



**HAL**  
open science

# **Performance and Environmental Impact of a 45 kWp Rooftop Grid-connected Solar PV System in a Semi-arid Academic Campus: A Case Study from Western India**

Rajesh Yadav, Anshu Kumari, H J Vyas

## **► To cite this version:**

Rajesh Yadav, Anshu Kumari, H J Vyas. Performance and Environmental Impact of a 45 kWp Rooftop Grid-connected Solar PV System in a Semi-arid Academic Campus: A Case Study from Western India. *Journal of Scientific Research and Reports*, 2025, 31 (4), pp.693-702. <10.9734/jsrr/2025/v31i42993>. <hal-05042922>

**HAL Id: hal-05042922**

**<https://hal.science/hal-05042922v1>**

Submitted on 22 Apr 2025

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons CC BY 4.0 - Attribution - International License



# Performance and Environmental Impact of a 45 kWp Rooftop Grid-connected Solar PV System in a Semi-arid Academic Campus: A Case Study from Western India

Rajesh Yadav <sup>a\*</sup>, Anshu Kumari <sup>a</sup> and H. J. Vyas <sup>b</sup>

<sup>a</sup> Indian Institute of Technology Kharagpur, West Bengal, 721302, India.

<sup>b</sup> Junagadh Agricultural University, Gujarat, 362001, India.

## Authors' contributions

This work was carried out in collaboration among all authors. Author RY designed the study, performed the statistical analysis, wrote the protocol, wrote the first draft of the manuscript, and managed the analyses of the study. Author AK in first draft of the manuscript, helped in literature searches. Author HJV supervised the project. All authors read and approved the final manuscript.

## Article Information

DOI: <https://doi.org/10.9734/jsrr/2025/v31i42993>

## Open Peer Review History:

This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: <https://pr.sdiarticle5.com/review-history/134651>

Original Research Article

Received: 16/02/2025

Accepted: 18/04/2025

Published: 21/04/2025

## ABSTRACT

**Aims:** This study aimed to evaluate the technical performance and environmental impact of a 45 kWp rooftop grid-connected solar photovoltaic (PV) system installed at the College of Agricultural Engineering and Technology (CAET), Junagadh Agricultural University, Gujarat.

**Methodology:** The system was monitored over five months (August–December 2018). Real-time data on energy output, meteorological parameters, and system efficiencies were recorded.

\*Corresponding author: E-mail: [rajeshyadav.iitkgp@gmail.com](mailto:rajeshyadav.iitkgp@gmail.com), [rajeshyadav2501@gmail.com](mailto:rajeshyadav2501@gmail.com);

**Cite as:** Yadav, Rajesh, Anshu Kumari, and H. J. Vyas. 2025. "Performance and Environmental Impact of a 45 KWp Rooftop Grid-Connected Solar PV System in a Semi-Arid Academic Campus: A Case Study from Western India". *Journal of Scientific Research and Reports* 31 (4):693-702. <https://doi.org/10.9734/jsrr/2025/v31i42993>.

Performance metrics such as array yield, final yield, module and system efficiencies, performance ratio (PR), and CO<sub>2</sub> emission reduction were analyzed using IEC 61724 guidelines.

**Results:** The system generated 22,205 kWh of DC energy and exported 20,829.26 kWh of AC energy to the grid. It achieved an average final yield of 3.37 kWh/kWp/day and a performance ratio of 71%. The average module, inverter, and system efficiencies were 11.26%, 93.84%, and 10.56% respectively. A total of 20,494 kg of CO<sub>2</sub> emissions were avoided.

**Conclusion:** The solar PV system showed reliable performance and high efficiency across seasonal conditions. It proved effective for reducing institutional carbon footprint and demonstrated the feasibility of rooftop solar adoption in semi-arid academic environments.

*Keywords: Rooftop solar photovoltaic; grid-connected system; performance ratio; energy yield; CO<sub>2</sub> emission reduction.*

## 1. INTRODUCTION

Energy is one of the fundamental requirements for the progress of modern civilization. In the present era, energy plays a crucial role in shaping the economy, infrastructure, and lifestyle of nations. India, being a developing country with a high population density, is witnessing a rapid increase in energy demand due to factors like industrial growth, urbanization, and technological advancement (Dincer, 2000; Cucumo et al., 2005; Twidell, 2021). However, the energy sector in India is still highly dependent on fossil fuels such as coal, petroleum, and natural gas. These non-renewable resources are limited and are causing environmental pollution and greenhouse gas emissions, leading to global warming and climate change. Recognizing the urgency to shift towards cleaner energy sources, India has embraced renewable energy as a viable alternative (Parida et al., 2011; Kumar et al., 2024; Saha and Mandal, 2025). Among all renewable energy sources, solar energy has emerged as one of the most promising due to the country's geographical location, which receives ample sunlight throughout the year. The government has launched initiatives such as the Jawaharlal Nehru National Solar Mission (JNNSM), aiming to establish India as a global leader in solar energy. As a part of this mission, India set an ambitious target of installing 100 GW of solar power capacity by the year 2022 ((Jawaharlal Nehru National Solar Mission (Phase I, II and III) – Policies - IEA, n.d.). Solar photovoltaic (PV) technology, which converts sunlight directly into electricity using semiconductor materials, is at the heart of this transition. Solar PV systems are categorized as off-grid and grid-connected systems. In recent years, grid-connected rooftop solar PV systems have gained popularity due to their potential for decentralized power generation and utilization of idle roof space (Kymakis et al., 2009; Shukla et

al., 2016; Kar et al., 2023; Majdi et al., 2023a; Majdi et al., 2023b; Elmnifi et al., 2024a; Elmnifi et al., 2024b). These systems not only reduce the load on the conventional grid but also offer economic benefits and contribute towards sustainable energy goals.

A number of studies have been conducted worldwide to evaluate the performance of solar PV systems under different climatic and operational conditions. Mondol et al. (2006) analyzed the performance of a 13 kWp rooftop grid-connected PV system and found the monthly average daily PV, system, and inverter efficiencies to vary between 4.5% to 9.2%, 3.6% to 7.8%, and 50% to 87%, respectively. The performance ratio (PR) ranged from 0.29 to 0.66. Ayompe et al. (2010) evaluated a 1.72 kWp system in Ireland, reporting annual energy generation of 885.1 kWh/kWp with PR and system efficiency of 81.5% and 12.6%, respectively. In India, Sharma and Chandel (2013) studied a 190 kWp grid-connected PV plant in Punjab and reported a final yield of 1.45 to 2.84 kWh/kWp/day, reference yield of 2.29 to 3.53 kWh/kWp/day, and PR ranging from 55% to 83%. The average annual energy yield of the plant was 812.76 kWh/kWp with a system efficiency of 8.3%. Kumar and Nagarajan (2016) analyzed an 80 kWp rooftop transformer-less plant, finding a performance ratio of 83.82% and system efficiency of 4.16%. Chaita and Kluabwang (2016) in Thailand studied a 3.5 kWp rooftop system and reported PR from 59% to 76.4%, with annual energy generation of 4869 kWh. Other notable studies include the work of Pundir et al. (2016) at IIT Roorkee and Yadav & Bajpai (2018) at Lucknow University, which provided insights into energy yield, system losses, and CO<sub>2</sub> reduction for rooftop solar plants. Rawat (2018) used PVSYS to simulate a 100 kWp rooftop system and reported a PR of 77.79% and CUF of 18.10%. These studies

contribute significantly to understanding the behavior and performance of solar PV systems under various scenarios. However, most research has focused either on large-scale plants or on simulated performance rather than real-time operational analysis under specific climatic conditions.

While there is extensive literature on the performance of solar PV systems, there is a lack of studies focusing on small-to-medium scale rooftop systems under semi-arid climatic conditions, especially in western India. Most prior work focuses on large-scale or simulated systems, lacking real-world data. Furthermore, very few studies document institutional rooftop solar plants designed for dual purposes—power generation and academic research. While there is extensive literature on the performance of solar PV systems, there is a lack of studies focusing on small-to-medium scale rooftop systems under semi-arid climatic conditions, especially in western India. Most existing studies either deal with megawatt-scale installations or are simulation-based, lacking practical insights from actual field data. Furthermore, very few studies document institutional rooftop solar plants designed for dual purposes—power generation and academic research.

The objectives of this study were to analyze the performance of a 45 kWp rooftop grid-connected solar PV system installed at the College of Agricultural Engineering and Technology (CAET), Junagadh Agricultural University. The study aimed to evaluate energy output, array yield, final yield, and reference yield, along with assessing key performance indicators such as module efficiency, inverter efficiency, and overall system efficiency. Additionally, it sought to determine the performance ratio (PR) and quantify losses including capture losses, system losses, and inverter losses. The performance trends of the system under varying meteorological conditions were also explored

over the monitoring period. Another important objective was to estimate the environmental impact, particularly the reduction in carbon dioxide emissions, achieved through the use of solar energy. Ultimately, this research provided real-world, field-based data that contributes to the existing knowledge base on solar PV systems, especially within the context of institutional setups in semi-arid regions of India.

## 2. MATERIALS AND METHODS

This study was carried out to assess the real-time performance of a 45 kWp rooftop grid-connected solar photovoltaic (PV) power plant installed at the College of Agricultural Engineering and Technology (CAET), Junagadh Agricultural University, Junagadh, Gujarat, India. The methodology used in this study included detailed site analysis, component description, instrumentation, monitoring of operational parameters, meteorological data collection, and performance evaluation through established metrics.

### 2.1 Installed Location and Meteorological Data

The rooftop solar PV system is installed on the main building of CAET, Junagadh Agricultural University, situated at 21.515471° N latitude and 70.4579° E longitude. The location falls under a semi-arid climate with high solar insolation, making it ideal for solar power generation. The system layout covers a total area of approximately 323.34 m<sup>2</sup> and comprises polycrystalline modules. The installed system capacity is 45 kWp, and all electricity generated is directly fed into the grid, as shown in Fig. 1. Meteorological data were collected from the university's meteorological department and verified using NASA datasets. Table 1 provides the monthly averages during the monitoring period.

**Table 1. Metrological data of the location**

Month	Temperature (°C)	Humidity (%)	Rainfall (mm)	No. of rainy days	Wind speed (km/h)	Solar irradiation (kW/m <sup>2</sup> /day)
August	27.70	83	88.60	12	9.3	3.4
September	27.80	71	51.50	5	5.2	5.23
October	29.50	47	00	0	2.7	5.61
November	27.10	47	00	0	2.7	4.82
December	22.00	47	00	0	3.7	4.42
Total			140.10	17		
Mean	25.82	59			4.72	4.67



**Fig. 1. Location of 45 kWp rooftop grid connected solar power plant**

## 2.2 Basic Components of Grid Connected PV System

A grid-connected photovoltaic (PV) system primarily consisted of several key components that worked together to convert solar energy into usable electrical power and feed it into the grid. The core component was the PV module, which captured solar radiation and converted it into direct current (DC) electricity. The PV modules used in the installation are polycrystalline silicon-based, each rated at 315 W. Table 2 summarizes the technical specifications of the modules. These modules were arranged in series-parallel configurations to meet the required system voltage and current. The DC distribution and combiner box gathered outputs from the PV modules and ensured proper circuit protection before directing power to the inverters. The Power

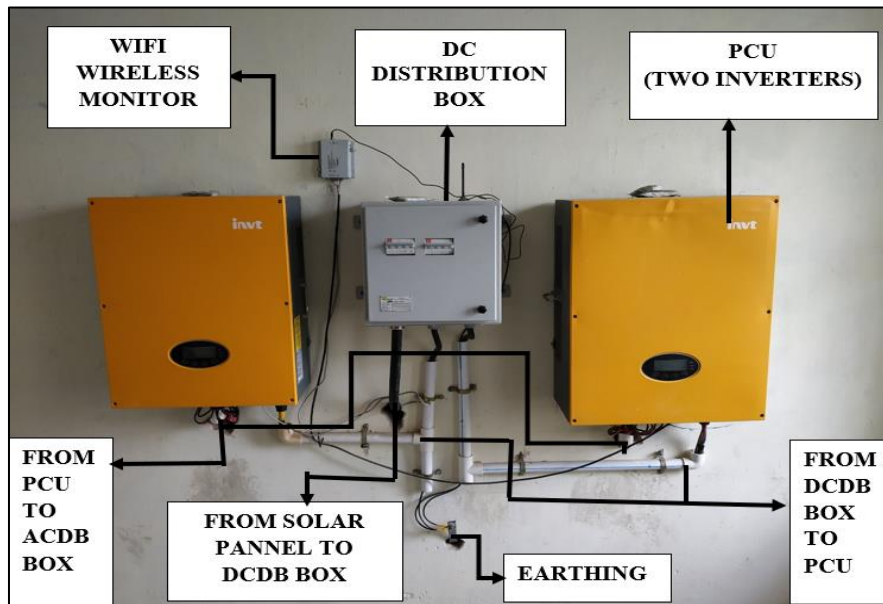
Conditioning Unit (PCU), which included two inverters of 15 kW and 30 kW capacity respectively, converted DC power into alternating current (AC) with the appropriate voltage and frequency for grid compatibility (Fig. 2) and specifications are given in Table 3. The AC distribution box handled the output from the inverters and was equipped with protective devices such as MCCBs, surge protectors, and current transformers (CTs) for accurate energy monitoring and system safety. Additionally, a monitoring system was integrated to track real-time system performance, including voltage, current, and energy output. Other essential components included earthing arrangements, environment monitoring instruments, and net metering equipment such as generation and bi-directional meters, which enabled seamless interaction between the solar power system and the utility grid.

**Table 2. PV module specifications**

Parameter	Specification
1. Power max ( $P_{max}$ )	315 W
2. Voltage at max power ( $V_{max}$ )	36 V
3. Current at max power ( $I_{max}$ )	8.75 A
4. System voltage (V)	1000 V
5. Open circuit voltage ( $V_{oc}$ )	44 V
6. Short circuit current ( $I_{sc}$ )	9.40 A
7. Series fuse rating	15 A
8. Area of panel (A)	2.16 m <sup>2</sup>
9. By pass diode rating	20 A
10. Nominal ratings at STC	1000 W/ m <sup>2</sup>

**Table 3. Specification of PCU inverters**

Specification	Inverter 1	Inverter 2
Model	BG15KTR	BG30KTR
Max. DC vol.(v)	1000	1000
MPPT Vol.	180-800	280-800
Max DC power(w)	15600	31200
Max. input current(A)	21×2	33×2
Rated output power	15000	30000
Max. AC current(A)	24	48
Max. efficiency	98.30%	98.5%
MPPT efficiency	99.9%	99.9%



**Fig. 2. A view of components of solar PV system**

### 2.3 Instrumentation and Data Logging

To monitor the performance of the rooftop solar photovoltaic system, a variety of instruments were employed for accurate and reliable data collection. A pyranometer and a solarimeter were used to measure the solar irradiance incident on the tilted plane of the PV modules. For temperature monitoring, RTD (Resistance Temperature Detector) sensors were installed to record both ambient and module surface temperatures, which are critical for evaluating thermal effects on system efficiency. Electrical parameters such as voltage and current from the PV modules and inverters were measured using digital multimeters and clamp meters, ensuring precise readings during different operating conditions. Additionally, a weather station was set up near the installation site to record essential meteorological parameters such as humidity, rainfall, and wind speed, providing a

comprehensive environmental dataset that supported the performance evaluation of the system.

### 2.4 Performance Evaluation Metrics

Performance was assessed using standard definitions from IEC 61724 such array yield (energy output from the array per kwp), final yield (net energy delivered to the grid per kwp), reference yield (total in-plane solar irradiation divided by reference irradiance), performance ratio (ratio of final yield to reference yield), module efficiency (efficiency of converting incident sunlight into dc power), inverter efficiency (efficiency of dc to ac conversion) and system efficiency (efficiency of converting total incident solar energy to ac output).

The performance losses were calculated as capture loss, system loss and total loss. The

capture loss (loss due to temperature effects, soiling, shading, and wiring) was the difference between reference and array yield while the system loss (loss due to conversion and mismatch) was the difference between array and final yield. The total loss (overall energy loss from reference irradiance to grid) was the difference between reference yield and final yield.

### 3. RESULTS AND DISCUSSION

This section presents a comprehensive performance analysis of the 45 kWp rooftop grid-connected solar PV system installed at CAET, Junagadh Agricultural University. The results are based on real-time data collected from August to December 2018. Key performance parameters including energy output, various yield metrics, efficiency figures, system losses, and environmental impact are discussed based on the recorded operational data.

#### 3.1 Monthly Energy Generation and Yields

The energy output and performance parameters for each month were calculated and are summarized in Table 4. These include energy generated (DC and AC), array yield ( $Y_A$ ), final yield ( $Y_F$ ), reference yield ( $Y_R$ ), and losses (capture, system, and total). In August month, the lowest energy generation was observed due to frequent cloud cover and moderate solar irradiance during the monsoon season. Despite this, the system maintained a decent final yield of 2.08 kWh/kW<sub>p</sub>/day. From September onward, a steady increase in generation and yield was observed, corresponding with clearer skies and higher solar insolation. In October, the plant recorded the highest energy generation at 6084.10 kWh, with the maximum array yield

(4.36 h/d) and final yield (4.08 h/d) during the monitoring period.

In November and December, a slight decline in performance was observed due to shorter daylight hours and mild reductions in irradiation. However, the system still maintained good stability with average daily final yields of 3.70 and 3.30 kWh/kW<sub>p</sub>/day, respectively. The consistent performance ratio around 70%–77% across all months suggests that the system operated efficiently despite seasonal variations.

#### 3.2 Efficiency and Performance Ratio

The system's performance was further evaluated based on module, inverter, and system efficiencies, along with the monthly performance ratio (PR), as shown in Table 5. Throughout the monitoring period, the inverter efficiency remained consistently high, averaging 93.84%. This stability indicates the reliability and good quality of the power conditioning unit (PCU) used in the system. The variation in inverter efficiency across months was minimal, ranging from 93.51% to 94.21%, reflecting minimal power conversion losses during the DC to AC conversion process.

The module efficiency showed a gradual increase from August to November, peaking at 12.10% in November. This improvement can be attributed to clearer skies, cooler temperatures, and stable irradiance conditions, which generally enhance PV module performance by reducing thermal losses. In December, although the solar irradiance was lower compared to previous months, the module and system efficiencies remained fairly high at 11.80% and 11.08%, respectively. This indicates that the system was effectively utilizing available solar radiation even under sub-optimal conditions.

**Table 4. Average monthly performance parameters of 45 kwp grid-connected solar PV system**

Month 2018	Energies		Yields			Losses		
	Energy $E_{DC}$ kWh	Energy $E_{AC}$ kWh	Array Yield $Y_A$ (h/d)	Final Yield $Y_F$ (h/d)	Reference Yield $Y_R$ (h/d)	Capture Loss $L_C$ (h/d)	System Loss $L_S$ (h/d)	Total Loss $L_T$ (h/d)
Aug	1063.54	998.57	2.15	2.08	3.40	1.26	0.13	1.39
Sept	5223.17	4889.21	4.00	3.75	5.23	1.23	0.26	1.48
Oct	6084.10	5689.12	4.36	4.08	5.61	1.25	0.28	1.53
Nov	4957.62	4657.99	3.93	3.70	4.82	0.89	0.24	1.13
Dec	4876.57	4594.37	3.50	3.30	4.42	0.93	0.20	1.13
Total	22205.0	20829.26	17.99	16.84	23.48	5.56	1.11	6.63
Mean	4441.00	4165.85	3.60	3.37	4.70	1.11	0.22	1.33

System efficiency followed a similar trend, ranging from 8.82% in August to 11.41% in November, with an overall mean efficiency of 10.56%. The increase in system efficiency from the monsoon to post-monsoon period highlights the impact of improved solar exposure and reduced atmospheric moisture on the performance of the overall PV system.

The performance ratio (PR), which reflects the overall effectiveness of the PV system by comparing actual output to the theoretical potential, ranged between 0.59 in August and 0.77 in November. The average PR across the monitoring period was 0.71, indicating good system performance in line with international benchmarks. The relatively lower PR in August was primarily due to reduced solar availability and environmental factors such as cloud cover and rainfall.

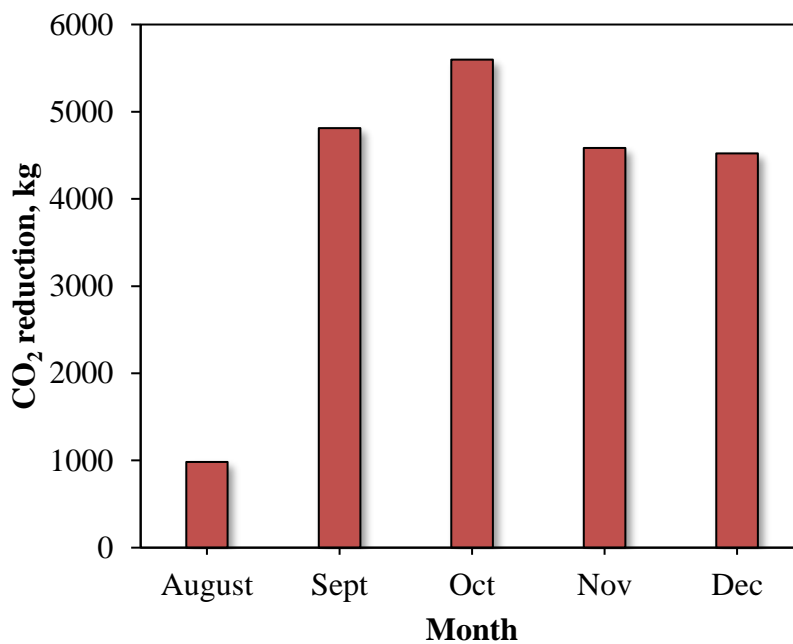
### 3.3 Environmental Impact: CO<sub>2</sub> Emission Reduction

The environmental benefits of the 45 kWp rooftop solar PV system were quantified by calculating the amount of carbon dioxide (CO<sub>2</sub>) emissions avoided through clean electricity generation. Since the energy generated by the plant displaces the equivalent energy that would otherwise be produced from conventional fossil-fuel-based power plants, it contributes directly to emissions reduction. The month wise CO<sub>2</sub> emission reductions are given in Fig. 3.

According to the Central Electricity Authority (2018), the standard grid emission factor for the Indian power sector is 0.984 kg CO<sub>2</sub> per kilowatt-hour of electricity. Using this value, the total CO<sub>2</sub> emissions avoided during the monitoring period were calculated based on the actual AC energy

**Table 5. Average monthly module, inverter and system efficiencies, and performance ratio**

Month	Module efficiency (%)	Inverter efficiency (%)	System efficiency (%)	Performance ratio
August	9.39	93.89	8.82	0.59
September	11.40	93.61	10.66	0.72
October	11.60	93.51	10.82	0.73
November	12.10	93.96	11.41	0.77
December	11.80	94.21	11.08	0.74
Mean	11.26	93.84	10.56	0.71



**Fig. 3. Reduction of CO<sub>2</sub> in the different months**

exported to the grid. Given the total AC energy output of 20,829.26 kWh, the total CO<sub>2</sub> emission avoided was 20,496 kg CO<sub>2</sub>.

#### 4. CONCLUSION

The performance evaluation of the 45 kWp rooftop grid-connected solar photovoltaic (PV) system installed at CAET, Junagadh Agricultural University, was carried out over a five-month period from August to December 2018. The analysis included detailed assessment of energy generation, yield metrics, efficiency parameters, system losses, and environmental benefits. The system generated a total of 22,205 kWh of DC energy, out of which 20,829.26 kWh was successfully delivered to the utility grid. The average daily final yield was found to be 3.37 kWh/kWp/day, while the mean performance ratio (PR) over the study period was 71%, indicating efficient and consistent system operation. Module, inverter, and system efficiencies averaged 11.26%, 93.84%, and 10.56% respectively, confirming the quality and suitability of the installed components. One of the most significant outcomes of the installation was its contribution to environmental sustainability. The system helped avoid approximately 20,494 kg of CO<sub>2</sub> emissions over five months, supporting institutional commitments to green energy and climate action. In conclusion, the study validates the technical feasibility, operational efficiency, and environmental effectiveness of deploying rooftop grid-connected solar PV systems in academic institutions. The results provide a strong foundation for scaling similar systems in other campuses across India, especially in regions with high solar potential. Furthermore, the data collected and analyzed can serve as a valuable resource for future research, policymaking, and system design improvements.

#### DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

#### ACKNOWLEDGEMENTS

The authors express their gratitude to the College of Agricultural Engineering and Technology, JAU, Gujarat for granting access to the research facilities.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

#### REFERENCES

- Ayompe, L., Duffy, A., McCormack, S., & Conlon, M. (2010). Measured performance of a 1.72kw rooftop grid connected photovoltaic system in ireland. *Energy conversion and management*, 52(2), 816–825. <https://doi.org/10.1016/j.enconman.2010.08.007>
- Central Electricity Authority. (2018). CO<sub>2</sub> baseline database for the Indian power sector: User guide (Version 13.0). Ministry of Power, Government of India. <https://cea.nic.in>
- Chaita, A. & Kluabwang, J. (2016). Performance Evaluation of 3.5 kWp Rooftop Solar PV Plant in Thailand. *Proceedings of the International MultiConference of Engineers and Computer Scientists, Vol II*, 572- 575.
- Cucumo, M., De Rosa, A., Ferraro, V., Kaliakatsos, D., & Marinelli, V. (2005). Performance analysis of a 3kW grid-connected photovoltaic plant. *Renewable Energy*, 31(8), 1129–1138. <https://doi.org/10.1016/j.renene.2005.06.005>
- Dincer, I. (2000). Renewable energy and sustainable development: a crucial review. *Renewable and sustainable energy reviews*, 4(2), 157–175. [https://doi.org/10.1016/s1364-0321\(99\)00011-8](https://doi.org/10.1016/s1364-0321(99)00011-8)
- Elmnifi, M., Khaleel, M., Vambol, S., Yeremenko, S., Nassar, Y. F., & Dzhulai, O. (2024b). Ensuring sustainability in Libya with renewable energy and pumped hydro storage. *Ecological Questions*, 35(3), 1–17. <https://doi.org/10.12775/eq.2024.036>
- Elmnifi, M., Mhmood, A. H., Saieed, A. N. A., Alturaihi, M. H., Ayed, S. K., & Majdi, H. S. (2024a). A technical and economic feasibility study for on-Grid Solar PV in Libya. *Mathematical Modelling and Engineering Problems*, 11(1), 91–97. <https://doi.org/10.18280/mmep.110109>
- Izam, N. S. M. N., Itam, Z., Sing, W. L., & Syamsir, A. (2022). Sustainable

- development perspectives of solar energy technologies with focus on solar photovoltaic—a review. *Energies*, 15(8), 2790. <https://doi.org/10.3390/en15082790>
- Jawaharlal Nehru National Solar Mission (Phase I, II and III) – Policies - IEA. (n.d.). IEA. <https://www.iea.org/policies/4916-jawaharlal-nehru-national-solar-mission-phase-i-ii-and-iii>
- Kar, M. K., Kanungo, S., Dash, S., & Parida, R. N. R. (2023). Grid connected solar panel with battery energy storage system. *International Journal of Applied Power Engineering (IJAPE)*, 13(1), 223. <https://doi.org/10.11591/ijape.v13.i1.pp223-233>
- Kumar, R., Saha, R., Simic, V., Dev, N., Kumar, R., Banga, H. K., Bacanin, N., & Singh, S. (2024). Rooftop solar potential in micro, small, and medium size enterprises: an insight into renewable energy tapping by decision-making approach. *Solar energy*, 276, 112692. <https://doi.org/10.1016/j.solener.2024.112692>
- Kumar, S. S., & Nagarajan, C. (2016). Performance-Economic and energy loss analysis of 80 kWp grid connected roof top transformer less photovoltaic power plant. *Circuits and Systems*, 07(06), 662–679. <https://doi.org/10.4236/cs.2016.76056>
- Kymakis, E., Kalykakis, S., & Papazoglou, T. M. (2009). Performance analysis of a grid connected photovoltaic park on the island of Crete. *Energy Conversion and Management*, 50(3), 433–438. <https://doi.org/10.1016/j.enconman.2008.12.009>
- Majdi, H. S., Elmnifi, M., Rahel, R. G., Abdullah, A. R., & Habeeb, L. J. (2023a). Potential of solar energy utilization using concentrated solar technique for power generation in Libya and transmission to Italy. *Journal of Engineering Science and Technology*, 210-224.
- Majdi, H. S., Younis, A., Abdullah, A. R., Elmnifi, M., & Habeeb, L. J. (2023b). A comparative analysis of the efficiency of monocrystalline and polycrystalline photovoltaic modules: CTI-80 and YHM-205-27P. *International Journal of Design & Nature and Ecodynamics*, 18(4), 775–782. <https://doi.org/10.18280/ijdne.180403>
- Mondol, J. D., Yohanis, Y., Smyth, M., & Norton, B. (2006). Long term performance analysis of a grid connected photovoltaic system in northern Ireland. *Energy conversion and management*, 47(18–19), 2925–2947. <https://doi.org/10.1016/j.enconman.2006.03.026>
- Parida, B., Iniyar, S., & Goic, R. (2011). A review of solar photovoltaic technologies. *Renewable and sustainable energy reviews*, 15(3), 1625–1636.
- Pundir, K. S. S., Varshney, N., & Singh, G. K. (2016). Comparative study of performance of grid connected solar photovoltaic power system in IIT Roorkee campus. In Paper of international conference on innovative trends in science, engineering and management held at New Delhi, India (pp. 422-31).
- Rawat, P. (2018). Simulation and Performance Analysis of 100 kWp Grid Connected Rooftop Solar Photovoltaic Plant Using PVSYST. *International Journal of Science and Research (IJSR)*, 7(1).
- Saha, S., Mandal, R.K. (2025). RCPI Controller-Based Multilevel Multistring Grid Following Inverter For Large Rooftop Pv Power Plant Application. *Electr Eng* 107, 3285–3305. <https://doi.org/10.1007/s00202-024-02643-x>
- Sharma, V., & Chandel, S. (2013). Performance analysis of a 190 kWp grid interactive solar photovoltaic power plant in India. *Energy*, 55, 476–485. <https://doi.org/10.1016/j.energy.2013.03.075>
- Shukla, A. K., Sudhakar, K., & Baredar, P. (2016). Simulation and performance analysis of 110 kWp grid-connected photovoltaic system for residential building in India: A comparative analysis of various PV technology. *Energy Reports*, 2, 82–88. <https://doi.org/10.1016/j.egyr.2016.04.001>
- Twidell, J. (2021). *Renewable energy resources*. <https://doi.org/10.4324/9780429452161>
- Yadav, S. K., & Bajpai, U. (2018). Performance evaluation of a rooftop solar photovoltaic power plant in Northern

India. Energy Sustainable Development, 43, 130–138.  
Development/Energy for Sustainable https://doi.org/10.1016/j.esd.2018.01.006

**Disclaimer/Publisher's Note:** The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of the publisher and/or the editor(s). This publisher and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.

© Copyright (2025): Author(s). The licensee is the journal publisher. This is an Open Access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>), which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

*Peer-review history:*

*The peer review history for this paper can be accessed here:*  
<https://pr.sdiarticle5.com/review-history/134651>