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Research paper

Impact of weather variables on roof top green energy production in a multibuilding, multi-capacity ecosystem – A regression based study of 'SAI MITRA’

Rameswar Prusty [a], **N. Sivakumar** [b,*]

[a] *Department of Management and Commerce, Sri Sathya Sai Institute of Higher Learning, Sri Sathya Sai Center for Sustainable Development, Prasanthinilayam Campus, Sri Sathya Sai District, AP*

[b] *Department of Management and Commerce, Sri Sathya Sai Institute of Higher Learning, Sri Sathya Sai Center for Sustainable Development, Brindavan Campus, Kadugodi, Bengaluru, Karnataka*

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ABSTRACT

The importance of green energy in the current times cannot be understated. The ill effects of traditional forms of energy generation, make solar energy one of the most environmentally friendly alternatives. SAI MITHRA – a roof top multi building, multi-capacity solar energy generation system, executed by Sri Sathya Sai Central Trust at Prasanthinilayam in South India is a prime example for promotion of green energy. Using a regression model, this study attempts to understand the impact of weather variables on solar energy production across different production capacities using high frequency daily data. In order to provide predictive insights, the impact of weather variables with t-1 and t-2 days lags on solar energy generation have also been studied. The study identifies the three important weather variables that have an impact on solar energy production – atmospheric pressure, relative humidity and dew point temperature. The insights from the paper are relevant for multi-capacity solar energy systems for improving operational efficiencies and promoting green energy ecosystems.

1. INTRODUCTION

In contemporary times, the imperative of green energy stands as a beacon of hope amidst environmental concerns. Among the plethora of renewable energy options, solar energy emerges as a prominent contender due to its minimal ecological footprint. The execution of SAI MITHRA, a multi-capacity solar energy generation system by the Sri Sathya Sai Central Trust in South India, exemplifies the

* *Corresponding author, E-mail address: nsivakumar.sssihl@gmail.com*

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pivotal role of solar energy in fostering sustainable ecosystems. This study delves into the nuanced relationship between weather variables and solar energy production, employing high-frequency daily data to discern patterns across different production capacities. By identifying key weather parameters influencing solar energy output, this research offers actionable insights for enhancing operational efficiencies of green energy ecosystems.

2. LITERATURE REVIEW

This section discusses the research in the area of the impact of weather variables on solar energy production and forecasting.

With regard to the impact of weather variables on solar energy production, Gherboudj and Ghedira (2016) analysed the atmospheric variables influencing the desert climate in the UAE for solar energy applications. The variables included in the study were solar irradiance, dust loading, water vapor, wind speed, air temperature, and relative humidity. The study found higher solar irradiance in summer, significant dust loading in late spring/summer, and varying water vapor content. The results of the study showed that for PV facilities, without environmental considerations, highly suitable areas covered 32% in the north eastern areas of UAE, reducing to 9.7% considering risks. On the other hand, CSP suitability, concentrated in 2.7% in the coastal and southern areas of UAE and decreased to 1% with risks.

Zainaa et al. (2021) studied optimizing residential electrical energy scheduling using solar photovoltaics (PV) in Qatar, considering climatic conditions. The study employed statistical models to integrate factors like building load and renewable PV energy. The study analyzed real-time data from November 2014 to October 2015 which showed a strong correlation between weather parameters (humidity, temperature, dust, irradiation) and solar power generation. Load demand correlated with temperature and humidity.

Tarawneh, Q. Y., & Faraj, T. K. (2020) investigated the impact of anthropogenic activities on climate change and solar irradiation in Saudi Arabia (SA) over the period 1986 to 2014. The analysis revealed a general warming trend in SA, with increased warm nights and warm days, and decreased cold nights and cold days. Solar irradiation had declined, attributed to anthropogenic factors such as particulate matter from industrial and development projects. The study emphasized the need for environmental policies to control greenhouse gas emissions and promote renewable energy.

In relation to solar energy production forecasting, Gazela and Mathioulakis (2001) proposed the Weather Year for Solar Systems (WYSS) method as a new approach for generating typical weather data to predict the long-term performance of a solar hot water system (SHWS). The method involved three stages: calculating monthly solar gains using simulation methods for 21 years, selecting typical months based on solar gains, and smoothing the data to eliminate abrupt changes. When compared to existing methods, the results of using WYSS showed that it introduced slightly larger deviations in yearly solar gains but performed better in monthly and daily solar gain estimates. The method was considered advantageous due to its system-oriented nature and applicability with limited data.

Kim et al. (2017) proposed an adaptive daily prediction model for solar power generation, which dynamically adjusted its control parameters to fit the reality without human intervention. The model incorporated weather forecast information, including cloud cover and temperature, to predict solar radiation and adjusted for potential losses due to PV module degradation or failure. The proposed model outperformed existing models, including linear regression and artificial neural networks, in terms of accuracy. The model was embedded into a solar PV monitoring system in Korea and demonstrated improved performance for supply-demand planning in the electrical grid.

Hi and Bouhelal (2023) analysed solar energy production forecasting by using machine learning approaches for prediction. The study evaluated the impact of meteorological conditions like global horizontal irradiation and temperature on solar panel performance. The analysis included regression and classification models, with experimentation on various algorithms including XGB, RF, ET, KNN and LSTM. In regression, the study applied feature selection and demonstrated improved performance with reduced input variables. However, it noted challenges in predicting peak values, with LSTM exhibiting the best generalization. In classification, the study created distinct power classes and compared their performance. XGB emerged as a high-performing algorithm in both regression and classification, while LSTM demonstrated strong classification capabilities.

Sun et al. (2020) proposed a weather scenario generation-based probabilistic solar power forecasting (wsp-SPF) method to enhance the accuracy of solar power forecasts by considering correlation among weather variables. The study used the Copula theory, Gaussian mixture models, and a Gibbs sampling model for creating a machine learning-based multi-model (M3) for deterministic weather forecasts. Modeling marginal weather probability distributions using a Gaussian mixture model, and utilizing Copula-based Gibbs sampling for weather scenario generation, the study generated probabilistic solar power forecasts for various weather scenarios. The results showed significant improvements in pinball loss, indicating enhanced probabilistic forecasting accuracy.

Rana et al. (2016) presented a novel approach for forecasting the half-hourly PV solar power profile for the next day based on previous power output, weather data, and weather predictions. The study used clustering to determine groups of days with similar weather patterns and then built separate prediction models using ensemble neural networks for each cluster. This innovative approach achieved a high level of accuracy, outperforming other methods used for comparison.

Wang et al. (2017) proposed a Weather type Pair Pattern (WPP) approach for predicting the solar power output for the next day at half-hourly intervals. By clustering days based on weather characteristics and then forming pair patterns of consecutive days within the clusters, the method created a separate prediction model using neural networks (NN) or support vector regression (SVR) for each pair pattern group. The method was evaluated using two years of Australian data, demonstrating superior performance compared to other state-of-the-art methods such as clustering-based machine learning models, non-clustering-based machine learning models, statistical models, and baselines. The study found that the WPP approach using NN outperformed all other methods, showcasing the advantage of considering the relationship between consecutive days' weather characteristics.

Detyniecki, et al. (2012) used fuzzy decision trees (FDTs) to improve the accuracy of predicting solar panel energy production based on weather forecasts. The study involved a standard home solar panel subjected to real weather conditions. Traditional methods and baseline predictions were compared with FDT-based predictions. The FDTs, providing human-understandable rules, demonstrated a 30% improvement over constant predictions, with an average energy difference of 106 W-hr. The weather forecast-based approach, despite its 40% inaccuracy, enhanced predictions.

Köhler et al. (2017), studied the photovoltaic (PV) power in Germany's electricity mix. The paper emphasised the importance of accurate numerical weather prediction (NWP) forecasts for solar radiation, highlighting errors in cloud cover predictions as a major source of PV power prediction discrepancies. To address this, the study introduced a Low Stratus Risk (LSR) algorithm, based on the SK-Scheme, to enhance forecasting by considering factors like saturation deficit and inversion strength. Through this, the paper showed that the reliability of day-ahead PV power forecasts can be improved.

The above review of literature points out to the following research gaps:

1. While the influence of weather variables on solar energy production has been studied in other parts of the world, a similar study focusing on the India is yet to be done.
2. Apart from understanding the influence of weather variable on solar energy production, it would also be useful to provide a basis for forecasting solar energy production using weather variables.

The current study is an attempt to address these research gaps and has the following objectives:

1. To understand the impact of weather variables on solar energy production in the Indian conditions using the case example of Sai Mithra, a multi-capacity solar generation system at Prasanthinilayam, India.
2. To provide a basis for solar generation forecasting by understanding the lagged impact of weather variables on solar energy production over 1 and 2 days.

The following sections explain the remaining aspects of the study.

3. SAI MITHRA - A BRIEF INTRODUCTION

The SAI MITHRA project, initiated by the Sri Sathya Sai Central Trust, exemplifies a pioneering endeavor in sustainable energy by any Charitable Trust. Through the installation of multiple solar energy plants across various facilities at Prasanthinilayam in South India, the project showcases a commitment to green energy adoption and environmental stewardship. With capacities ranging from 10 kW to 150 kW, these solar plants contribute significantly to reducing carbon footprints while promoting energy self-sufficiency. With installed capacities of approx. 6300Kwp, the SAI MITHRA stands as a testament to the Trust's dedication to fostering renewable energy ecosystems and serves as a beacon of inspiration for sustainable development initiatives globally.

Weather in Prasanthinilayam - an introduction

Prasanthi Nilayam, located in Puttaparthi, (14.1688 degrees North and 77.8110 degrees East) India, experiences a subtropical climate characterized by hot summers and mild winters. Summers, from March to June, are scorching with temperatures often soaring above 40°C (104°F), accompanied by dry conditions. Monsoon season arrives in July, bringing relief from the heat with occasional heavy rainfall until September. Winters, from November to February, are pleasantly mild, with temperatures averaging around 20-25°C (68-77°F). With abundant sunlight year-round, its suitable for harnessing solar energy efficiently, mitigating dependence on conventional power sources.

4. METHODOLOGY OF THE STUDY

Research design

Hi and Bouhelal (2023) and Salemdeeb and Wadi (2024) adopted a machine learning research design to study the impact of weather on solar energy production. Based on these studies, the current study adopted a similar approach aligned to the discussion by Maulud and Abdulazeez (2020), who advocated using the regression methodology in the machine learning research design. Similar to previous studies (Kim et al., 2017), a multiple regression model which detailed the relationship between green energy production and weather variables was developed in this study. Scholars have used a variety of weather variables to study the impact of weather on solar energy production (Gherboudj and Ghedira, 2016; Zainaa et al., 2021). To ensure that impact of weather on solar energy production is studied holistically, a total of 38 weather variables were selected for the study. The weather variables included were related to either the whole day of 24 hours and only during the daytime period when solar energy production is possible. After checking for multicollinearity 5 weather variables were excluded from analysis. The details of the variables used in the study are given in Annex 2.

Energy production in rooftop solar plants is usually measured using the capacity utilisation factor (CUF) (Tursunov et al., 2023). In India, CUF is the most preferred ratio for measuring the efficiency of solar energy plants (Solar Energy Corporation, 2015).

The daily capacity utilization factor of a solar plant, expressed as a percentage is given by the following formula:

CUF = Solar plant output in kWh / (Installed plant capacity in kWp x *24) %*

The regression model developed for the study is:

$$y = a + \sum_{i=1}^{34} b_i x_i$$

where

y = Capacity utilisation factor of the solar plant
x_1 = Installed capacity of the solar plant and
x_2 to x_{34} represent weather variables as follows:

- x_2 = Day time duration
- x_3 = Minimum full day temperature
- x_4 = Average full day temperature
- x_5 = Maximum full day dew point temperature
- x_6 = Average full day dew point temperature
- x_7 = Maximum full day relative humidity
- x_8 = Minimum full day relative humidity
- x_9 = Average full day relative humidity
- x_{10} = Maximum full day wind speed
- x_{11} = Minimum full day wind speed
- x_{12} = Average full day wind speed
- x_{13} = Maximum full day atmospheric pressure
- x_{14} = Minimum full day atmospheric pressure
- x_{15} = Average full day atmospheric pressure
- x_{16} = Full day not calm wind conditions
- x_{17} = Full day not fair-weather conditions
- x_{18} = Maximum full day/daytime temperature
- x_{19} = Minimum daytime temperature
- x_{20} = Average daytime temperature
- x_{21} = Maximum daytime dew point temperature
- x_{22} = Minimum daytime dew point temperature
- x_{23} = Average daytime dew point temperature
- x_{24} = Maximum daytime relative humidity
- x_{25} = Minimum daytime relative humidity
- x_{26} = Average daytime relative humidity
- x_{27} = Maximum daytime wind speed
- x_{28} = Minimum daytime wind speed
- x_{29} = Average daytime wind speed

x_{30} = Maximum daytime atmospheric pressure
x_{31} = Minimum daytime atmospheric pressure
x_{32} = Average daytime atmospheric pressure
x_{33} = Daytime not calm wind conditions
x_{34} = Daytime not fair-weather conditions
a, b_1 *to* b_{34} represent the regression coefficients

The installed capacity of the solar plant was used as a control variable in the regression model.

Sampling methodology

Solar energy plant selection: The study included selected solar energy plants installed under the Sai Mithra project at Prasanthinilayam – the headquarters of the Sri Sathya Sai Central Trust. Totally 41 solar power generation plants of different capacities installed in Prasanthinilayam were considered for this study. The details of these plants are given in Annex 1.

Data collection

The capacity utilization factor (CUF) of each solar energy plant was collected on a daily basis for the entire calendar year of 2023. The daily data on weather variables related to Prasanthinilayam were collected from wunderground.com and weather.com databases. The data collected was cleaned and finally a total of 4,79,560 data points were used for analysis.

Data analysis

Regression analysis: Based on the research design adopted for the study, the regression model developed was run separately for:

- All the solar plants aggregated for the entire year
- The solar plants with smaller capacity (less than 50 kWp) aggregated for the entire year
- The solar plants with larger capacity (50 kWp or more) aggregated for the entire year
- All the solar plants for the summer season (February 15 to July 15) at Prasanthinilayam
- All the solar plants for the monsoon season (July 16 to October 15) at Prasanthinilayam
- All the solar plants for winter season (October 16 to February 14) at Prasanthinilayam

Each of the above regressions were performed under three temporal conditions:

- Daily regression (t0): In this analysis the daily data of weather variables and the CUF of solar plants were regressed.
- One day lagged regression (t-1): In this analysis, the daily data of weather variables were regressed with one day lagged data of the CUF of solar plants.
- Two days lagged regression (t-2): In this analysis, the daily data of weather variables were correlated with two days lagged data of the CUF of solar plants.

Therefore, a total of 18 full cases of regression studies were performed for the study.

5. RESULTS OF THE STUDY

The results of study are presented in this section under the heads goodness of fit statistics and regression results.

Goodness of fit.

To understand the goodness of fit of the regression studies, the F statistic and the r^2 values in each case of regression was studied. Table 1 below gives the details of the F values of the regression studies.

Table 1. F statistic of the regression studies

Regression Model	t0		t-1		t-2	
	F value	Sig	F value	Sig	F value	Sig
All the solar plants aggregated for the entire year	300.31	0.00	173.52	0.00	125.14	0.00
The solar plants with smaller capacity (less than 50 kWp) aggregated for the entire year	227.33	0.00	125.85	0.00	89.85	0.00
The solar plants with larger capacity (50 kWp or more) aggregated for the entire year	72.11	0.00	44.37	0.00	32.09	0.00
All the solar plants for the Summer season	72.03	0.00	42.67	0.00	43.13	0.00
All the solar plants for the Winter season	144.34	0.00	94.33	0.00	80.90	0.00
All the solar plants for the Monsoon season	112.19	0.00	69.56	0.00	66.17	0.00

Note: The shaded cells show values which are significant at 95% confidence level

An analysis of Table 1 shows that the F statistic in each of the 18 cases are significant based on their p-values. Discussing the importance of analysing the F statistic in regression, Sureiman and Mangera (2020) emphasised that the statistic indicates whether the regression model provides a better fit to the data than a model that contains no independent variables. If the p-value of the F statistic is significant, there is sufficient evidence to conclude that the regression model fits the data better than the model with no predictor variables.

Table 2 gives the details of r^2 of the regression studies. The r^2 of all the 18 cases vary between 0.21 and 0.55. Ozili (2023) discussed the acceptable r^2 in empirical modelling for social science research and stated that a r^2 that is between 0.10 and 0.50 is acceptable only when some or most of the explanatory variables are statistically significant. Where the r^2 is between 0.51 and 0.99, it is acceptable when most of the explanatory variables are statistically significant. Using this approach, the percentage of variables that were significant at 95% confidence level in each of 18 regression studies are also presented in Table 2.

Table 2 shows that in 2 out of 18 cases, the r^2 is greater 0.50 and in 16 out of the 18 cases, the r^2 is between 0.21 and 0.50. In 14 of these 18 cases (78%) a majority of the explanatory variables are significant at 95% confidence level. It is only in 1 case, less than 40% of the regression variables are significant.

Therefore, while Table 1 shows that all the regression models have a good fit based on the F statistic, Table 2 shows that based on the r^2 in all cases, except one, there are clear indications of good fit. Based on goodness of fit of the regression analysis, the results of the study are presented next.

Table 2. Details of r^2 of the regression studies

Regression Model	t0		t-1		t-2	
	r^2	**% of significant variables**	**r^2**	**% of significant variables**	**r^2**	**% of significant variables**
All the solar plants aggregated for the entire year	0.45	63%	0.32	60%	0.25	74%
The solar plants with smaller capacity (less than 50 kWp) aggregated for the entire year	0.46	51%	0.32	63%	0.25	74%
The solar plants with larger capacity (50 kWp or more) aggregated for the entire year	0.41	40%	0.30	29%	0.24	46%
All the solar plants for the Summer season	0.31	63%	0.21	77%	0.21	69%
All the solar plants for the Winter season	0.55	50%	0.45	47%	0.41	71%
All the solar plants for the Monsoon season	0.54	63%	0.42	86%	0.41	83%

Regression results

The entire results of the 18 full cases of regression analysis are presented in Annex 3 from Table 6 to Table 11. Figures 1 to 3 capture the overall relationship between weather variables and solar energy production across the three temporal situations of t0, t-1 and t-2 for all solar plants across the entire year.

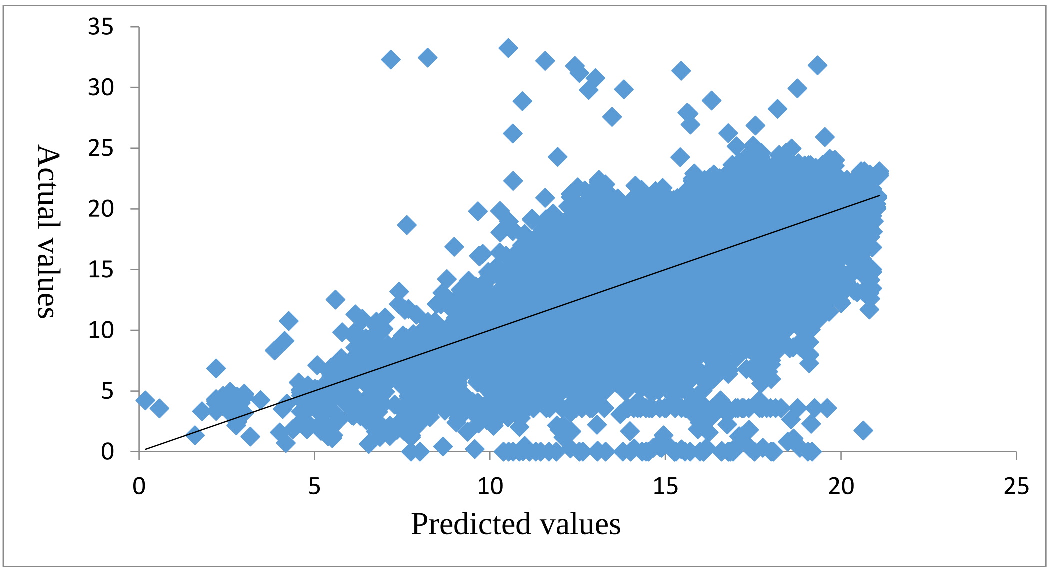

Fig 1. Scatter plot of actual and predicted values for t0 regression analysis

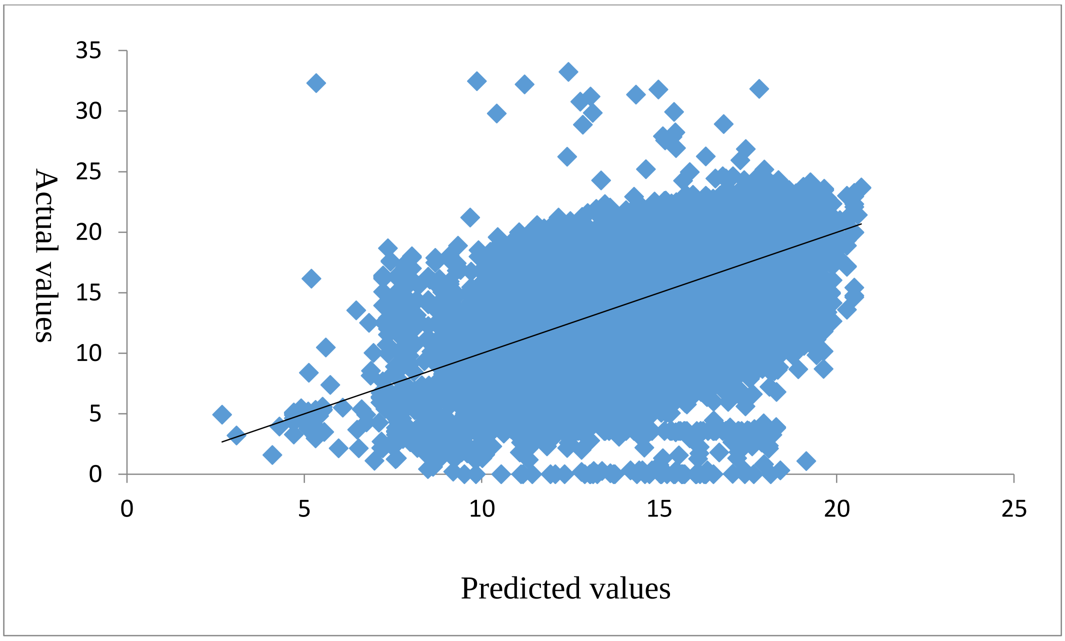

Fig 2. Scatter plot of actual and predicted values for t-1 regression analysis

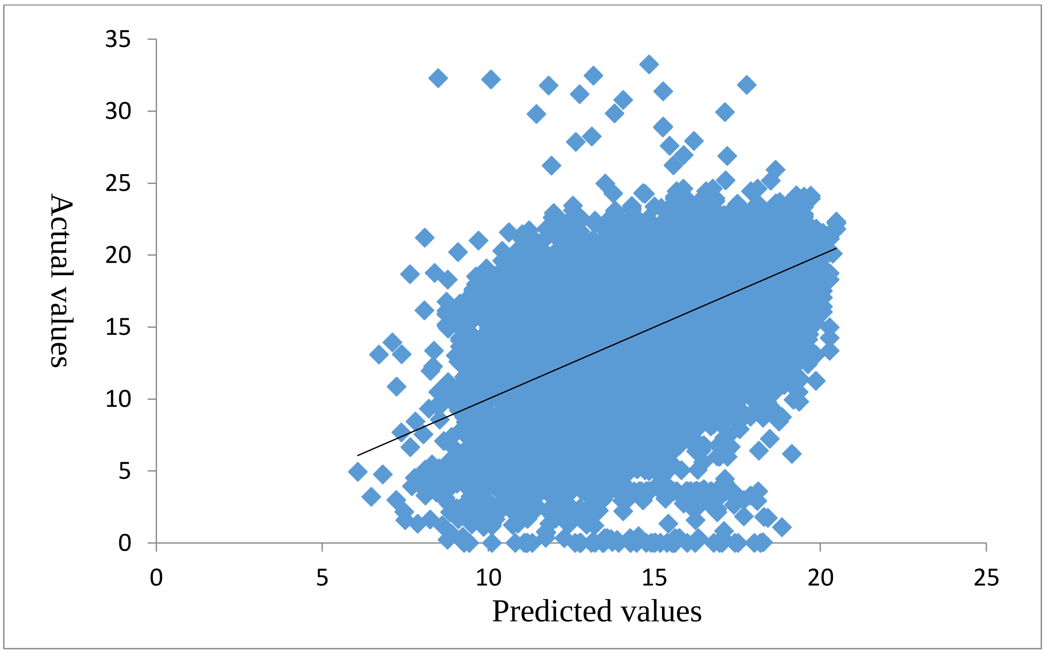

Fig 3. Scatter plot of actual and predicted values for t-2 regression analysis

Tables 6 to 11 show the overall results of the regression analysis. To understand the specific insights from these results, the most significant variables in each of the 18 cases have been identified and presented in the next section.

Table 3. Most significant weather variables

Classification	t0		t-1		t-2	
	Highest Negative impact	**Highest Positive impact**	**Highest Negative impact**	**Highest Positive impact**	**Highest Negative impact**	**Highest Positive impact**
All seasons - All capacities	Minimum full day atmospheric pressure	Minimum daytime atmospheric pressure	Average daytime relative humidity	Minimum daytime dew point temperature	Minimum full day atmospheric pressure	Minimum daytime atmospheric pressure
All seasons - Smaller capacity plants (<50 kWp)	Minimum full day atmospheric pressure	Average full day atmospheric pressure	Average daytime relative humidity	Minimum daytime dew point temperature	Minimum full day atmospheric pressure	Minimum daytime relative humidity
All seasons - Larger capacity plants (>50 kWp)	Average daytime atmospheric pressure	Average full day atmospheric pressure	Average daytime relative humidity	Minimum daytime dew point temperature	Average daytime relative humidity	Minimum daytime relative humidity
Summer season - All capacities	Minimum daytime dew point temperature	Average daytime dew point temperature	Minimum full day atmospheric pressure	Average daytime dew point temperature	Minimum daytime dew point temperature	Average daytime dew point temperature
Winter season - All capacities	Average full day temperature	Average daytime dew point temperature	Average daytime relative humidity	Average daytime atmospheric pressure	Minimum daytime dew point temperature	Minimum full day relative humidity
Monsoon season - All capacities	Minimum full day atmospheric pressure	Minimum daytime atmospheric pressure	Minimum daytime atmospheric pressure	Minimum full day atmospheric pressure	Minimum full day atmospheric pressure	Minimum full day atmospheric pressure

6. INSIGHTS AND DISCUSSION

Table 3 identified the most significant variables that impact the production of solar energy in each of the 18 cases. The important insights that can be derived from this include:

- At the daily (t0) level of analysis the atmospheric pressure is the most significant variable of solar energy production. While Kadampur (2024) showed the importance of atmospheric pressure in solar energy production in the Saudi Arabian context, the current study showed the importance of this weather variable pressure as a predictor of green energy production in the Indian context.
- At the one-day lag (t-1) level of analysis while relative humidity has the most significant positive impact, the dew point temperature has the most significant negative impact on solar energy production. Nicoletti and Bevilacqua (2024) and Salemdeeb and Wadi (2024) explained the importance of humidity and dew point temperature in impacting solar energy production. Similar to these studies, the current study has shown the importance of these variables at the t-1 level.
- At the two-day lag (t-2) level of analysis it is interesting to note that all the three variables namely atmospheric pressure, relative humidity and dew point temperature have a significant impact on solar energy production.

It is interesting to note that out of the several weather variables analyzed, mainly three variables atmospheric pressure, relative humidity and dew point temperature have significant impact on solar energy production.

Some of the results obtained in this study are similar to other studies done in India to understand the influence of weather variables on solar energy production, which include the importance of the duration of solar radiation, the day temperatures and the wind conditions (Jain, 2021; Vasisht, et al, 2016). However, the current study has provided additional insights in pointing out the impact of atmospheric pressure, relative humidity and dew point temperature as significant weather variables on solar energy production, which were not covered in previous studies in the Indian context.

7. CONCLUSION

The study underscores the critical significance of transitioning to green energy sources, particularly solar energy, given the detrimental impacts of conventional energy generation methods on the environment. Through a comprehensive analysis of weather variables' influence on solar energy production, exemplified by the Sai Mithra project, the research offers valuable insights for enhancing operational efficiencies and fostering green energy ecosystems. Key findings reveal the pivotal role of atmospheric pressure, relative humidity and dew point temperature in impacting solar energy generation, leading to a nuanced understanding essential for advancing sustainable energy practices.

DEDICATION

The authors humbly dedicate the paper to Bhagawan Sri Sathya Sai Baba, the Founder Chancellor of Sri Sathya Sai Institute of Higher Learning, Prasanthinilayam, India.

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ANNEX 1

Table 4. Details of selected Solar energy plants of Sai Mithra project

Sl No	Location	Capacity (Kw)
1	Bakery	50
2	Chaitanya Jyothi	150
3	Ice cream stall	50
4	Information Technology office	50
5	Institute campus	50
6	Ladies Sevadal block	50
7	North Block 1	20
8	North Block 2	20
9	North Block 3	40
10	North Block 4	40
11	North Block 5	40
12	North Block 6	20

13	North Block 7	20
14	North Block 8	20
15	North Block 9	40
16	North Indian canteen	20
17	Paatashala Block	15
18	Planetarium	130
19	Radio Sai 1	20
20	Radio Sai 2	30
21	Round Building 1	10
22	Round Building 2	10
23	Round Building 3	10
24	Round Building 4	20
25	Round Building 5	20
26	Sai Kulwant Hall 1	50
27	Sai Kulwant Hall 2	40
28	Sewage Treatment plant	80
29	Shanti Bhavan	50
30	Shopping complex	50
31	South Block 1A	20
32	South Blocks 1 and 2	20
33	South Blocks 7 and 9	30
34	South Indian canteen	70
35	Sri Sathya Sai Airport	10
36	West Block 9	30
37	West Blocks 3 and 4 A	30
38	West Blocks 3 and 4 B	30
39	West Blocks 5 and 6 A	30
40	West Blocks 5 and 6 B	30
41	West Blocks 7 and 8 A	30
42	West Blocks 7 and 8 B	30

ANNEX 2

Table 5. Weather variables used in the study

Sl No	Weather Variable	Units
Full day weather variables (24 hrs)		
1	Minimum full day temperature	Fahrenheit
2	Maximum full day temperature	Fahrenheit
3	Average full day temperature	Fahrenheit
4	Maximum full day dew point temperature	Fahrenheit

5	Average full day dew point temperature	Fahrenheit
6	Maximum full day relative humidity	Percentage
7	Minimum full day relative humidity	Percentage
8	Average full day relative humidity	Percentage
9	Maximum full day wind speed	Miles per hour
10	Minimum full day wind speed	Miles per hour
11	Average full day wind speed	Miles per hour
12	Maximum full day atmospheric pressure	Inches
13	Minimum full day atmospheric pressure	Inches
14	Average full day atmospheric pressure	Inches
15	Full day not calm wind conditions	Hours
16	Full day not fair-weather conditions	Hours
Daytime weather variables		
17	Daytime duration	Minutes
18	Minimum daytime temperature	Fahrenheit
19	Average daytime temperature	Fahrenheit
20	Maximum daytime dew point temperature	Fahrenheit
21	Minimum daytime dew point temperature	Fahrenheit
22	Average daytime dew point temperature	Fahrenheit
23	Maximum daytime relative humidity	Percentage
24	Minimum daytime relative humidity	Percentage
25	Average daytime relative humidity	Percentage
26	Maximum daytime wind speed	Miles per hour
27	Minimum daytime wind speed	Miles per hour
28	Average daytime wind speed	Miles per hour
29	Maximum daytime atmospheric pressure	Inches
30	Minimum daytime atmospheric pressure	Inches
31	Average daytime atmospheric pressure	Inches
32	Daytime not calm wind conditions	Hours
33	Daytime not fair-weather conditions	Hours
Variables excluded		
1	Minimum full day dew point temperature	Fahrenheit
2	Full day calm wind conditions	Hours
3	Full day fair weather conditions	Hours
4	Daytime calm wind conditions	Hours
5	Daytime fair weather conditions	Hours

Note: As the maximum full day temperature is same as the maximum daytime temperature, it has not been mentioned among daytime weather variables.

ANNEX 3

Table 6. Regression results for all the solar plants aggregated for the entire year

Variable	t0		t-1		t-2	
	Beta	**Sig**	**Beta**	**Sig**	**Beta**	**Sig**
Constant	-37.04	0.11	-100.75	0.00	-124.92	0.00
Installed capacity of the solar plant	-0.13	0.00	-0.13	0.00	-0.13	0.00
Day time duration	0.18	0.00	0.28	0.00	0.27	0.00
Minimum full day temperature	-0.05	0.33	0.07	0.16	0.21	0.00
Average full day temperature	-0.19	0.05	-0.20	0.05	-0.70	0.00
Maximum full day dew point temperature	0.08	0.01	0.08	0.02	-0.06	0.09
Average full day dew point temperature	-0.23	0.00	0.25	0.01	0.56	0.00
Maximum full day relative humidity	0.06	0.01	0.15	0.00	0.09	0.00
Minimum full day relative humidity	0.56	0.00	-0.77	0.00	-0.25	0.00
Average full day relative humidity	0.12	0.07	-0.10	0.16	-0.49	0.00
Maximum full day wind speed	-0.08	0.00	-0.06	0.00	-0.10	0.00
Minimum full day wind speed	-0.08	0.00	0.03	0.00	0.00	0.92
Average full day wind speed	0.07	0.00	0.09	0.00	0.11	0.00
Maximum full day atmospheric pressure	-0.18	0.00	0.28	0.00	0.36	0.00
Minimum full day atmospheric pressure	-1.49	0.00	-0.65	0.26	-1.40	0.02
Average full day atmospheric pressure	0.71	0.00	-0.17	0.19	-0.41	0.00
Full day not calm wind conditions	0.10	0.00	-0.06	0.00	0.04	0.07
Full day not fair-weather conditions	-0.20	0.00	0.01	0.62	0.04	0.16
Maximum full day/daytime temperature	0.29	0.00	0.12	0.03	0.59	0.00
Minimum daytime temperature	0.02	0.61	0.05	0.28	0.15	0.00
Average daytime temperature	-0.23	0.01	-0.30	0.00	-0.46	0.00

Maximum daytime dew point temperature	0.28	0.00	0.00	0.97	0.56	0.00
Minimum daytime dew point temperature	-0.05	0.68	0.67	0.00	-0.07	0.65
Average daytime dew point temperature	-0.21	0.26	0.07	0.74	-0.55	0.01
Maximum daytime relative humidity	0.01	0.74	0.23	0.00	0.34	0.00
Minimum daytime relative humidity	-0.35	0.00	-0.03	0.56	0.78	0.00
Average daytime relative humidity	-0.58	0.00	-0.99	0.00	-1.24	0.00
Maximum daytime wind speed	0.01	0.71	-0.02	0.39	-0.07	0.00
Minimum daytime wind speed	0.02	0.16	-0.05	0.00	0.03	0.08
Average daytime wind speed	0.03	0.15	0.02	0.36	0.02	0.58
Maximum daytime atmospheric pressure	0.02	0.80	0.24	0.00	0.01	0.90
Minimum daytime atmospheric pressure	1.08	0.04	0.61	0.30	0.87	0.16
Average daytime atmospheric pressure	-0.13	0.40	-0.23	0.18	0.64	0.00
Daytime not calm wind conditions	-0.12	0.00	-0.10	0.00	-0.13	0.00
Daytime not fair-weather conditions	0.02	0.34	-0.07	0.00	-0.09	0.00

Table 7. Regression results for the solar plants with smaller capacity (less than 50 kWp) aggregated for the entire year

Variable	**t0**		**t-1**		**t-2**	
	Beta	**Sig**	**Beta**	**Sig**	**Beta**	**Sig**
Constant	-32.56	0.22	-107.44	0.00	-127.56	0.00
Installed capacity of the solar plant	-0.07	0.00	-0.07	0.00	-0.07	0.00
Day time duration	0.17	0.00	0.28	0.00	0.27	0.00
Minimum full day temperature	-0.06	0.26	0.10	0.09	0.19	0.00
Average full day temperature	-0.19	0.08	-0.26	0.03	-0.67	0.00
Maximum full day dew point temperature	0.06	0.06	0.06	0.13	-0.08	0.05
Average full day dew point temperature	-0.14	0.12	0.33	0.00	0.69	0.00

Maximum full day relative humidity	0.07	0.01	0.17	0.00	0.10	0.00
Minimum full day relative humidity	0.58	0.00	-0.83	0.00	-0.27	0.01
Average full day relative humidity	0.07	0.38	-0.17	0.04	-0.54	0.00
Maximum full day wind speed	-0.09	0.00	-0.07	0.00	-0.09	0.00
Minimum full day wind speed	-0.08	0.00	0.04	0.00	0.00	0.85
Average full day wind speed	0.10	0.00	0.12	0.00	0.13	0.00
Maximum full day atmospheric pressure	-0.21	0.00	0.26	0.00	0.37	0.00
Minimum full day atmospheric pressure	-1.73	0.00	-0.71	0.30	-1.39	0.05
Average full day atmospheric pressure	0.68	0.00	-0.17	0.27	-0.48	0.00
Full day not calm wind conditions	0.09	0.00	-0.09	0.00	0.04	0.11
Full day not fair-weather conditions	-0.19	0.00	0.01	0.86	0.02	0.49
Maximum full day/daytime temperature	0.31	0.00	0.15	0.02	0.60	0.00
Minimum daytime temperature	0.05	0.27	0.07	0.16	0.14	0.01
Average daytime temperature	-0.30	0.01	-0.35	0.00	-0.52	0.00
Maximum daytime dew point temperature	0.33	0.00	-0.03	0.80	0.63	0.00
Minimum daytime dew point temperature	-0.01	0.95	0.66	0.00	-0.09	0.60
Average daytime dew point temperature	-0.32	0.14	0.16	0.52	-0.62	0.02
Maximum daytime relative humidity	0.00	0.96	0.24	0.00	0.31	0.00
Minimum daytime relative humidity	-0.39	0.00	-0.02	0.75	0.79	0.00
Average daytime relative humidity	-0.58	0.00	-1.03	0.00	-1.25	0.00
Maximum daytime wind speed	0.00	0.89	-0.01	0.71	-0.09	0.00
Minimum daytime wind speed	0.02	0.14	-0.05	0.00	0.03	0.10
Average daytime wind speed	0.03	0.36	0.01	0.76	0.01	0.69

Maximum daytime atmospheric pressure	-0.05	0.50	0.27	0.00	0.03	0.76
Minimum daytime atmospheric pressure	1.20	0.05	0.68	0.33	0.80	0.27
Average daytime atmospheric pressure	0.11	0.54	-0.24	0.23	0.75	0.00
Daytime not calm wind conditions	-0.13	0.00	-0.10	0.00	-0.14	0.00
Daytime not fair-weather conditions	0.01	0.77	-0.07	0.01	-0.08	0.01

Table 8. Regression results for the solar plants with larger capacity (50 kWp or more) aggregated for the entire year

Variable	t0		t-1		t-2	
	Beta	Sig	Beta	Sig	Beta	Sig
Constant	-47.50	0.32	-82.93	0.11	-117.26	0.03
Installed capacity of the solar plant	-0.11	0.00	-0.11	0.00	-0.11	0.00
Day time duration	0.21	0.00	0.29	0.00	0.27	0.00
Minimum full day temperature	-0.01	0.94	0.01	0.95	0.27	0.01
Average full day temperature	-0.18	0.32	-0.06	0.75	-0.78	0.00
Maximum full day dew point temperature	0.11	0.06	0.12	0.05	-0.01	0.90
Average full day dew point temperature	-0.44	0.01	0.06	0.71	0.26	0.14
Maximum full day relative humidity	0.04	0.40	0.10	0.04	0.08	0.12
Minimum full day relative humidity	0.52	0.00	-0.65	0.00	-0.19	0.24
Average full day relative humidity	0.25	0.06	0.06	0.67	-0.38	0.01
Maximum full day wind speed	-0.07	0.03	-0.04	0.23	-0.12	0.00
Minimum full day wind speed	-0.08	0.00	0.01	0.62	0.00	0.92
Average full day wind speed	0.01	0.76	0.02	0.70	0.06	0.20
Maximum full day atmospheric pressure	-0.12	0.35	0.34	0.01	0.34	0.01
Minimum full day atmospheric pressure	-0.94	0.37	-0.53	0.64	-1.44	0.22
Average full day atmospheric pressure	0.80	0.00	-0.18	0.49	-0.24	0.38

Full day not calm wind conditions	0.13	0.00	0.01	0.68	0.04	0.34
Full day not fair-weather conditions	-0.21	0.00	0.03	0.51	0.08	0.14
Maximum full day/daytime temperature	0.25	0.01	0.05	0.66	0.57	0.00
Minimum daytime temperature	-0.05	0.49	-0.01	0.88	0.19	0.03
Average daytime temperature	-0.05	0.77	-0.20	0.31	-0.31	0.13
Maximum daytime dew point temperature	0.17	0.30	0.08	0.66	0.40	0.03
Minimum daytime dew point temperature	-0.16	0.53	0.72	0.01	-0.01	0.96
Average daytime dew point temperature	0.03	0.93	-0.14	0.72	-0.41	0.32
Maximum daytime relative humidity	0.06	0.52	0.20	0.04	0.42	0.00
Minimum daytime relative humidity	-0.25	0.02	-0.06	0.59	0.76	0.00
Average daytime relative humidity	-0.62	0.00	-0.92	0.00	-1.24	0.00
Maximum daytime wind speed	0.02	0.65	-0.04	0.33	-0.01	0.80
Minimum daytime wind speed	0.01	0.72	-0.03	0.32	0.02	0.50
Average daytime wind speed	0.06	0.24	0.06	0.24	0.02	0.70
Maximum daytime atmospheric pressure	0.18	0.16	0.18	0.21	-0.03	0.83
Minimum daytime atmospheric pressure	-0.72	0.02	-0.20	0.54	0.37	0.29
Average daytime atmospheric pressure	-0.11	0.00	-0.11	0.00	-0.10	0.00
Daytime not calm wind conditions	0.05	0.23	-0.07	0.13	-0.11	0.02
Daytime not fair-weather conditions	0.80	0.45	0.46	0.69	1.06	0.37

Table 9. Regression results all the solar plants for the summer season

Variable	t0		t-1		t-2	
	Beta	**Sig**	**Beta**	**Sig**	**Beta**	**Sig**
Constant	-182.88	0.00	-261.65	0.00	-318.62	0.00
Installed capacity of the solar plant	-0.10	0.00	-0.10	0.00	-0.10	0.00

Day time duration	-0.29	0.00	-0.24	0.00	-0.63	0.00
Minimum full day temperature	-0.14	0.06	-0.29	0.00	-0.17	0.04
Average full day temperature	1.20	0.00	1.56	0.00	1.00	0.00
Maximum full day dew point temperature	-0.11	0.02	-0.03	0.56	-0.46	0.00
Average full day dew point temperature	-1.12	0.00	-0.64	0.00	0.22	0.22
Maximum full day relative humidity	-0.20	0.00	-0.26	0.00	-0.25	0.00
Minimum full day relative humidity	0.23	0.06	-1.31	0.00	-0.77	0.00
Average full day relative humidity	2.00	0.00	2.01	0.00	1.44	0.00
Maximum full day wind speed	-0.20	0.00	-0.12	0.00	-0.17	0.00
Minimum full day wind speed	0.01	0.50	0.01	0.53	-0.01	0.78
Average full day wind speed	0.18	0.00	0.20	0.00	0.19	0.00
Maximum full day atmospheric pressure	-0.13	0.19	0.38	0.00	0.78	0.00
Minimum full day atmospheric pressure	0.27	0.69	-1.77	0.01	0.56	0.44
Average full day atmospheric pressure	-0.23	0.26	-0.44	0.04	-1.49	0.00
Full day not calm wind conditions	0.00	1.00	-0.18	0.00	0.17	0.00
Full day not fair-weather conditions	-0.61	0.00	-0.43	0.00	-0.28	0.00
Maximum full day/daytime temperature	0.01	0.89	-0.52	0.00	0.28	0.00
Minimum daytime temperature	-0.22	0.00	-0.23	0.00	0.08	0.11
Average daytime temperature	-0.14	0.29	0.04	0.80	-0.30	0.04
Maximum daytime dew point temperature	-1.65	0.00	-1.40	0.00	-1.26	0.00
Minimum daytime dew point temperature	-2.31	0.00	-0.08	0.85	-2.15	0.00
Average daytime dew point temperature	4.25	0.00	2.76	0.00	3.47	0.00
Maximum daytime relative humidity	-0.33	0.00	-0.30	0.00	-0.11	0.17

Minimum daytime relative humidity	-0.22	0.01	-0.99	0.00	0.33	0.00
Average daytime relative humidity	-0.58	0.00	0.21	0.25	-0.26	0.15
Maximum daytime wind speed	0.12	0.00	0.03	0.39	-0.02	0.50
Minimum daytime wind speed	-0.02	0.25	0.00	0.99	0.03	0.18
Average daytime wind speed	-0.07	0.06	-0.10	0.01	-0.06	0.13
Maximum daytime atmospheric pressure	0.25	0.01	0.65	0.00	0.61	0.00
Minimum daytime atmospheric pressure	-0.17	0.81	2.63	0.00	-0.50	0.50
Average daytime atmospheric pressure	0.13	0.59	-1.24	0.00	0.30	0.22
Daytime not calm wind conditions	-0.17	0.00	0.00	0.84	-0.15	0.00
Daytime not fair-weather conditions	0.29	0.00	0.26	0.00	0.19	0.00

Table 10. Regression results all the solar plants for the winter season

Variable	t0		t-1		t-2	
	Beta	Sig	Beta	Sig	Beta	Sig
Constant	-108.55	0.04	-109.15	0.06	146.97	0.02
Installed capacity of the solar plant	-0.15	0.00	-0.15	0.00	-0.15	0.00
Day time duration	0.02	0.37	0.18	0.00	0.33	0.00
Minimum full day temperature	0.11	0.22	0.42	0.00	0.54	0.00
Average full day temperature	-0.77	0.00	-0.99	0.00	-2.27	0.00
Maximum full day dew point temperature	-0.14	0.07	-0.27	0.00	0.33	0.00
Average full day dew point temperature	0.80	0.00	0.96	0.00	1.47	0.00
Maximum full day relative humidity	0.09	0.01	0.26	0.00	0.22	0.00
Minimum full day relative humidity	0.58	0.00	-0.12	0.48	1.99	0.00
Average full day relative humidity	-0.31	0.12	-0.55	0.01	-1.97	0.00
Maximum full day wind speed	0.15	0.00	0.05	0.20	0.08	0.06

Minimum full day wind speed	-0.07	0.00	0.00	0.91	0.03	0.28
Average full day wind speed	-0.18	0.00	0.02	0.79	-0.04	0.53
Minimum full day atmospheric pressure	0.34	0.00	0.18	0.07	-0.28	0.01
Average full day atmospheric pressure	-0.38	0.02	-0.28	0.11	0.38	0.04
Full day not calm wind conditions	0.01	0.85	-0.14	0.00	-0.23	0.00
Full day not fair-weather conditions	-0.19	0.00	0.06	0.16	0.11	0.02
Maximum full day/daytime temperature	0.02	0.81	0.38	0.00	-0.11	0.29
Minimum daytime temperature	0.03	0.73	0.17	0.11	0.27	0.01
Average daytime temperature	0.35	0.04	-0.22	0.27	0.74	0.00
Maximum daytime dew point temperature	0.00	0.99	0.53	0.00	-1.03	0.00
Minimum daytime dew point temperature	-0.61	0.01	-0.43	0.09	-3.63	0.00
Average daytime dew point temperature	-0.15	0.62	-0.43	0.22	1.55	0.00
Maximum daytime relative humidity	0.05	0.56	0.11	0.18	0.61	0.00
Minimum daytime relative humidity	-0.31	0.00	0.72	0.00	0.46	0.00
Average daytime relative humidity	-0.22	0.21	-1.06	0.00	-0.04	0.86
Maximum daytime wind speed	-0.21	0.00	-0.07	0.14	-0.04	0.43
Minimum daytime wind speed	0.00	0.94	0.02	0.49	0.23	0.00
Average daytime wind speed	0.25	0.00	-0.03	0.61	-0.23	0.00
Maximum daytime atmospheric pressure	0.21	0.07	-0.06	0.62	-0.04	0.79
Minimum daytime atmospheric pressure	-0.24	0.08	-0.92	0.00	-0.09	0.54
Average daytime atmospheric pressure	0.12	0.63	1.11	0.00	-0.04	0.88
Daytime not calm wind conditions	-0.03	0.30	-0.05	0.16	0.06	0.07
Daytime not fair-weather conditions	-0.04	0.22	-0.09	0.01	-0.17	0.00

Table 11. Regression results all the solar plants for the monsoon season

Variable	t0		t-1		t-2	
	Beta	Sig	Beta	Sig	Beta	Sig
Constant	-93.29	0.16	-558.26	0.00	-496.81	0.00
Installed capacity of the solar plant	-0.15	0.00	-0.15	0.00	-0.15	0.00
Day time duration	-0.05	0.01	-0.07	0.00	-0.27	0.00
Minimum full day temperature	-0.04	0.26	0.15	0.00	0.38	0.00
Average full day temperature	0.43	0.00	-0.77	0.00	-1.19	0.00
Maximum full day dew point temperature	-0.17	0.00	-0.23	0.00	-0.19	0.00
Average full day dew point temperature	0.04	0.61	-0.01	0.89	0.57	0.00
Maximum full day relative humidity	0.05	0.23	0.30	0.00	0.28	0.00
Minimum full day relative humidity	-0.18	0.09	-0.93	0.00	-0.57	0.00
Average full day relative humidity	0.13	0.07	-0.17	0.04	-0.53	0.00
Maximum full day wind speed	-0.04	0.13	-0.12	0.00	-0.05	0.06
Minimum full day wind speed	-0.09	0.00	0.12	0.00	0.15	0.00
Average full day wind speed	0.14	0.00	0.15	0.00	0.46	0.00
Maximum full day atmospheric pressure	-0.13	0.11	0.31	0.00	-0.26	0.00
Minimum full day atmospheric pressure	-1.71	0.01	2.53	0.00	-4.97	0.00
Average full day atmospheric pressure	0.46	0.00	-0.50	0.00	-0.18	0.18
Full day not calm wind conditions	0.23	0.00	0.30	0.00	0.03	0.51
Full day not fair-weather conditions	0.05	0.13	0.03	0.51	-0.02	0.63
Maximum full day/daytime temperature	-0.01	0.91	0.49	0.00	-0.33	0.00
Minimum daytime temperature	-0.32	0.00	0.43	0.00	0.17	0.02
Average daytime temperature	0.63	0.00	0.10	0.59	1.54	0.00

Maximum daytime dew point temperature	0.49	0.00	0.00	0.97	0.57	0.00
Minimum daytime dew point temperature	0.28	0.02	0.33	0.02	0.90	0.00
Average daytime dew point temperature	-0.59	0.00	0.68	0.00	-1.53	0.00
Maximum daytime relative humidity	-0.35	0.00	0.26	0.01	0.27	0.01
Minimum daytime relative humidity	-0.31	0.00	0.58	0.00	-0.09	0.44
Average daytime relative humidity	0.69	0.00	-0.94	0.00	0.50	0.03
Maximum daytime wind speed	0.04	0.20	0.11	0.00	-0.01	0.87
Minimum daytime wind speed	0.11	0.00	-0.16	0.00	-0.09	0.00
Average daytime wind speed	-0.12	0.01	0.01	0.83	-0.18	0.00
Maximum daytime atmospheric pressure	-0.03	0.71	-0.27	0.00	-0.55	0.00
Minimum daytime atmospheric pressure	1.70	0.01	-3.02	0.00	4.39	0.00
Average daytime atmospheric pressure	-0.28	0.12	1.13	0.00	1.67	0.00
Daytime not calm wind conditions	-0.12	0.00	-0.32	0.00	-0.09	0.02
Daytime not fair-weather conditions	-0.17	0.00	-0.10	0.00	-0.12	0.00

Note: In all Tables, the shaded cells represent variables which are significant at 95% confidence level