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An Empirical Analysis of Off-Grid Solar Energy Adoption in Uttar Pradesh, Bihar, Rajasthan, and Chhattisgarh (2018-2023)

Dr. Ashutosh Chandra Dwivedi*, & Nikita Jaiswal**

***Professor Sri JNM PG College Lucknow**
****Research Scholar***

ABSTRACT

This study presents an empirical analysis of the Off-Grid and Decentralized Solar PV Application Programme under India's National Solar Mission (NSM), focusing on four rural states—Uttar Pradesh, Bihar, Rajasthan, and Chhattisgarh—from 2018 to 2023. The research examines trends in the installation of solar home lights, solar lamps, solar street lights, solar pumps, and solar power plants, utilizing both cumulative and annual data sourced from the Ministry of New and Renewable Energy (MNRE). The study employs a combination of bar and line charts, regression analysis, and a linear regression model to evaluate growth patterns and forecast future trends in solar energy adoption. The findings reveal substantial progress in Uttar Pradesh and Bihar for solar lamp and streetlight while Rajasthan outperforms other states in terms of the capacity of the solar power plant. However, growth slows down in Bihar and Chhattisgarh signifying the need to have state-specific policies to spur the solar industry.

KEYWORDS

National Solar Mission, Solar energy, SDG 7, Off grid Solar PV applications, Energy Poverty, Sustainable development, renewable energy.

INTRODUCTION

India has a potential to thrive on solar energy because it is located in a tropical zone. The government of India takes special interest to encourage the use of renewable energy in the country. India has launched many schemes, policies and initiatives to promote solar energy usage. The schemes which promote the use of solar energy are PM-KUSUM (Pradhan Mantri Kisan Urja Suraksha evam Utthaan Mahabhiyan), Saubhagya Scheme (Pradhan Mantri Sahaj Bijli Har Ghar Yojana), Rooftop Solar Programme (Phase-II), PM Surya Ghar: Muft Bijli Yojana, Atal Jyoti Yojana (AJAY). The PM-KUSUM scheme was launched in 2019 with an objective to encourages the use of solar energy for irrigation by giving farmers with solar pumps and establishing solar power plants on agricultural property. Its aim is to reduce dependency on grid electricity and diesel for agricultural irrigation. The Saubhagya Scheme came in 2017 with an objective to provide electricity to every household, particularly in rural and disadvantaged areas, including off-grid solar options for remote areas. The Rooftop Solar Programme (phase-II) was launched in 2019 with an aim to encourage rooftop solar projects in residential and commercial structures, with a goal of 40 GW from rooftop solar by 2022 also provided financial incentives for installation including up to 40% subsidies for residential customers and reduced incentives for bigger installations. The PM Surya Ghar: Muft Bijli Yojana came up in February 15 2024 aims to encourage rooftop solar installations, provides subsidies to homeowners who install solar systems of more than 3 kW. It makes the application procedure easier and encourages widespread use of solar energy. The Atal Jyoti Yojana (AJAY) was launched in 2016 with an aim to install Solar Street lights in rural, semi-urban, and metropolitan regions, with a focus on states with low electrification rates.

There were some major policies which needs to mentioned because these policies provide a long-term framework for solar energy development, including strategic goals, incentives, and regulations. These are more comprehensive and serve as the foundation for subsequent schemes and initiatives. The major one is National Solar Mission also known as Jawaharlal Nehru National Solar Mission (JNNSM). This policy was launched in 2010 and it is a part of National Action Plan on Climate change (NAPCC). NSM aims to make India a global leader in solar energy by deploying large-scale solar projects. The first target was to install 20 GW by 2022, which was then increased to 100 GW (40 GW from rooftop solar and 60 GW from large/medium-scale solar projects).It is one of the most major projects launched by the Indian government to achieve the dual objectives of energy security and sustainable development, ultimately contributing to global climate change mitigation efforts. The mission is divided into three 10-year phases, with targets set based on prior phases' success and advancements in solar energy technology. The Phase 1 (2010-2013) aimed to deliver 1100 MW of grid-connected solar power and 200 MW for off-grid applications, with the majority of projects delivered on time. In Phase 2 (2013–2017), the aims were raised to 4000-10,000 MW of grid-connected power, with a greater emphasis on rooftop installations and off-grid solutions. This phase includes included 25 solar parks and mega-solar projects. The Phase 3 (2017-2022) has set an ambitious target of 100,000 MW for grid-connected capacity and 2000 MW for off-grid installations, reflecting India's intensified push for solar energy adoption. This mission is based on the fundamental objectives of Affordable, Reliable, and Clean energy for all, corresponding to the SDG 7 of UN Sustainable Development Goals.

As Shrimali et al. (2012) recognized JNNSM as one of India's most important solar energy policies. They conclude that even though the policy's objective and methodology could be ambitious, it still has the power to drastically alter billions of people's lives nationwide. The JNNSM has implemented a variety of schemes and policies to meet the targets of increasing solar power. The idea of solar cities was first proposed by the MNRE with guidance from the Indian government. About 10% of the anticipated demand for currently used conventional energy sources is what these solar cities hope to reduce. (Raina & Sinha, 2019). Along with the creation of solar cities, solar parks are also being developed. These will be built in areas with a solar capacity greater than 500 MW, with the government providing the necessary funding to build the required infrastructure. (Suman et al 2018). The International Solar Alliance was an innovative initiative taken by the government under this mission. The ISA was launched in 2015 during COP21 Jointly by India and France. The objective is to build a partnership of nations with abundant solar energy resources that desired to advance solar technology, especially in poor nations, and increase the use of solar energy worldwide .The target set by the ISA is to raise $1 trillion in investment to help member nations increase their solar capacity by 2030.The Off grid and decentralised solar pv application programme was also a part NSM and it was launched in 2010and it aims to offer solar power options, such as solar lanterns, street lights, solar home lighting systems, and solar pumps for irrigation and drinking water, to places where grid electricity is unstable or nonexistent. Under this programme, millions of solar lights, pumps, and house lighting systems have been installed. In this research paper we are going to study this particular programme in detail. If we talk above the achievements of National Solar Mission, as on 31 March 2023, India had achieved a total installed solar capacity of 70.10 GW, which is a remarkable increase compared to the previous year. This progress is achieved due to various factors, the successful implementation of government schemes, the growing interest of private investors, and advancement in solar technology. The rooftop solar programme has witnessed substantial growth, with the total installed capacity reaching 13.89 GW as on 31 March 2023.

OFF-GRID AND DECENTRALIZED SOLAR PV APPLICATION PROGRAMME

The Off-Grid and Decentralized Solar PV Application Programme is one of the major components of India's National Solar Mission (NSM), which focuses on meeting the energy demands of the rural and remote regions that cannot avail grid connectivity. The primary objective of the program is to create sustainable, independent decentralized energy system using solar energy and decrease the use of conventional energy sources and enhance the standard of living in these underserved regions. Its focus aligns with India's broader commitment to achieving climate goals and Sustainable Development Goal (SDG) 7: Affordable and Clean Energy, through the use of clean, renewable resources of energy.

The Off-Grid & Decentralized Solar PV Programme is aimed at rural area electrification since they don't have access to electricity or have low quality supply from the grid. It encourages the application of diversified solar technologies like solar home lighting systems, irrigation through solar pumps, solar street lighting, and small power projects for energy needs. These solar technologies contribute not only to offer the reliable electricity, but also to enhance people's safety, education and health and increase the productive capacity within the agricultural sectors in rural areas of developing countries. For example, Solar Home Systems supply which are healthier and cheaper than the kerosene lamps which are dangerous to use in the home and in the streets. Solar pumps, for their part, help to promote efficient agriculture as it keeps out farmers from diesel or grid-electric pumping methodologies lowering operational expenses. Solar street lights provide improved illumination to public areas at night making it possible to carry out economic and social activities in rural regions. Solar packs are also used to provide energy to small scale solar power stations that can supply energy to rural facilities such as schools, health facilities, and businesses for development of the local economies.

To make such technologies popular and acceptable by the public, there are financial incentives and subsidies from the MNRE that makes solar energy solutions attainable by the rural communities. Various schemes under this program entitle the public to subsidies for acquisition costs of installations and funds for maintenance and staff training. Manufacturing, distribution, and maintenance of these solar systems also involves public-private partnerships to guarantee the sustainability of such systems in the rural settings.

However, in the Off-Grid Solar PV Programme there are still challenges that need to be addressed. Most rural homes never get to know of such advantages, and the upfront cost can be extremely expensive even with subsidy. it is also very important to ensure that people get aware of such a service and its benefits while better financing can help increase the amount of people willing to use such a service. Ongoing maintenance of solar systems in remote areas is also an inconvenience so there must be reinforcement and support locally to achieve recurring success in the long-run. Secondly, this has been a result of poor implementation across the states that has resulted in differential outcomes because some institutions in some states may be stronger than others.

The Off-Grid and Decentralized Solar PV Application Programme is a testimony to the achievement of SDG 7 through enhanced access to electricity from renewable sources in remote places. It assists in eradicating energy poverty, improves people's lives because it replaces kerosene lighting, and boost economic growth at the local level. Although a number of challenges persist, this scheme is a significant component of the government of India's ongoing efforts toward achieving its vision of 'one nation, one grid, one price' and providing affordable and clean energy to the country's rural population and toward helping the country achieve its renewable energy targets.

LITERATURE REVIEW

Mubarak Musa Umar, Praveen Kumar Yadaw (2024): The Jawaharlal Nehru National Solar Mission was launched in 2010 and seeks to add 22 000 MW of solar power projects through utility scale and decentralized systems. Till date, India has achieved this target and far gone ahead with cumulative solar installed capacity touching 63000 MW till August 2023 with an annual overgrowth rate of 18% over last five financial years. Nevertheless, the current engineering solar resources in India are roughly around 750 GW stressing on the fact that there is ample of more resources yet to be tapped. These views suggest that for India to continue with the expansion of its installed solar energy capacity, policy and regulation should be improved, private sector encouraged, and more funds allocated to research. Further, the issues connected with integration into the power grid, energy storage, and the financial structure will play a significant role in the development of the solar industry in the future.

Rafia Zaman, Stefan Borsky (2021): This paper explores the effects of market concentration on the increased uptake of solar home system within the rural off-grid markets in Bangladesh. Analyzing the data from 4.11 million solar home systems in 503 markets, during 2003-2017, it reveals that the increase in market concentration decreases both the installed number of SHSs and installed capacity. It is evident that this impact is highly significant in concentrated markets, although it also alters according to system dimensions and customer segments. It points out that the market structure can inform policy for rural electrification.

Ajay Kumar et al. (2018): This paper presents an index on the developments of solar energy in India particularly on the Jawaharlal Nehru National Solar Mission (JNNSM). Solar energy, tariff and incentives involve government related support programs, funding and subsidies, which are described for the analysis of the tariff policies. Also, the paper indicates how the future targets are being achieved through establishment of park of solar and rooftop systems enhanced through the net metering principle. In addition, several existing examples of success stories are described to show how potential solar energy resources have been maximally used in India.

Rajesh H. Acharya, Anver C. Sadath (2019): Energy poverty, defined as the unavailability and unaffordability of modern energy services to a population, remains a major hurdle to economic growth in the developing world with India being no exception. The study shows that energy poverty is still a big issue in India, and there is a strong regional variation in the results A general positive trend is clear, but larger and less developed states are lagging behind. Overall, there is a negative correlation between economic development and energy poverty, and education plays a bigger part in reducing the energy poverty than income does. The study reveals higher energy poverty for Dalits and Adivasis population and rural area has more energy poverty than urban area.

Gautam Raina, Sunanda Sinha (2019): Solar energy has a huge underlying potential for providing clean power for India, which has a bad habit of over relying on conventional energy sources that pollutes the environment. This paper looks at the provisions that have been made in order to encourage the use of solar energy as well as the factors that have contributed to the challenges in generation of solar electricity. It also offers some market information on the photovoltaic (PV) opportunities in India and identifies key entities in the solar industry. These efforts place India within inventor of the renewable energy revolution era.

OBJECTIVES

1. To analyze the trends in the installation of solar home lights, solar lamps, solar street lights, solar pumps, and solar power plants under the Off-Grid and Decentralized Solar PV Application Programme in Uttar Pradesh, Bihar, Rajasthan, and Chhattisgarh from 2018 to 2023.
2. To assess the effectiveness of solar energy initiatives in rural states of India through a trend analysis and linear regression model applied to cumulative and annual data.

RESEARCH METHODOLOGY AND DATA ANALYSIS

This empirical research focuses on the Off-Grid and Decentralized Solar PV Application Programme under the National Solar Mission (NSM), analyzing data from four rural states of India. These states include Uttar Pradesh (UP), Bihar, Rajasthan, and Chhattisgarh. The study incorporates five variables: solar home lights, solar lamps, solar street lights, solar pumps and solar power plants. The data has been taken from annual reports published by Ministry of New Renewable Energy (MNRE) from the year 2018 to 2023. Both the annual data and the cumulative data is used to achieve the goal of offering relatively broader insights.
To conduct the analysis on the annual data, variable-wise approach was used for purposes of making observations and trends to be evidenced and this was done through the use of bar charts. Additionally, a trend analysis was employed in order to derive at the long-term increase, decrease or stability of solar installations in the chosen states. For the cumulative data, line charts were used and trendlines and equations were included for the installation progression. The trendlines along with their equations were obtained using regression analysis, for which a linear regression model was used to forecast future trends and analyze the solar energy growth trends.

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Below is the data of five variables. It is shown in variable wise for better understanding.

Table: 1 (VARIABLE 1: SOLAR HOME LIGHT)

Solar Home Light Installations (Nos)								
Year	**Uttar Pradesh**		**Bihar**		**Rajasthan**		**Chhattisgarh**	
	Annual	**Cumulative**	**Annual**	**Cumulative**	**Annual**	**Cumulative**	**Annual**	**Cumulative**
2018-19	0	0	0	0	0	0	34478	34478
2019-20	0	0	0	0	0	0		34478
2020-21	0	0	0	0	0	0	0	34478
2021-22	0	0	0	0	0	0	0	34478
2022-23	0	0	0	0	0	0	0	34478

Table: 2 (VARIABLE 2: SOLAR LAMP)

Solar Lamp Installations (Nos)								
Year	**Uttar Pradesh**		**Bihar**		**Rajasthan**		**Chhattisgarh**	
	Annual	**Cumulative**	**Annual**	**Cumulative**	**Annual**	**Cumulative**	**Annual**	**Cumulative**
2018-19	**1055096**	**1055096**	**759915**	**759915**	**0**	**0**	**0**	**0**
2019-20	**947692**	**2002788**	**467184**	**1227099**	**0**	**0**	**0**	**0**
2020-21	**16282**	**2019070**	**0**	**1227099**	**0**	**0**	**0**	**0**
2021-22	**1685**	**2020755**	**0**	**1227099**	**0**	**0**	**0**	**0**
2022-23	**0**	**2020755**	**0**	**1227099**	**0**	**0**	**0**	**0**

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Table: 3 (VARIABLE 3: SOLAR STREET LIGHT)

Solar Street Light Installations (Nos)								
Year	Uttar Pradesh		Bihar		Rajasthan		Chhattisgarh	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
2018-19	16629	16629	12603	12603	0	0	0	0
2019-20	5316	21945	4610	17213	262	262	0	0
2020-21	10450	32395	7600	24813	0	262	750	750
2021-22	4689	37084	3207	28020	1167	1429	243	993
2022-23	4571	41655	1716	29736	265	1694	89	1082

Table: 4 (VARIABLE 4: SOLAR PUMP)

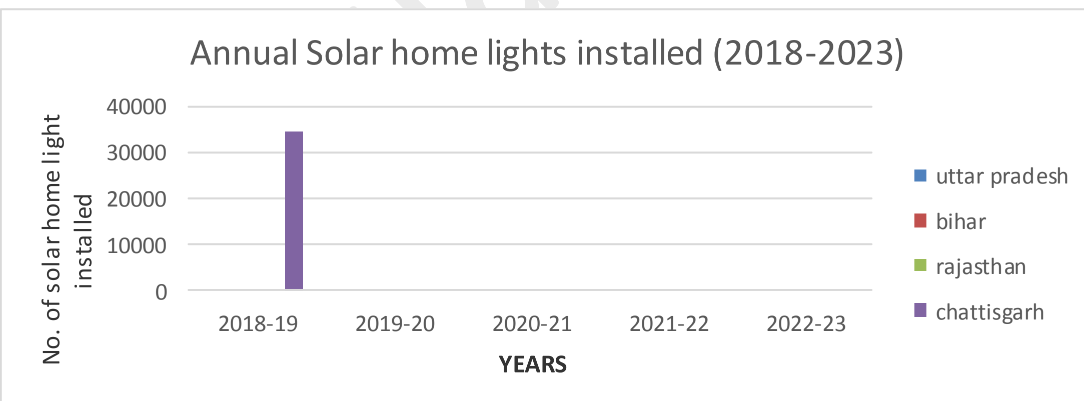
Solar Pump Installations (Nos)								
Year	Uttar Pradesh		Bihar		Rajasthan		Chhattisgarh	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
2018-19	8382	8382	225	225	7134	7134	22095	22095
2019-20	81	8463	706	931	0	7134		22095
2020-21	950	9413	0	931	5248	12382	0	22095
2021-22	3679	13092	0	931	16446	28828	0	22095
2022-23	5931	19023	0	931	31870	60698	57312	79407

Table: 5 (VARIABLE 5: SOLAR POWER PLANT)

Solar Power Plant(Kw)								
Year	Uttar Pradesh		Bihar		Rajasthan		Chhattisgarh	
	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative	Annual	Cumulative
2018-19	0	0	2601.4	2601.4	19499	19499	1019	1019
2019-20		0		2601.4		19499		1019
2020-21	0	0	30	2631.4	0	19499	0	1019
2021-22	0	0	105	2736.4	0	19499	0	1019
2022-23	0	0	0	2736.4	0	19499	0	1019

DATA ANALYSIS

Chart: 1 - Variable 1 Solar home lights



NOTE: Data from Table No. 1

Chhattisgarh is one of the states which has reported solar home light installations particularly in 2018-19 where 34,478 units were installed. However, there was no data reported for Chhattisgarh for the year 2019-20 while no installation was reported in any other state during the year. During the period 2020-21 to 2022-23, no installations of solar home lights has been made in any one of the four states, including Chhattisgarh. This may imply that though Chhattisgarh was quite active in

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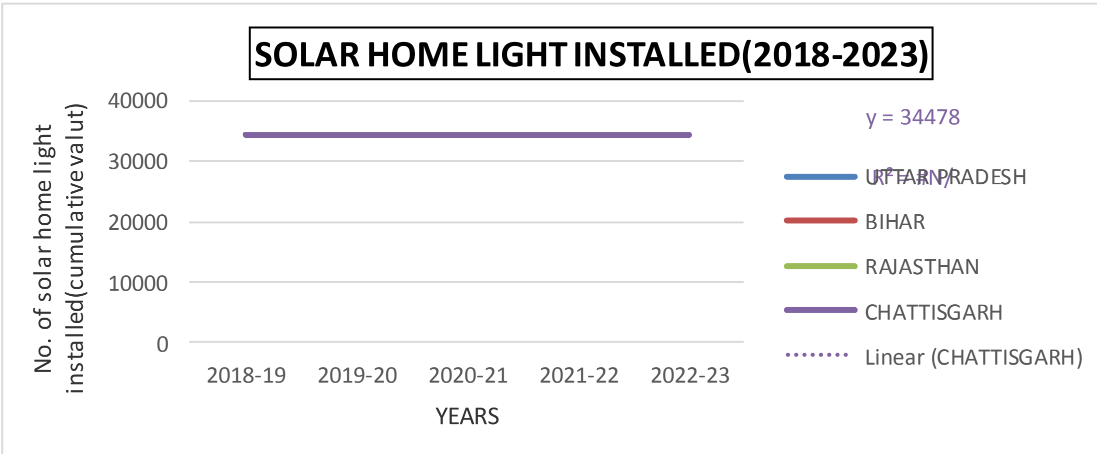
2018-2019. In fact the states of Uttar Pradesh, Bihar and Rajasthan have shown no improvement as to the installation of solar home lights over the last five years.

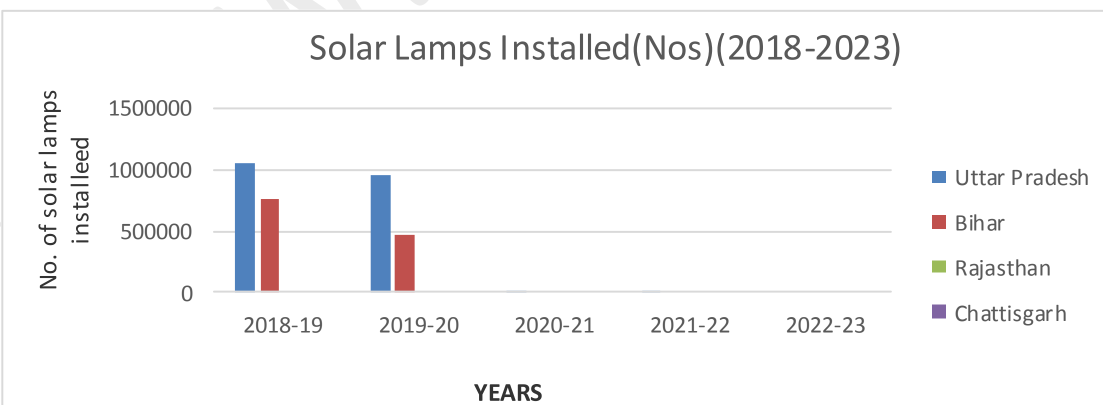
Chart: 2



NOTE: Data from Table No. 1

From the above graph we can observe that Chhattisgarh remained stagnant at 34,478 SHL during the entire course of the study period as evident from the flat disposition of the yellow line and the trend line equation y=34478 Meanwhile, Uttar Pradesh, Bihar, and Rajasthan, revealed minimal installation activities thereby suggesting limited advancements in SHL installation during the study period.

Chart: 3 - Variable 2 Solar Lamps

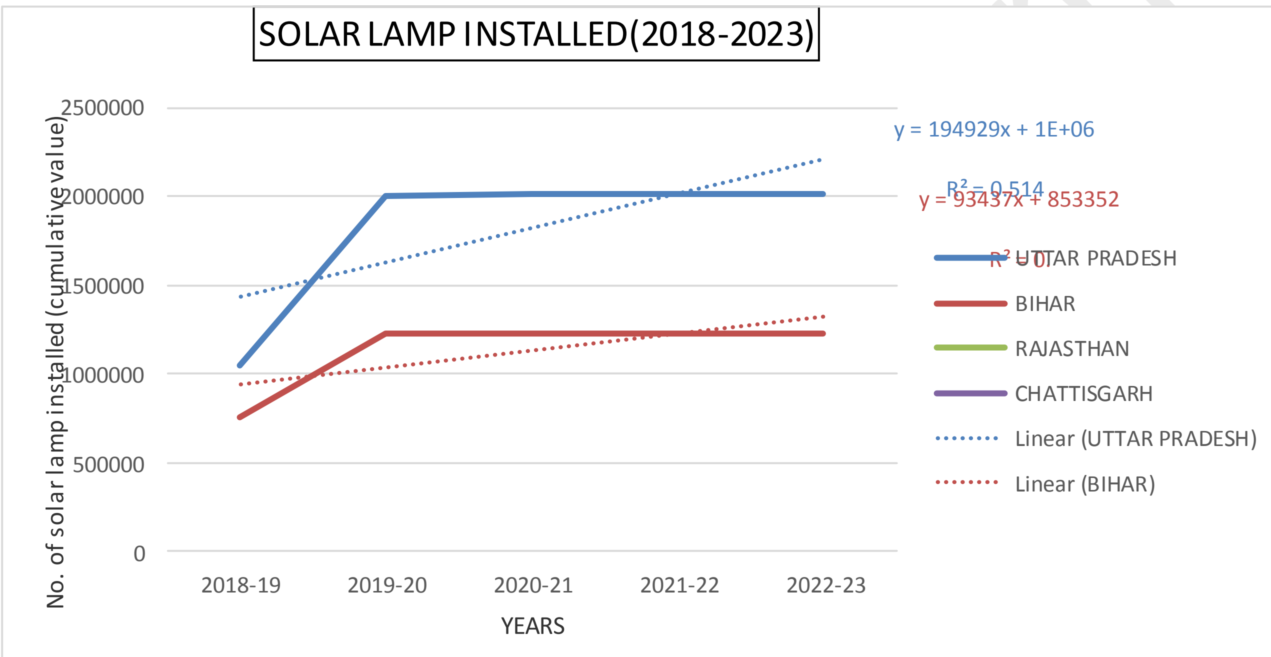


Note: Data from Table No. 2

The data of solar lamp installations for the financial years 2018-19 to 2022-23 show a declining trend, especially in UP and Bihar, whereas no installation was reported in Rajasthan and

Chhattisgarh during this period. The number of solar lamp installations in Uttar Pradesh stood at 1,055,096 in 2018-19 and came down in 2019-20 to 947,692. Funds for installation of the posts had equally reduced and by 2020-21 installations had reached 16,282 and still lowered to 1,685 in 2021-22 and nil in the year 2022-23. Likewise, Bihar, the number of solar lamps sold has reduced drastically, from 759,915 in 2018-19 to 467,184 in 2019- 20 and there was no sale for the solar lamps onward 2020-21. Rajasthan and Chhattisgarh had zero installation in each and every year of five years.

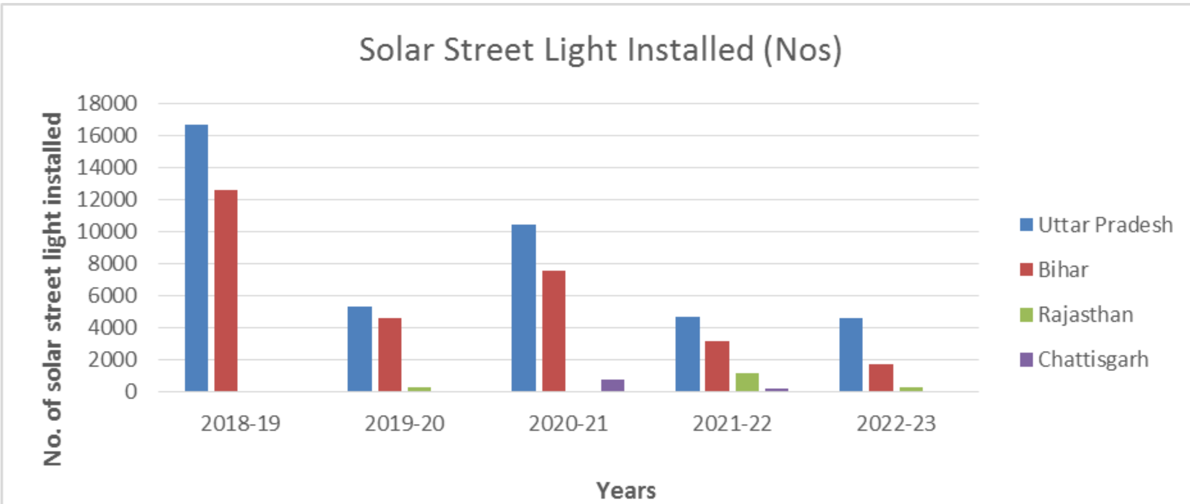
Chart:4



NOTE: Data from Table No. 2

From the above chart we can clearly see that the number of solar lamps installed grew more greatly in Uttar Pradesh from 2018-19 to 2019-20, although Bihar also witnessed a gradual rise. The trendline equations express moderate upward slope of the states and r square values are 0.5144 for Uttar Pradesh and 0.5 for Bihar, representing moderate model fits. On the other hand, Rajasthan and Chhattisgarh have very low and almost negligible installations that are represented by horizontal lines over the period.

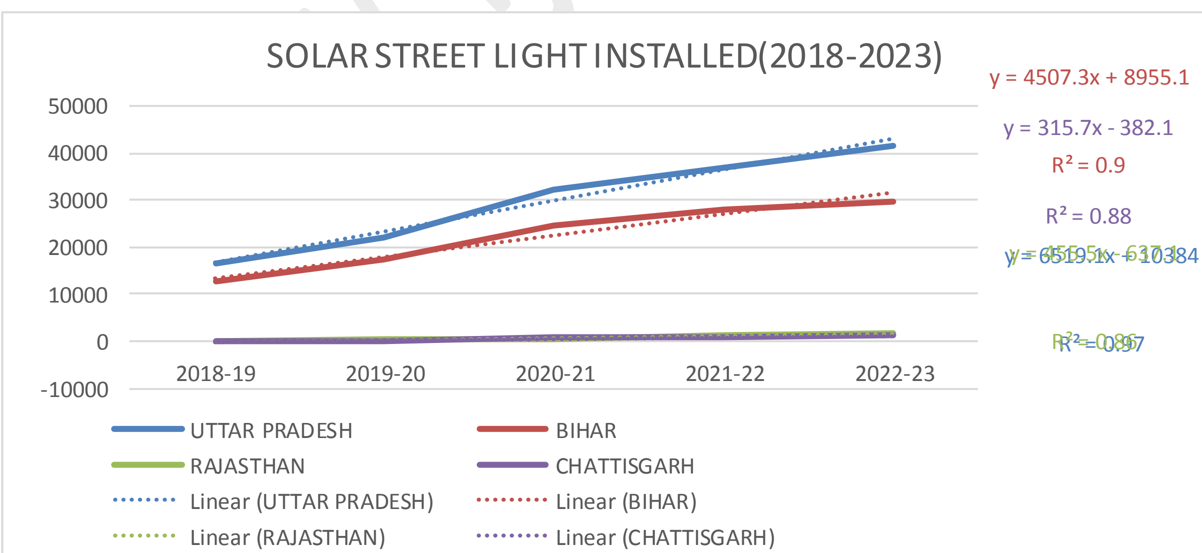
Chart: 5 - Variable 3 :Solar Street Light



NOTE: Data from Table No. 3

In Uttar Pradesh, installations began at 16,629 in 2018-19, came down to 10,450 in 2020-21, and furher got declined to 4,571 by 2022-23, indicating a drop in new projects. Bihar showed a similar pattern, starting with 12,603 installations, came down to 7,600 in 2020-21 and falling to 1,716 in 2022-23. Rajasthan had minimal activity, with only 262 installations in 2019-20, peaking at 1,167 in 2021-22, then declined to 265 by 2022-23. Chhattisgarh also remained low, with a peak of 750 in 2020-21 and just 89 installations in 2022-23.

Chart: 6



NOTE: Data from Table No. 3

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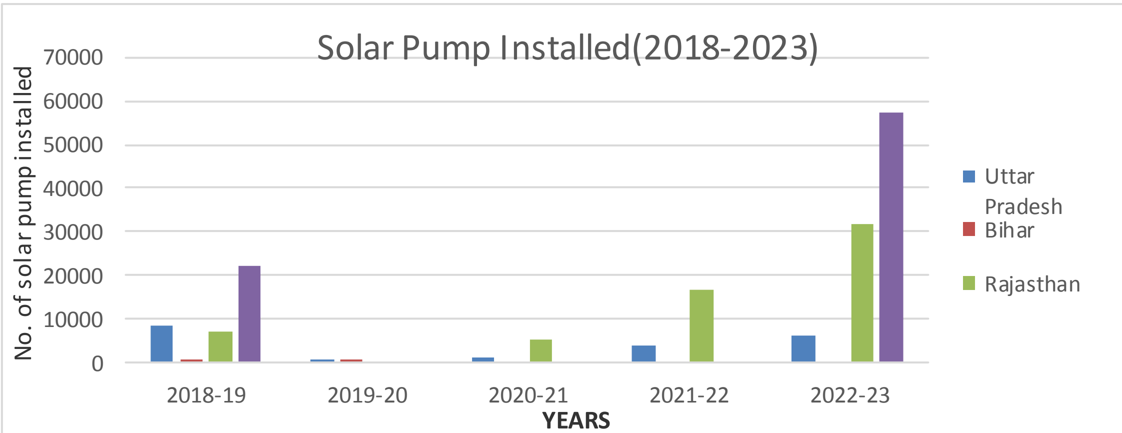
The highest growth rate is recorded for Uttar Pradesh, as marked by the trendline (*R*2=0.9761), followed by Bihar showing a strong trend line (*R*2=0.949) for solar street installations whereas Rajasthan and Chhattisgarh, on the other hand, have better but slow progress rate, less installation numbers, and modest upward movements.

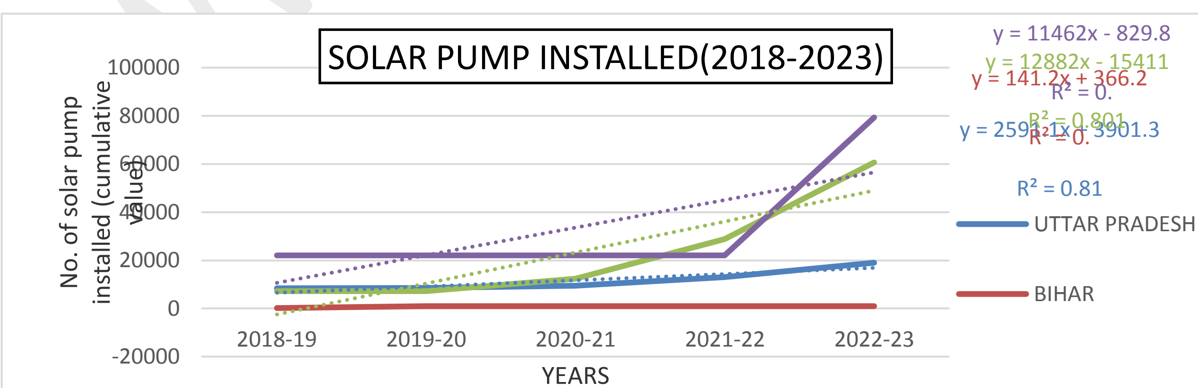
Chart: 7 - Variable 4 Solar Pumps



NOTE: Data from Table No. 4

The installation of solar pumps for the financial year 2018-19 to 2022-23 is presented in the above figure, which describes the pattern of solar pumps in different states. The installations in Uttar Pradesh started well at 8,382 in 2018-19 and then fluctuated sharply decreasing to 81 in 2019-20 but then rising again to 5,931 in 2022-23. Bihar was least active, beginning with 225 installations, followed by zero in the subsequent years, which raises concerns about project implementation. Rajasthan on the other hand saw reasonable increase from 7134 to 31870 which has technically implied good implementation of solar policy. Chhattisgarh, with 22,095 installations at the start, had a period of stagnation but then quickly rose to 57,312 in the 2022-23.

Chart: 8



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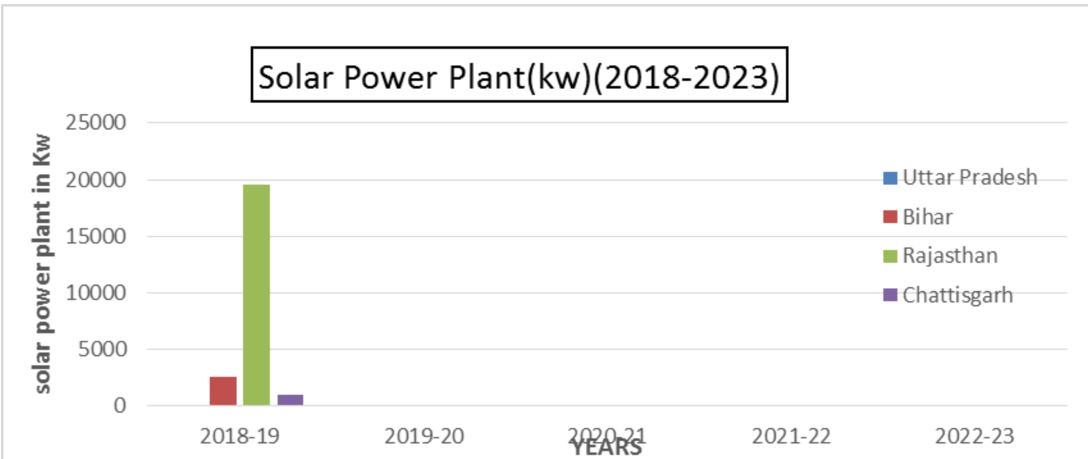
NOTE: Data from Table No. 4

From the above chart we can clearly see Rajasthan shows the highest growth rate, followed by Chhattisgarh, particularly in 2021-22 and 2022-23. However, Uttar Pradesh and Bihar experienced modest and poor increase, indicating a slowdown in solar pump implementation.

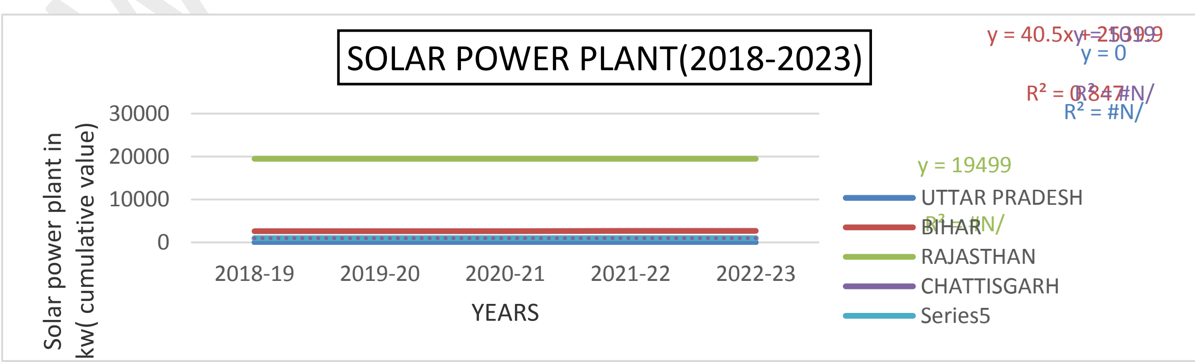
Chart: 9 - Variable 5 Solar Power Plant



NOTE: Data from Table No. 5

Analyzing the yearly data of the solar power plant from the years 2018-19 to 2022-23 shows a slowdown in Uttar Pradesh, Bihar, Rajasthan, and Chhattisgarh. In the same period, Uttar Pradesh has reported zero kW on new installations meaning no new project. Bihar had an initial capacity of 2,601.4 kW but the establishment witnessed negligible work, which included 30 kW in the period of 2019-20 and 105 kW in 2021-22. Rajasthan started with 19,499 kW but had no new connection after that. Chhattisgarh started with 1019 kW that remained the total, no further increase in the capacity. More generally, it is clear that solar power plant development has largely stagnated across these states

Chart: 10



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NOTE: Data from Table No. 5

The above figure shows solar power plant installations (in kW) throughout four states from 2018 to 2023. Rajasthan had the largest cumulative installations, with no significant variations over time, indicating that no new capacity was installed. Bihar experienced moderate but continuous growth, while Uttar Pradesh and Chhattisgarh made little to no gain, with Chhattisgarh having no recorded installations during this time.

FINDINGS

When we added a trendline to our line charts showing cumulative number of solar installations for the period of five years, we got certain equations for every selected stated states. Here, we try derive the results based on those equations. So, for the variable 1 i.e Solar home light we got only one equation representing Chhattisgarh as the data for other states is nil. The state installed 34,478 solar home lights (based on the trendline equation $y = 34478$). The flat line implies that there will be no new installations between 2018 and 2023, implying that the overall number of installations will remain constant over this time period. The absence of a value (denoted as #N/A) indicates that there is no variation or increase in the data, resulting in a constant cumulative number.

For the variable 2 i.e Solar Lamp we got only two equation representing U.P and Bihar as the data of other two states are nil. The trendline equation for Uttar Pradesh **is** $y = 194929x + 1E{+}06$, with a **R^2 of 0.5144**. This means that Uttar Pradesh installed an average of 194,929 additional solar lamps per year, starting with a base of around 1,000,000 lamps in 2018-19. With a R^2 of 0.5144, this linear trend can explain only roughly 51.44% of the variation in solar lamp installations, indicating moderate correlation. Bihar's trendline equation is $y = 93437x + 853352$, with a **R^2 of 0.5**. Bihar built an average of 93,437 extra solar lamps per year, starting with 853,352 lamps in 2018-19. The trendline accounts for 50% of the variation in solar lamp installations, demonstrating a moderate correlation ($R^2 = 0.5$).

For the variable 3 i.e Solar Street light we got four equation representing each state. The equation is **$y = 6519.1x + 10384$** for Uttar Pradesh means that there is an average addition of 6519 new solar street light per year beginning from 2018-19. The high **R^2 value of 0.9761** means that about 97.61% of variability in installations can be attributed to this trend, which demonstrates good growth, and which is consistent. The equation is **$y = 4507.3x + 8955.1$** for Bihar which shows an annual increase of 4,507 solar street lights, with 8,955 already installed at the beginning of the period. The **R^2 of 0.949** indicates that 94.9% of the variation in solar street light installations is captured by the trendline, suggesting consistent growth over time, though at a slightly slower rate than Uttar Pradesh. The equation **$y = 455.5x - 637.1$** for Rajasthan shows approximately 455.5 solar street lights are installed every year. However, the negative intercept (-637.1) indicates that Rajasthan had an extremely low or almost non-existent quantity of solar street lights in 2018-19. The **R^2 of 0.8685** indicates that the trendline accounts for 86.85% of the variation, indicating a slight rising trend but much slower development rate than Bihar and Uttar Pradesh. For Chattisgarh the equation we got is **$y = 315.7x - 382.1$** showing Chattisgarh has the slowest growth in solar street light installations among the states, with only 315.7 new installations per year. The negative intercept (-382.1) indicates that there were few or no installations at the start of the era. With a **R^2 of 0.8874**, the trendline accounts for 88.74% of the data variation, indicating a consistent but moderate growth in installations.

For variable 4 i.e Solar pump we got four equations representing each state. The Uttar Pradesh trendline equation is $\boldsymbol{y}$**=2591.1**$\boldsymbol{x}$**+3901.3**, with a R^2 value of 0.816. On average, Uttar Pradesh added 2,591 solar pumps per year, beginning with about 3,901 pumps in 2018-19. This trendline accounts for 81.6% of the variation in solar pump installations, showing a solid correlation (R^2= 0.816). The trendline equation of Bihar is y=141.2x+366.2, with **R^2 value of 0.5** indicating Bihar added 141 solar pumps every year on average, starting with 366 pumps in 2018-19. The trendline could explain 50% of the variation in installations, indicating a moderate correlation (R^2= 0.5). For Rajasthan the trendline equation is $\boldsymbol{y}$**=12882**$\boldsymbol{x}$**−15411**, with an **R^2 of 0.8013**. Rajasthan added 12,882 solar pumps every year on average, while the baseline for 2018-19 was somewhat negative (-15,411). The trendline can explain 80.13% of the variation in installations, indicating a significant connection (R^2= 0.8013). The trendline equation for Chattisgarh is $\boldsymbol{y}$**=11462**$\boldsymbol{x}$**−829.8**, with a **R^2 of 0.5**. Starting in 2018-19, indicating Chhattisgarh installed 11,462 extra solar pumps every year, from a baseline of -829.8 pumps. The trendline accounts for half of the variation, indicating a modest correlation (R2 = 0.5).

For variable 5 Solar Power Plant we got three equations, we didn't get equation for U.P as the of that state is nil for the selected time frame. According to the trendline equation of Bihar i.e **y = 40.5x + 2539.9, R^2 = 0.8477** we can say that Solar power plant installations in Bihar increase by 40.5 kW each year. The constant 2539.9 kW indicates the first year's installed capacity (2018-19). The linear trend accounts for 84.77% of the variance in solar power installations in Bihar (R^2 = 0.8477). This indicates a relatively strong relationship between years and installed solar capacity in the state. For Rajasthan the trendline equation is **y = 19499, R^2 = #N/A.** The value 19499 kW suggests that Rajasthan had a big constant cumulative capacity of solar installations from 2018 to 2023.The flat trendline indicates that no more solar capacity has been built over these years. A linear model cannot explain the data variability since the R^2 value is not applicable (N/A). For Chattisgarh we got **y = 1019, R^2 = #N/A** indicating similar to Rajasthan, Chhattisgarh's solar capacity stayed constant at 19,499 kW over a five-year period. The flat line and lack of variability suggest that no installations were added during this time period. The R^2 = N/A implies no change in capacity, making it impossible to fit a trend.

CONCLUSION

This study of off-grid solar energy adoption in Uttar Pradesh, Bihar, Rajasthan, and Chhattisgarh from 2018 to 2023 shows a mix of growth and stagnation. Solar home lighting system installations were completely stable across all states, with Chhattisgarh maintaining a cumulative total of 34,478 units during the five-year period and no installations in the other states. This stillness signals probable difficulties in program implementation or a shift in focus to other solar projects. Solar lamp installations, on the other hand, indicate strong development in both Uttar Pradesh and Bihar, however Uttar Pradesh's growth slowed significantly after 2019-20, possibly indicating that early targets were met. Rajasthan and Chhattisgarh had no significant installations of solar lamps, reflecting regional differences and the need for governmental involvement in these states.

Uttar Pradesh and Bihar showed substantial upward trends in solar street lighting, with consistent attempts to build solar streetlight infrastructure. Both states showed excellent R^2 values, indicating consistent improvement and effective program implementation. However, Rajasthan and Chhattisgarh lag significantly, with much lower installation rates, showing a lack of emphasis or problems in ramping up solar street lighting in these states.

The growth trends in solar pump installations on the other hand are slightly diverse. Rajasthan reflected the steepest incline in the installations with a peak growth in 2021-22 and 2022-23. Uttar Pradesh maintained consistent growth however the Chhattisgarh depicted moderate progression first and then hike up in the fiscal 2022-23. While many other states doubled down on the use of solar pumps Bihar froze with nearly no installation of solar pump, raising concerns about the effectiveness of its solar energy program.

Lastly, the analysis of the number of solar power plants installed in Uttar Pradesh revealed that the related growth was also gradual and more or less constant with an annual uptick of approximately 40.5 kW. This steady rise is attributed to the continued exertion of efforts to increase solar energy storage capacity. Neither the installed capacity during the observed period nor the state growth rate is significantly high; however, Rajasthan has the highest cumulative installed capacity (19,499 kW) but no subsequent development in the period. Likewise, Bihar and Chhattisgarh did not record any addition of solar power plant which may be due to lack of emphasis or impediments to expanding solar systems in these two states. Also, variability of these trends from one state to another suggests that policy interventions in each state would require assessment of the unique conditions that define each state to successfully spur solar energy deployment.

REFERENCES

i. Acharya, R. H., & Sadath, A. C. (2019). Energy poverty and economic development: Household-level evidence from India. *Energy and Buildings*, *183*, 785-791. doi:10.1016/j.enbuild.2018.11.047

ii. *Annual report 2018-19*. (2019). Retrieved from Ministry of New And Renewable Sources website: https://mnre.gov.in/annual-reports-2018-19/

iii. *Annual report 2019-20*. (2020). Retrieved from Ministry of New and Renewable Sources website: https://mnre.gov.in/annual-reports-2019-20/

iv. *Annual report 2020-21*. (2021). Retrieved from Ministry of New and Renewable Sources website: https://mnre.gov.in/annual-reports-2020-21-2/

v. *Annual report 2021-22*. (2022). Retrieved from Ministry of New and Renewable Sources website: https://mnre.gov.in/annual-reports-2021-22/

vi. *Annual report 2022-23*. (2023). Retrieved from Ministry of New and Renewable Sources website: https://mnre.gov.in/annual-reports-2022-23/

vii. Photovoltaic power generation in Indian prospective considering off-grid and grid-connected systems. (2018). *International Journal of Renewable Energy Research*, (v8i4). doi:10.20508/ijrer.v8i4.8287.g7502

viii. Raina, G., & Sinha, S. (2019). Outlook on the Indian scenario of solar energy strategies: Policies and challenges. *Energy Strategy Reviews*, *24*, 331-341. doi:10.1016/j.esr.2019.04.005

ix. Shrimali, G., & Rohra, S. (2012). India’s solar mission: A review. *Renewable and Sustainable Energy Reviews*, *16*(8), 6317-6332. doi:10.1016/j.rser.2012.06.018

x. Suman, S. K., & Ahamad, J. (2018). Solar energy potential and future energy of India: an overview. *International Journal of Engineering Science*, *8*(5), 17575-79.

xi. Yadaw, P. K., & Umar, M. M. (2024). Unleashing India's solar potential: A review of the national solar mission and the path to sustainable energy in India. *Journal of Technology Innovations and Energy*, *3*(2), 49-63. doi:10.56556/jtie.v3i2.930

xii. Zaman, R., & Borsky, S. (2021). The impact of supply structure on solar home system installations in rural off-grid areas. *Environmental Innovation and Societal Transitions*, *40*, 625-644. doi:10.1016/j.eist.2021.10.015