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Policy Support as a Catalyst for Expanding Solar Power Generation: Ensuring Sustainable Growth in Renewable Energy

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ABSTRACT

Introduction: The solar photovoltaic (PV) industry is critical to India's renewable energy future, with solar power positioned to help meet national climate goals and address energy security. Policy support plays an essential role in promoting the expansion of solar energy capacity, with India setting ambitious targets of reaching 280 GW of installed solar power by 2030. However, challenges such as over-reliance on international supply chains, volatile pricing of solar components, and the need for localized manufacturing persist.

Objectives: This study explores the crucial role of policy support in driving solar power generation, focusing on the impact of government initiatives in the Thirunelveli district of Tamil Nadu.

Methods: Through secondary data and survey-based primary research, this paper statistically examines the correlation between policy interventions and solar capacity buildup, while also evaluating how policy can further accelerate sustainable growth in the sector

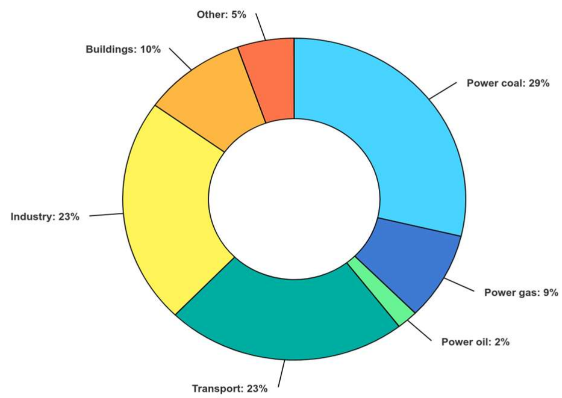
Keywords: Solar Power, Policy support, Government initiatives, Statistical Analysis Tirunelveli District

INTRODUCTION

Human activities, particularly the burning of fossil fuels, deforestation, and industrial-scale agriculture, have significantly increased the concentration of greenhouse gases (GHGs) in the atmosphere, contributing to the greenhouse effect and causing global warming. Key GHG emissions include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases. These emissions have intensified climate change and caused a marked rise in global temperatures, leading to severe ecological and economic impacts [1][2].

By 2019, the global average temperature had already risen by 1.1°C compared to pre-industrial levels, with projections showing that an increase of 2°C could have catastrophic effects on both the environment and human health. CO_2 emissions, largely driven by energy consumption in sectors like electricity and transport, are the main contributors to this warming. As of 2020, CO_2 concentrations in the atmosphere had risen by 48% compared to pre-industrial levels [3].

Sectoral CO_2 emissions are presented in Figure 1, showing the contribution of different sectors. A significant portion of emissions comes from coal combustion, accounting for 29% of total emissions from the energy sector, followed by industry and transport at 23% each. India, being one of the world's fastest-growing economies, has seen a steady increase in energy demand, primarily fulfilled by fossil fuels. However, India is also positioning itself as a leader in renewable energy, particularly in solar power, as part of its strategy to reduce emissions and meet international climate commitments [4].



In 2022, electricity and heat generation accounted for a 1.8% increase in global emissions, with coal remaining the dominant fuel for power generation, contributing over 10 $GtCO_2$ globally [5]. India's solar capacity expansion is driven by policies under the National Action Plan on Climate Change (NAPCC), including the National Solar Mission (NSM), which has set ambitious targets for solar power. These efforts align with India's goal to decarbonize the energy sector, reduce reliance on coal, and meet its 280 GW solar capacity target by 2030 [6].India aims to achieve a total of 500 GW of non-fossil fuel capacity by 2030, with substantial contributions from renewable energy sources. Renewable Energy by Source in India is indicated in Table :1

Table-1

Source	Capacity (GW) as on 2023	Capacity (GW) by 2030	Percentage Increase
Solar Power	85.47	280	228%
Wind Energy	46.65	140	199%
Hydropower	46.93	50	6%
Other Renewables (Biomass, etc.)	16.55	30	79%
	195.6	500	155%

This ambitious target underscores India's commitment to fostering a sustainable energy future. Achieving this will require not only policy support but also substantial investment in infrastructure and technology [7].This article, focused on the state of Tamil Nadu, aims to assess the impact of policy support on solar power capacity buildup and its electricity generation over the last decade. It also evaluates the correlation between government initiatives and the actual expansion of solar energy in the Nation and Tamil Nadu.

OBJECTIVES

The primary objective of this paper is to explore how policy support has driven the expansion of solar power generation in India and Tamil Nadu more broadly. Key objectives include

- Assessing Policy Impact: Evaluate how government initiatives like NSM, PLI Scheme, and the Solar Park Scheme have influenced solar capacity expansion in India and Tamil Nadu.
- Capacity vs. Generation Correlation: Analyze the relationship between solar capacity buildup and actual energy generation, using both secondary data and primary survey data.
- Statistical Analysis of Policy Effectiveness: Use correlation and regression analyses to quantify the impact of policy support on solar energy outcomes in the past decade.

SCOPE OF WORK

This study is limited to examining the role of policy support in driving solar power growth in the Nation and Tamil Nadu state, focusing on policies targeting grid-connected PV systems. While technology and supply chain challenges are recognized, this paper focuses primarily on government incentives, subsidies, and financial support aimed at expanding solar capacity. Technological advancements will be discussed as secondary factors.

LITERATURE REVIEW

The Phase I (2010–2013) and Phase II (2013–2017) of the NSM have demonstrated the effectiveness of government-led initiatives in promoting large-scale solar projects, including utility-scale solar parks and rooftop installations. These phases collectively allocated more than ₹12,000 crore ($1.6 billion) in funding to solar power projects across India, including Tamil Nadu, positioning it as a renewable energy leader in the region [9]. However, despite this significant progress, the solar sector still faces challenges, such as heavy reliance on imported solar modules, particularly from China, and an underdeveloped local manufacturing ecosystem. Studies suggest that further policy measures, such as Production Linked Incentives (PLI) for solar manufacturing, are crucial to achieving the ambitious 2030 goals [10].

METHODOLOGY.

Secondary data was collected from various government websites, including the Ministry of New and Renewable Energy (MNRE), the Ministry of Power, and the National Solar Mission (NSM). This data includes budget allocations, installed capacity records, and annual solar generation figures for the last decade in India and Tamil Nadu. The study analysed key policy milestones, including the budgetary provisions under the NSM, PLI scheme, and Solar Park Scheme, to assess the financial backing of solar projects in the district. The study also examined state-level policies and incentives provided by the Tamil Nadu government. In addition to qualitative insights, a statistical analysis was conducted based on the year-wise progressive budget allocations, solar capacity growth, and energy generation. Table:2 and statistical tests demonstrate the relationship between policy support and solar growth in Tamil Nadu.

Table 2: Summary of Supply-Side and Demand-Side Policy Support

Policy/Budgetary Support	Budget Allocation (₹ crore)	Target Capacity (MW)	Achieved Capacity (MW)	Time Frame	Remarks
National Solar Mission (NSM) Phase I	4,337	1,000.00	1,684.00	2010–2013	Exceeded
National Solar Mission (NSM) Phase II	8,100	9,000.00	18,316.00	2013–2017	Exceeded
Production Linked Incentive (PLI) Scheme	19,500	25,000.00	7,000.00	2022–2025	Ongoing
PM-KUSUM Scheme (Component A)	34,422	10,000.00	4,500.00	2019–2022	Ongoing
Solar Park Scheme	4,050	40,000.00	14,000.00	Ongoing (since 2014)	Ongoing
Green Energy Corridor	12,031	1,75,000	63,000.00	2021–2026	Ongoing

RESULTS

To further validate the relationship between budget allocations, solar capacity, and energy generation, a linear regression analysis was performed. In India, Year-wise Budget Allocation, Solar Capacity, and Energy Generation during the past 10years is shown in the table :3.

Table 3: INDIA: **Year-wise Budget Allocation, Solar Capacity, and Energy Generation**

Year	**Budget Allocation (₹ crore)**	**Cumulative Capacity (GW)**	**Energy Generation (TWh)**
2015	4,337	3.74	4.6
2016	4,337	6.76	7.5
2017	12,437	12.29	12.1
2018	12,437	21.65	25.9
2019	15,441	28.18	39.3
2020	15,441	34.63	50.1
2021	18,056	40.09	60.4

2022	23,056	56.95	73.5
2023	29,097	66.78	102.01
2024	48,597	81.81	115.97

Solar capacity installed at Tamilnadu is shown in Table:4
Table:4-Tamilnadu

Year	Capacity in MW
2018-19	2906.01
2019-20	3554.5
2020-21	4946.63
2021-22	6115.48
2022-23	7172.88
2023-24	7505.74

LINEAR REGRESSION RESULTS (INDIA)
Null Hypothesis (Ho): Solar capacity and energy generation are not dependent on budget allocations. Alternative Hypothesis (Ha): Solar capacity and energy generation are dependent on budget allocations. The analysis was conducted at a significance level (alpha) of 0.05, and linear regression results were obtained for both Cumulative Capacity (GW) and Energy Generation (TWh) against the Budget Allocation. (₹ crore). Linear Regression Results are placed at Table:5

Table-5

Dependent Variable	Cumulative Capacity (GW)	Energy Generation (TWh)
R-squared	0.899	0.877
Adjusted R-squared	0.886	0.861
F-statistic	70.90	56.79
P-value (Prob (F-statistic)):	3.02e-05	6.70e-05
Coefficients		
Intercept (const)	0.2814 (p-value: 0.957)	-2.1767 (p-value: 0.798)
Budget Allocation (₹ crore)	0.0019 (p-value: 0.000)	0.0028 (p-value: 0.000)

Interpretation of cumulative capacity (GW): The model explains approximately 89.9% of the variability in cumulative capacity as a function of budget allocation. For every ₹1 crore increase in the budget allocation, the cumulative solar capacity increases by 0.0019 GW.
Interpretation of Energy Generation (TWh):The model explains approximately 87.7% of the variability in energy generation as a function of budget allocation.For every ₹1 crore increase in the budget allocation, energy generation increases by 0.0028 TWh.

DISCUSSION:

Both models demonstrate a strong relationship between budget allocation and both cumulative capacity and energy generation. The p-values for budget allocation in both models are statistically significant (less than 0.05), indicating a strong effect of budgetary support on both outcomes. These findings support the hypothesis that policy support in the form of budget allocations has a significant impact on solar capacity and energy generation in India. The statistical analysis reveals that solar capacity and energy generation are significantly dependent on budgetary allocations. The strong R-squared values (0.899 for capacity, 0.877 for energy generation) further confirm the positive impact of budget support on the solar ecosystem.

ANALYSIS BASED ON PRIMARY DATA COLLECTION FROM TARGETED STAKEHOLDERS

The scholar created a well-structured Google survey to collect data from engineers and graduates working in grid-integrated PV solar power plants, specifically focusing on Tamil Nadu. This research aims to test the hypothesis regarding the impact of policy support on solar power generation. From April 6 to April 24, 2024, a total of 137 individuals participated in the survey, providing their insights. The research primarily centers on Tamil Nadu, with some responses collected from other states, classifying them into "Tamil Nadu" and "Other than Tamil Nadu. "Responses classification is indicated at Table:6

Table 6: Classification of Responses

Classification	Count
Tamil Nadu	102
Other than Tamil Nadu	35

AGE-WISE ANALYSIS

Out of the 137 responses, 102 are from Tamil Nadu, while the remaining 35 fall under "Other than Tamil Nadu." This analysis pertains to the demographic perception of the engineers and graduates involved in the survey, focusing on Tamil Nadu's geography. Distribution of the respondents based on age is shown in table:7.

Table 7: Age Distribution of Respondents

Age Group	Count
25 to 34	33
35 to 44	20
45 to 54	14
55 to 64	35

The age-wise analysis indicates that the maximum participants are experienced individuals in the 55 to 64 age group, followed by younger professionals in the 25 to 34 age bracket.

PERCEPTION OF BENEFITS FROM GOVERNMENT POLICIES

Q1. Have you directly benefited from any government policies or incentives for solar energy in your work?

Table 8: Responses to Government Policy Benefits

Response	Count
Yes	59
No	43

To analyse the responses, a Chi-square test was applied. The null hypothesis states that the perception of respondents is not influenced by solar energy policies.

RESULTS

- Chi-square statistic (χ^2): 0.0
- p-value: 1.0
- Significance level (α): 0.05

The p-value (1.0) is greater than the significance level (0.05), indicating no statistically significant evidence that respondents' perceptions are influenced by government solar energy policies. This suggests that while policies exist, they may not significantly impact perceptions across the population.

PERCEPTION RANKING OF POLICY SUPPORT

Rank the effectiveness of the following policy supports for solar energy: Subsidies, Tax Incentives, Feed-in Tariffs, Research and Development grants.The descriptive statistics based on rankings provided by respondents are indicated at Table:9.

Table 9: Ranking of Policy Supports

Policy Support	Mean	Standard Deviation	Mini Rank	Max Rank
Subsidies	3.03	2.02	1	4

Tax Incentives	2.96	0.97	1	4
Feed-in Tariffs	2.90	0.91	1	4
R&D Grants	2.77	0.99	1	4

A Kruskal-Wallis H Test was conducted to compare the effectiveness rankings across various policy supports due to the ordinal nature of the data, which does not assume a normal distribution—making it ideal for the ranking data collected from respondents. This test effectively compares more than two independent groups, allowing for a detailed analysis of the rankings of four different types of policy supports. Furthermore, the Kruskal-Wallis H Test assesses differences in median ranks, providing meaningful insights into public perceptions of policy effectiveness without being influenced by extreme values. Additionally, this method is suitable for smaller sample sizes, which is particularly relevant given the limited number of survey respondents. Ultimately, this test ensures a thorough and statistically valid analysis of public perceptions regarding the effectiveness of various solar energy policy supports in Tamil Nadu.

RESULTS

-Test Statistic (H): 4.75
- p-value: 0.19

The "Kruskal-Wallis H Test" yields a test statistic of 4.75 with a corresponding p-value of 0.19. At a significance level (α) of 0.05, this p-value indicates that there is no statistically significant difference in the rankings among the four solar energy policy supports assessed in the study (Subsidies, Tax Incentives, Feed-in Tariffs, and R&D Grants).

DISCUSSION

P-value of 0.19 exceeds the significance threshold of 0.05, suggesting that the observed differences in rankings among the policy supports can likely be attributed to random variation rather than a genuine difference in effectiveness. The null hypothesis (H_0) posited that there is no significant difference in the effectiveness rankings of the four policy supports. Given the high p-value, we fail to reject the null hypothesis, reinforcing the conclusion that respondents do not perceive a substantial difference in the effectiveness of these policy supports.The results suggest that while respondents may have slightly varied preferences in ranking these supports, the overall perceptions do not significantly differentiate them. This indicates a potential consensus among respondents regarding the effectiveness of these policies, or it may imply that all policies are viewed as relatively comparable in their effectiveness. Although the test results do not show significant differences, policymakers may still want to explore why certain supports were ranked higher or lower. Qualitative feedback from respondents could provide insights into specific aspects of each policy that could be improved or emphasized to enhance overall effectiveness and public perception.

In conclusion, while the statistical analysis did not reveal significant differences in public perception among the various solar energy policy supports, it highlights the importance of continuous evaluation and improvement in policy design to meet the evolving needs of the solar energy sector.

Perception Rating of Current Policy for Solar Ecosystem

Q3. On a scale from 1 to 10, rate the current policy environment for solar energy in Tamil Nadu in terms of its supportiveness.

Descriptive Statistics

- Mean Rating: 6.76
- Standard Deviation: 2.09
- Minimum Rating: 1
- Maximum Rating: 10

Respondents were categorized based on their ratings

- 1 to 4 (Unsupportive): 13 respondents
- 5 (Neutral): 9 respondents
- 6 to 10 (Supportive): 78 respondents

A one-sample t-test was performed to determine if the average rating differs significantly from a neutral value of 5.

Test Results:

- t-statistic: 8.52
- p-value: 1.63×10^{-13}

Since the p-value is significantly less than 0.05, we reject the null hypothesis, indicating that respondents perceive the policy environment as more supportive than neutral. The analysis indicates a strong consensus among respondents in Tamil Nadu that the solar energy policy environment is moderately to highly supportive. Most respondents rated the environment as supportive, suggesting that while there are some who view the policies as less effective, the general perception leans toward supportiveness.

Perception of Policy Support and Investment

Q4. By what percentage have policy supports increased the investment in solar energy projects in your experience?

Descriptive Statistics:
- Mean Percentage Increase: 41.05%
- Standard Deviation: 22.99%
- Minimum Percentage Increase: 5%
- Maximum Percentage Increase: 88%

Statistical Test: One Sample test

To determine whether the average percentage increase is significantly different from 0, we conducted a one sample test.

Null Hypothesis (H_0): The average perceived increase is 0%, indicating no significant impact of policy supports on investment.
Alternative Hypothesis (H_1): The average perceived increase is significantly different from 0%, indicating a substantial impact of policy supports on investment.

Test Results:

t-statistic: 18.03
p-value: 2.44×10^{-33} (extremely close to zero)

Discussion:

Since the p-value is significantly less than the significance level of 0.05, we reject the null hypothesis. This suggests that respondents perceive a significant increase in investment due to policy supports, with an average increase far from 0%. The analysis indicates that respondents from Tamil Nadu believe policy supports have led to a substantial increase in investment in solar energy projects. With an average perceived increase of 41.05%, the statistical significance highlights that policy supports are seen as a major driver of investment in the solar energy sector. The variation in responses (standard deviation of 22.99%) suggests diverse experiences, but the general consensus points to a positive impact.

Perception of Policies adequacy

Q5. To what extent do you agree that current government policies adequately support the growth of the solar energy sector in Tamil Nadu? 1 = Strongly Disagree, 5 = Strongly Agree)

Descriptive Statistics:

-Mean Agreement Score: 3.58
-Standard Deviation: 0.94
-Minimum Rating: 1 (Strongly Disagree)
-Maximum Rating: 5 (Strongly Agree)

Statistical Test: One Sample test

To determine whether the average agreement score is significantly different from a neutral score of 3, we conducted a one sample test.

Null Hypothesis (H_0): The average agreement score is 3, indicating a neutral view on the adequacy of government policies.
Alternative Hypothesis (H_1): The average agreement score is significantly different from 3, indicating a clear opinion on the adequacy of government policies.

Test Results:

t-statistic: 6.23
p-value: 1.09×10^{-8} (extremely close to zero)

Since the p-value is significantly less than the significance level of 0.05, we reject the null hypothesis. This suggests that respondents' views are significantly different from neutral. The positive t-statistic indicates that respondents tend to agree more than disagree that government policies adequately support the growth of the solar energy sector.The analysis shows that respondents from Tamil Nadu generally agree that government policies adequately support solar energy growth, with an average agreement score of 3.58. The moderate variation (standard deviation of 0.94) suggests that while some respondents hold different views, the majority lean towards agreement. The one sample test confirms that this perception is significantly more favourable than neutral, suggesting that government policies are seen as positively contributing to the growth of the solar energy sector.

Perception of policy change

Q6. Describe the policy change that would most benefit the solar energy sector in Tamil Nadu or in India.

The responses have been categorized as described in table -10

Table-10

Category	Count
Other	67
Financial Policies	19
Infrastructure Development	8
Technology and R&D Support	6
Regulatory Reforms	1

Out of 102 respondents from Tamil Nadu, 101 individuals provided responses. The majority of responses (67) did not directly fit into the predefined categories, possibly suggesting more diverse or nuanced views on policy changes. Among the categorized responses, Financial Policies had the highest number of suggestions (19), followed by Infrastructure Development (8) and Technology and R&D Support (6). Regulatory reforms were less frequently mentioned, with only 1 response in that category.

DISCUSSION AND RECOMMENDATIONS

The solar energy sector in Tamil Nadu, supported by strong government policy, has shown substantial potential for continued growth. However, delays in project execution threaten to undermine progress in solar capacity development as outlined in national and state-level policies. Based on survey feedback and statistical analysis, several key recommendations are proposed to align with public perception and reinforce the role of policy support in achieving planned solar energy goals.

ADEQUACY OF CURRENT POLICIES

A one-sample test comparing respondents' views to a neutral score of 5 on the supportiveness of current policies yielded a mean rating of 6.76 with a p-value close to zero, indicating a strong belief that the policy framework supports solar energy growth. This perception reflects respondents' confidence in the policies governing solar energy in Tamil Nadu. However, delays in project execution—such as in the PMKUSUM Scheme, Rooftop Solar Program, and Floating Solar Projects—could hinder progress, with a combined shortfall of 46,750 MW pointing to the need for focused implementation efforts.

Recommendation: To maintain momentum, the government should accelerate the execution of lagging projects. Real-time monitoring of projects at various stages—from central to state levels—is essential. A mechanism incorporating technologies such as AI, ML, IoT, and Blockchain can be deployed to streamline project monitoring and ensure timely completion, helping to align actual progress with policy goals. This will reinforce the positive perception of policy support and maintain the sector's trajectory toward meeting its capacity targets.

INFRASTRUCTURE AND GRID CAPACITY

The Green Energy Corridor, essential for transmitting solar energy across regions to the national grid, is currently delayed, with 112,000 MW of planned capacity unconnected. This limits the ability to maximize benefits from completed or developing solar energy projects. Survey responses highlight the importance of infrastructure development, with 19% identifying grid integration as a key area for improvement.

Recommendation: Prioritize the completion of the Green Energy Corridor to ensure effective transmission of solar energy from new projects. Fast-tracking this project will help meet solar capacity goals and maintain confidence in the policy framework.

INVESTMENT AND FINANCIAL INCENTIVES

A one-sample test comparing perceived investment increases due to policy support against zero revealed a significant average increase of 41.05%, with a p-value of 2.44×10^{-33}. This indicates that respondents see a positive impact from financial incentives like the Production Linked Incentive (PLI) Scheme and subsidies.

Recommendation: While financial policies have attracted investment, they must be complemented by improvements in project execution and regulatory processes. Timely project approvals and financial disbursements will help convert investments into actual capacity growth, reinforcing public confidence in the policy framework.

BATTERY STORAGE AND ENERGY SECURITY

Battery storage is critical for supporting solar energy growth, yet the Battery Storage PLI Scheme has only achieved 20 GWh of the planned 50 GWh. Without adequate storage capacity, integrating solar energy into the grid could be hampered.

Recommendation: Prioritize the completion of the Battery Storage PLI Scheme and expand R&D investments in storage technology to enable the grid to absorb more solar energy.

POLICY AGREEMENT ON SUPPORT FOR SOLAR ENERGY GROWTH

Respondents expressed general agreement about current government policies, with a mean score of 3.58 out of 5 and a p-value of 1.09×10^{-8}. While the policies are positively perceived, practical challenges must be addressed for full potential realization.

Recommendation: Streamline regulatory processes and improve coordination between state and national authorities to expedite project completion and reinforce the adequacy of current policies.

POLICY CHANGE RECOMMENDATIONS FROM RESPONDENTS

Qualitative analysis reveals the need for improvements in financial policies, infrastructure development, and technology support. 19% of respondents prioritized financial policies, while 8% emphasized the importance of completing infrastructure projects.

Recommendation: Implement reforms to streamline financial and regulatory processes, ensuring timely payments and tariff adjustments that incentivize continued investment in solar projects. Additionally, leveraging advanced technologies such as AI, ML, and IoT can provide recommendations on potential disruptions, particularly those arising from geopolitical factors affecting supply chains.

CONCLUSION

Statistical analyses and qualitative feedback indicate that respondents from Tamil Nadu view current solar energy policies as generally supportive of the sector's growth. However, delays in infrastructure development, battery storage capacity, and project execution present significant challenges. To maintain and build on the positive public perception of solar energy policies, the government must accelerate project timelines, increase storage capacity, and continue providing strong financial incentives. Moreover, the integration of advanced monitoring technologies will facilitate better oversight of project execution and help mitigate the impact of potential disruptions in the solar energy landscape.

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