renewable sources, solar energy is leading in India both in terms of installed capacity and electricity generation from the source. Given this increasing importance of solar energy in India's energy mix, it become necessity to study how efficiently solar energy systems convert available inputs into useful energy outputs. The study uses Principal Component Analysis (PCA) for some selected states. The states have been selected based on their performance in terms of installed solar capacity, showing leadership in renewable energy adoption and infrastructure development. Nine states are selected in the study from different regions based on their highest installed capacity in the specific regions. From the northern region Rajasthan and Uttar Pradesh are selected as they possess highest installed capacity for solar in the region. From the western region Gujarat, Madhya Pradesh and Maharashtra are selected. From the southern region Tamil Nadu, Karnataka and Andhra Pradesh are selected. From the eastern region only Odisha was selected. From north-eastern region no state is selected as they lack behind in installed capacity of solar energy. The study is based on three specific indicators such as solar installed capacity, plant load factor (PLF) and electricity generation from solar energy sources. PCA is applied in the study to generate specific composite score for each state and rank them based on those composite scores. These rankings shows how each state is performing and which factor is mainly responsible for its performance. Secondary data is used in the study compiled from different sources, such as Ministry of New and Renewable Energy (MNRE), NITI Aayog Energy Dashboard and Central Electricity Authority (CEA). The results of the study shows that solar performance among selected states are primarily driven by electricity generation from solar energy and Installed capacity. The PLF variable in PC1 shows relatively moderating loading, showing lower contribution to solar development. But in PC2 primarily driven variable is PLF, showing operational efficiency of solar power plants. The composite solar index scores of different states shows that Rajasthan ranks first with composite score of 2.70, showing it performs best in terms of solar energy among the selected states. The performance attributed to its high installed capacity, significant electricity generation and high PLF, even supported by favourable solar potential. Karnataka ranked second with the composite score of 1.01 showing its good performance followed by Andhra Pradesh and Tamil Nadu.

Keywords: Renewable sources, Solar energy, Sustainable Development, Installed Capacity, State Performance

INTRODUCTION

The Brundtland Report, Our Common Future, presented one of the first and most important definitions of sustainable development. It highlights the balance between environmental preservation, economic development, and intergenerational equality.

Sustainable development means type of development that satisfies the demands of current generation without compromising the ability of future generation to satiate their own. (Brundtland, 1987). A significant element of sustainable development is the supply of sufficient and stable energy services at reasonable prices. That should be in a safe, environmentally friendly manner, and in harmony with the need of social and economic development.

(Cîrstea et.al 2018). The widespread search for sustainable and renewable energy has been growing due to concerns about climate change, environmental deterioration, and the depletion of fossil fuel resources. The expanding energy needs of India's growing population further highlight the significance of adopting sustainable energy solutions.

Conventional energy sources such as coal, oil, and natural gas have historically helped industrial and economic development. In world's energy mix they play a major role. However, their use has contributed remarkably to greenhouse gas emissions and environmental degradation. As these resources are rapidly depleting, necessitating research on sustainable and alternative sources of energy. (Pourasl et.al 2023). Many nations are now putting efforts for transitioning toward cleaner energy systems in order to achieve long-term energy security and lower greenhouse gas emissions. The principal motive for supporting renewable energy is to lower down reliance on fossil fuels. This has a positive influence on the growth of energy and also diminish ecological imbalance. (Saxena et.al 2024). Expansion potential of different renewable energy varies across states. In general, hydropower, tidal and geothermal energy faces higher environmental deterioration effects, whereas solar and wind faces less obstacles. (Song et al. 2026).

Among the available renewable energy sources options, solar power has become one of the most promising and rapidly expanding technologies due to its abundant availability, declining installation costs, and minimal environmental impact. India, with its extensive geographical area and tremendous solar irradiation levels, possesses notable potential for the development and large-scale deployment of solar energy technologies. Recognizing this potential, the government has initiated several policy initiatives such as the National Solar Mission boost the adoption of cleaner energy. These initiatives aim to boost solar power generation capacity, and reduce the country's dependence on conventional sources.

The shift toward sustainable energy systems is not merely a technological shift but it encompasses several aspects related to economic, environmental, and policy dimensions. Solar energy technologies, incorporates photovoltaic systems and solar thermal applications. They play a significant role in underpinning the development of green technology infrastructure while contributing to sustainable economic growth. However, the execution of solar power projects also shows several techno-analytical barriers such as efficiency optimization, cost-effectiveness, grid integration, and long-term sustainability assessment.

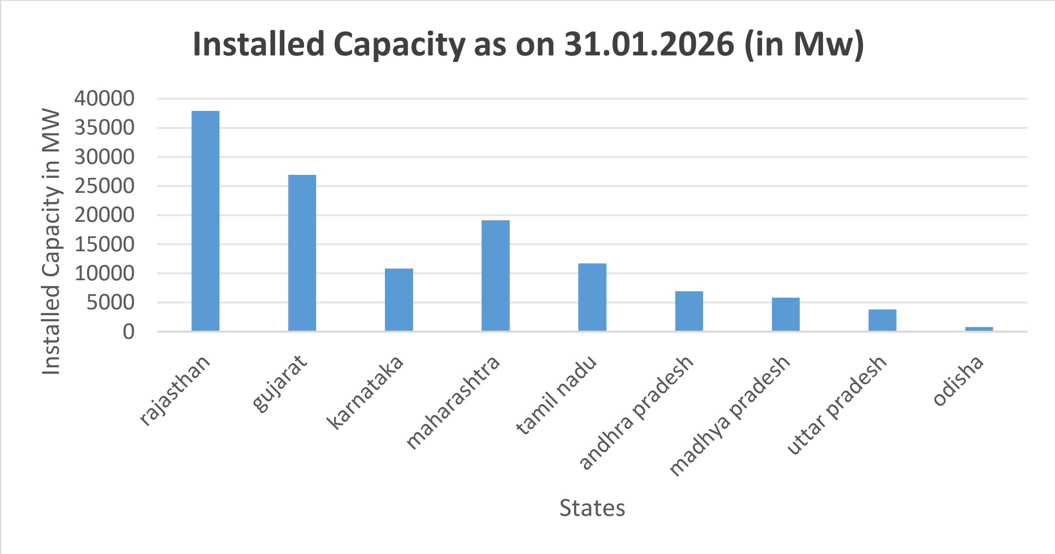
In this context, a comprehensive comparative analysis of solar power development among states becomes crucial to comprehend its effectiveness in facilitating India's sustainable energy transition. This study therefore compares the performance of some selected states based on the indicators installed capacity, electricity generation and PLF. The performance of selected states are compared by using Principal Component Analysis (PCA). To assess the purpose of solar power in accelerating green technology development in India. The research provides insights into how solar power can contribute to completing sustainable energy goals while supporting India's transition toward a low-carbon and environmentally resilient energy system.

Overview of India's solar energy sector:

The graph below shows installed solar energy capacity of some selected states in India. It shows that Rajasthan had the highest solar energy installed capacity followed by Gujarat and Karnataka. Odisha had lowest solar installed capacity in the selected states. The solar installed capacity of Rajasthan as on 31.01.2026 was 37.9 GW , followed by Gujarat 26.9 GW, Maharashtra 19.1 GW,Karnataka 10.8 GW and Odisha only 0.77 GW. The disparity in solar installed capacity is due to numerous reason. The most significant cause behind this is their geographical loaction. As climatic conditions and solar radiation differ from place to place. In addition, the growth of solar power plants also effected by government policies, land availability, grid infrastructure, and investment capacity.

Figure 1: Installed Solar Installed Capacity in MW as on 31.01.2026

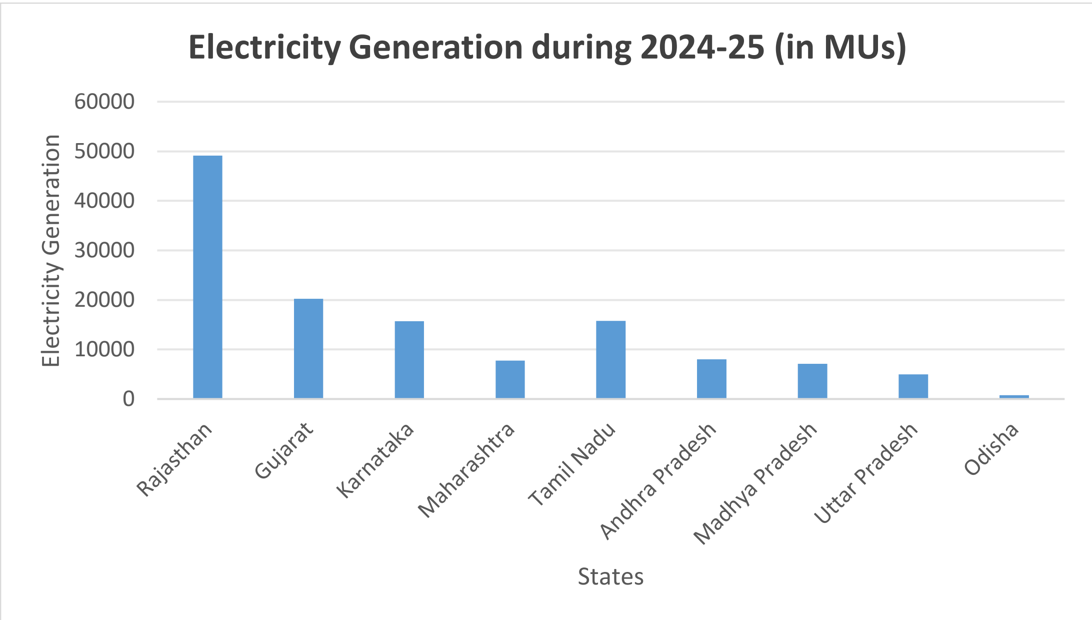
ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VI June 2026



Source: MNRE

The graph below shows electricity generation from solar energy for different states in 2024-25. The electricity generation from solar energy in Rajasthan was highest, 49101.6 MU followed by Gujarat 20219.5 MU, Tamil Nadu 15739.3 MU. Rajasthan possesses the highest installed power generation capacity among the selected states, followed by Gujarat, Maharashtra, and Tamil Nadu. Although having a relatively large installed capacity, Maharashtra lags behind when it comes to converting this installed capacity to real electricity output. This reveals that having larger installed capacity doesn't guarantee higher electricity generation from the source. It is also influenced by a few additional elements.

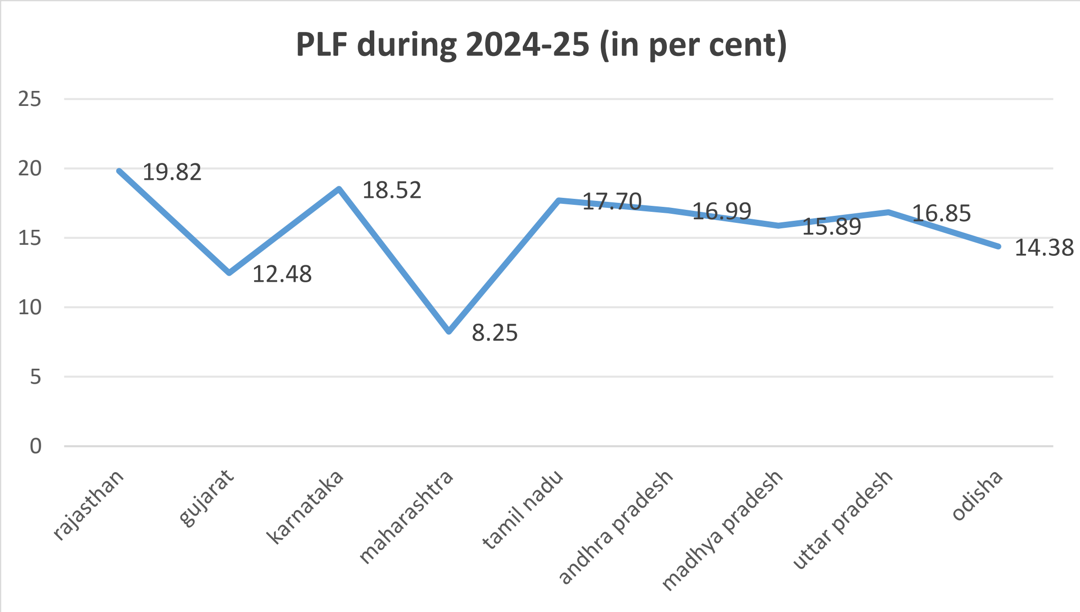
Figure 2: Electricity Generation from Solar Power during 2024-25 (in MUs)



Source: Renewable Energy Statistics 2024-25

The graph below shows Plant Load Factor of solar power plants for different states in India during 2024-25. Pl ant Load Factor shows the efficiency with which potential power generation converted into actual power gener ation.The data revealed that during the period plant load factor of Rajasthan was highest 19.82 per cent followe d by Karnataka 18.52 per cent and Tamil Nadu 17.7 per cent. The plant load factor of Andhra Prades was 16.99 per cent followed by Uttar Pradesh 16.85 per cent, Madhya Pradesh 15.89 per cent and Odisha 14.38 per cent. The plant load factor of Maharashtra was 8.25 per cent during 2024-25 lowest in the group.

Fig. 3 PLF of Solar Power Plants during 2024-25 (in per cent)



Source: NITI Aayog India Climate and Energy Dashboad

METHODOLOGY

The study is based on secondary data. Data is collected from different reliable sources, Ministry of New and Renewable Energy website, its annual reports and from NITI Aayog energy dashboard. The data obtained for last six years were carefully compiled and analyzed for the purpose of the study. Principal Component Analysis is applied in the study to assess the productivity of the chosen states. PCA is a statistical method used to generate composite score. These scores are further used for ranking them. The study is based on three indicators installed capacity of solar energy, electricity generation from solar energy, and plant load factor (PLF). For the analysis the study selected nine states, two from northern region, three each from western region and southern region and one from eastern region. The states are selected from each region based on their highest installed capacity. India is classified into five regions, Northern region, Western region, Southern region, Eastern region and North-Eastern region. States are selected from all regions, except North- Eastern region. From the Northern region Rajasthan and Uttar Pradesh were selected as they possess highest installed capacity for solar in the region. From the Western region Gujarat, Madhya Pradesh and Maharashtra were selected. From the Southern region Tamil Nadu, Karnataka and Andhra Pradesh were selected. From the eastern region only Odisha was selected. From North- Eastern region no state was selected as they lack behind in installed capacity of solar energy. Two states are selected from Northern region, three are selected from Western region and Southern region each, only one state is selected from eastern region and no selected from North- Eastern region. As solar potential in North-Eastern region was much lower as compared to other region. Therefore, including north- eastern region would not provide any meaningful comparison.

RESULTS AND DISCUSSION

The study used PCA (Principal Component Analysis) to construct a single measure that is used to compare the overall performance of selected states. In this analysis data is complied from multiple sources. For the analysis Excel and R software are used. For PCA, using the data mean and standard deviation of each indicator is calcul ated. Using these values Z score is calculated for each indicator, each state and for all time period. These Z sco res are further used to draw a correlation matrix. After that eigenvalues and component loading matrix are cons tructed which is further used to construct solar index scores. Based on these solar index scores states are ranked on their overall solar performance.

Table 1: Principal Components Eigenvalues and Variance

Component	Eigenvalue	Variance (%)	Cumulative (%)
PC1	2.17	72.2	72.2
PC2	0.82	27.23	99.43
PC3	0.017	0.57	100

The table above shows that PC1 has the highest eigenvalue and explains 72.2 per cent of total variance. This reveals that majority of information is explained by PC1. This means PC1 catches majority of information contained in the chosen indicators, installed solar capacity, electricity generation from solar energy and solar PLF. As a result, PC1 is considered as dominant factor that reveals the performance of solar energy among the selected states.

The PC2 has an eigenvalue of 0.82 and it explains only 27.23 per cent of total variance. Its variance shows that it explains some additional information, but its explanation power is significantly lower than that of PC1.

The PC3 has lowest eigenvalue of 0.017 and it explains only 0.57 per cent of total variance. This shows that its contribution is negligible in explaining the dataset.

The eigenvalues of PC1, PC2 and PC3 are 2.17, 0.82 and 0.017 respectively. By applying kaiser criterion, PC1 is retained for further analysis. Kaiser criterion states that, only those principal components should be selected whose eigenvalues are greater than 1, as only those components are considered significant. In the results only PC1 has eigenvalue greater than 1, as a result only PC1 is retained for further analysis . It confirms that a single component is enough to explain the variation in the indicators.

Component Loading Matrix

Table 2: Component Loading Matrix

Indicator	PC1	PC2	PC3
Installed Capacity	0.63	-0.40	-0.67
Electricity Generation	0.67	-0.15	0.73
PLF	0.39	0.90	-0.17

The table above shows loading on PC1, PC2 and PC3. The data reveals that PC1 shows strong positive loading of installed capacity and electricity generation indicators. This shows that solar energy performance among the selected states are majorly driven by installed capacity and electricity generation from the source. The PC1 shows relatively moderate loading for PLF, showing lower contribution to solar development. Although, in PC2 primarily driven variable is PLF, showing operational efficiency of solar power plants.

Ranking of states:

Table 3: States Ranking:

State	Score	Rank
Rajasthan	2.70	1
Karnataka	1.01	2
Andhra Pradesh	0.10	3

Tamil Nadu	0.07	4
Gujarat	0.016	5
Madhya Pradesh	-0.63	6
Maharashtra	-0.915	7
Uttar Pradesh	-0.96	8
Odisha	-1.39	9

The table above reveals, composite solar index scores and rankings of selected states. The composite solar index scores are computed for selected states by using Principal Component Analysis. Rajasthan ranks first with the composite solar index score of 2.70. It shows that Rajasthan performs best in terms of solar energy among the selected states. Rajasthan's performance is attributed to its high installed capacity, significant electricity generation from solar energy and high PLF. This performance was even supported by favourable geographical location and huge solar potential.

Karnataka ranked second among the selected state with the composite solar index score of 1.01. Andhra Pradesh and Tamil Nadu ranked third and fourth with the composite solar index score of 0.10 and 0.07 respectively, showing states performed well. Gujarat ranked fifth among the selected states with the composite solar index score of 0.015. This composite score reveals that even after considerable solar installed capacity and electricity generation its operational efficiency is not as high as leading states. Maharashtra and Madhya Pradesh ranked sixth and seventh with composite solar index scores of -0.63 and -0.91 respectievly. Odisha ranked last among the selected states that its solar energy development and utilization are comparatively limited among the states considered in the study.

CONCLUSION

The study reveals the regional differences in solar energy development across India. To reveal this regional difference some states are selected in the study. The states are selected from different regions. States are selected from all regions, except North- Eastern region. From the Northern region Rajasthan and Uttar Pradesh were selected as they possess highest installed capacity for solar in the region. From the Western region Gujarat, Madhya Pradesh and Maharashtra were selected. From the Southern region Tamil Nadu, Karnataka and Andhra Pradesh were selected. From the eastern region only Odisha was selected. From North- Eastern region no state was selected as they lack behind in installed capacity of solar energy. PCA is used in the study, to draw composite solar index scores, it was used to calculate the rank to oversee the performance of states. PCA is used on three indicators, installed solar capacity, electricity generation from solar energy and PLF of solar. The study conclude that Rajasthan, Karnataka, Andhra Pradesh and Tamil Nadu emerged as leaders in solar energy development. This performance was supported by high solar installed capacity, substantial electricity generation and effective plant operation. States like Odisha, Uttar Pradesh, Maharashtra and Madhya Pradesh lag behind, as they are not performing well. This indicates states like Odisha, Uttar Pradesh, Maharashtra and Madhya Pradesh needs policy support, better utilization of capacity, and infrastructural improvements. The study demonstrates that installed capacity alone does not guarantee higher electricity generation, and efficiency also play an significant role in overall performance.

REFERENCES

1. Brundtland, G. Our Common Future; Report of the World Commission on Sustainable Development; United Nations: Geneva, Switzerland, 1987.
2. Cîrstea, S. D., Moldovan-Teselios, C., Cîrstea, A., Turcu, A. C., & Darab, C. P. (2018). Evaluating renewable energy sustainability by composite index. Sustainability, 10(3). https://doi.org/10.3390/su10030811

3. Kharesaxena, A., Saxena, S., & Sudhakar, K. (2024). Solar Energy Policy for India: An Overview. CSEE Journal of Power and Energy Systems, 10(6), 2308–2320. https://doi.org/10.17775/CSEEJPES.2020.03080
4. Kumbhar, S. R., Satpute, S. T., & Patil, Y. S. (2026). Harnessing green power: A comprehensive analysis of India's renewable energy growth and future outlook. Next Energy, 10(December 2025), 100493. https://doi.org/10.1016/j.nxener.2025.100493
5. Gambhir, A., & Dixit, S. (2025). Pathway to a Renewable Energy-centric Energy Transition. Economic and Political Weekly, 60(2), 70–77.
6. Pourasl, H. H., Barenji, R. V., & Khojastehnezhad, V. M. (2023). Solar energy status in the world: A comprehensive review. Energy Reports, 10(July 2022), 3474–3493. https://doi.org/10.1016/j.egyr.2023.10.022
7. Roy, S., Shibly, S. A., Tonmoy, F. A. T., & Chowdhury, S. (2025). Tracking India's rise in renewable energy: Capacity, composition and comparisons. World Journal of Advanced Research and Reviews, 26(3), 400–409. https://doi.org/10.30574/wjarr.2025.26.3.2157
8. Karimi, K., & Karimi, A. F. (2025). The economic impacts of renewable energy adoption: A comparative analysis of developed and developing nations. Journal of Social Science, 2(1), 32–46. https://doi.org/10.59613/xfwkz407.
9. Kumar, A., Kumar, K., Kaushik, N., Sharma, S., & Mishra, S. (2010). Renewable energy in India: Current status and future potentials. Renewable and Sustainable Energy Reviews, 14, 2434–2442. https://doi.org/10.1016/j.rser.2010.04.003.
10. Kharesaxena, A., Saxena, S., & Sudhakar, K. (2024). Solar Energy Policy for India: An Overview. CSEE Journal of Power and Energy Systems, 10(6), 2308–2320. https://doi.org/10.17775/CSEEJPES.2020.03080.
11. Singh, K., & Jana, S. K. (2025). Renewable Energy Development and Its Key Determinants in Leading Indian States. International Journal of Innovative Research in Engineering and Management, 12(6), 136–142. https://doi.org/10.55524/ijirem.2025.12.6.24
12. Kaewkhunok, S. (2019). Solar energy expansion and the lesson from India and China. Int. J. Sustainable Society, 11(1), 1–12.
13. Song, R., Yin, F., Muller, J., Povey, A. C., Swain, B., Huang, C., & Grainger, R. G. (2026). Coal plants persist as a large barrier to the global solar energy transition. Nature Sustainability. https://doi.org/10.1038/s41893-026-01836-5