IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429 Volume 6, Issue 1, June 2026 Impact Factor: 8.2

Review of Temperature, Humidity, and Cloud Cover on Solar Radiation and PV Energy Output

Patil Nitinkumar Surgonda[1] and Dr. Brijendra Mishra[2]
[1]Research Scholar, Department of Electrical Engineering
[2]Research Guide, Department of Electrical Engineering
Vikrant University, Gwalior, M.P, India

Abstract: *Solar photovoltaic generation is strongly dependent on the availability and quality of solar radiation, which varies with atmospheric and meteorological conditions. Among the major climatic parameters, temperature, relative humidity, and cloud cover have significant but different effects on solar radiation reaching the PV module and on the electrical conversion efficiency of the module. High ambient and module temperatures generally reduce PV efficiency because the voltage of semiconductor cells decreases as cell temperature increases. Relative humidity affects solar radiation through atmospheric absorption, scattering, water vapour, condensation, and its interaction with dust and soiling.*

Cloud cover is one of the most important short-term determinants of solar irradiance because clouds attenuate direct radiation and modify the proportion of diffuse radiation. Recent reviews indicate that increasing module temperature commonly reduces PV efficiency by approximately 0.4–0.5% per °C for conventional PV technologies, while cloud conditions can cause substantial reductions and short-term fluctuations in PV output. This review synthesizes existing literature on the individual and combined effects of temperature, humidity, and cloud cover on solar radiation and PV energy output, compares their mechanisms of influence, and identifies implications for PV forecasting, system design, operation, and climatic adaptation.

Keywords: Solar radiation, photovoltaic systems, temperature, relative humidity, cloud cover, PV efficiency, solar irradiance, energy output, climatic parameters.

I. INTRODUCTION

The rapid expansion of photovoltaic technology has made solar energy an important component of sustainable electricity generation. However, PV electricity production is inherently variable because the amount of solar radiation received by a PV module changes with atmospheric conditions, geographical location, season, time of day, and weather. Meteorological variables therefore play an important role in determining both instantaneous PV power and accumulated daily or seasonal energy generation. Alskaif et al. (2020), in a systematic analysis of meteorological variables, demonstrated that variables including temperature, relative humidity, cloud cover, wind, dew-point temperature, and precipitation can be useful for estimating PV output.

Temperature, humidity, and cloud cover influence PV systems through different physical pathways. Temperature mainly affects the electrical conversion process after solar radiation reaches the module, whereas humidity and cloud cover can modify the radiation itself before it reaches the PV surface. The relationship is therefore not simply linear. For example, high solar irradiance can simultaneously increase electricity generation and raise module temperature, with the latter reducing conversion efficiency. Similarly, humid conditions can reduce solar transmission but may also moderate module temperature under particular atmospheric conditions.

Temperature is particularly important because silicon PV cells experience a decline in electrical efficiency as operating temperature increases. Reviews by Skoplaki and Palyvos (2009) and Dubey et al. (2013) established the importance of module operating temperature in determining PV efficiency and power output. More recent research indicates that typical PV efficiency losses associated with increasing temperature are approximately 0.4–0.5% per °C, although the exact value depends on PV technology and operating conditions.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 1, June 2026
Impact Factor: 8.2

Cloud cover represents another major source of variability. Clouds reduce direct normal irradiance and can produce rapid changes in irradiance as they move across the sky. Thick clouds generally produce substantial attenuation, whereas broken clouds can produce alternating shading and solar exposure and occasionally create short-lived irradiance enhancement near cloud edges.

Humidity is comparatively less straightforward. Water vapour and condensed water droplets can scatter, reflect, and refract radiation, while persistent humidity can contribute to corrosion, condensation, and dust adhesion on module surfaces. Consequently, understanding the combined effects of these climatic parameters is essential for accurate PV performance assessment.

II. TEMPERATURE AND SOLAR PV PERFORMANCE

1. Effect of temperature on PV efficiency

Temperature is one of the most extensively investigated environmental variables affecting PV performance. When solar radiation is absorbed by a PV module, part of the energy is converted into electricity and the remainder is transformed into heat. Consequently, high irradiance often produces elevated module temperatures.

For conventional crystalline-silicon modules, increasing cell temperature generally reduces the open-circuit voltage and consequently decreases maximum power output. Skoplaki and Palyvos (2009) reviewed the mathematical relationships used to describe temperature-dependent PV performance and demonstrated that module operating temperature is a fundamental variable in PV electrical modelling.

Dubey et al. (2013) similarly concluded that PV cell performance decreases with increasing temperature because of semiconductor-related changes, particularly increased carrier recombination and reduced voltage.

Recent literature generally reports a temperature-related efficiency reduction of approximately 0.4–0.5% for every 1°C increase in module temperature for conventional PV technologies, although technology-specific coefficients differ.

Table 1. General influence of temperature on PV performance

Temperature condition	Effect on solar radiation	Effect on PV module	Expected PV output
Low temperature	Radiation availability may remain high	Higher electrical voltage	Generally higher efficiency
Moderate temperature	Normal radiation absorption	Normal operating efficiency	Normal output
High temperature	Radiation may remain high	Voltage and efficiency decrease	Reduced power output
Very high temperature	Often associated with strong irradiance	Significant thermal losses	Substantial efficiency reduction

2. Temperature and solar radiation interaction

The relationship between temperature and solar radiation is important because high temperatures do not necessarily indicate poor solar resources. In many regions, the highest module temperatures occur during periods of strong solar irradiance. Therefore, a PV system can receive abundant solar energy while simultaneously experiencing reduced conversion efficiency because of thermal effects.

This creates an important distinction between solar resource availability and PV conversion performance. Solar radiation determines the energy input, whereas module temperature influences how efficiently that energy is converted into electricity.

The relationship can be conceptually expressed as:

DOI: 10.48175/568

$$P_{PV} = P_{STC}\left(\frac{G}{G_{STC}}\right)[1+\gamma(T_c - T_{ref})]$$

where:

- P_{PV} = PV power output,
- P_{STCP} = rated power at standard test conditions,
- G = actual solar irradiance,
- G_{STC} = reference irradiance,
- γ = temperature coefficient of power,
- T_c = cell temperature,
- T_{ref} = reference cell temperature.

Because γ is normally negative for conventional PV modules, increasing cell temperature generally decreases power output.

3. Relative Humidity and Solar Radiation

Relative humidity represents the amount of water vapour in the atmosphere relative to the maximum amount possible at a particular temperature. Although humidity has a weaker and more complex influence than irradiance, it can affect both solar radiation transmission and PV module performance.

Water vapour and suspended moisture can scatter, absorb, reflect, or refract incoming radiation. Hasan et al. (2022) reported that water droplets associated with humidity can reduce the direct component of radiation reaching solar cells. Persistent humidity can also contribute to condensation, corrosion, moisture penetration, and degradation of encapsulation materials.

Humidity can also influence PV output indirectly through its interaction with dust. High humidity can make deposited dust more adhesive, increasing soiling losses. Hasan et al. (2022) noted that humid conditions can therefore worsen the impact of dust accumulation on PV surfaces.

Table 2. Influence of relative humidity on solar PV systems

Humidity condition	Radiation effect	Module effect	PV output tendency
Low humidity	Relatively low atmospheric moisture scattering	Limited moisture-related degradation	Generally favourable
Moderate humidity	Moderate atmospheric attenuation	Limited moisture effect	Moderate
High humidity	Greater scattering/absorption and possible condensation	Moisture and soiling problems	Generally lower
Very high humidity	Potentially substantial atmospheric and surface effects	Corrosion, condensation and degradation risks	Reduced output

Importantly, the relationship between humidity and PV output should not be interpreted as universally linear. Humidity frequently changes simultaneously with temperature, cloud cover, rainfall, and atmospheric aerosols. Therefore, an observed correlation between humidity and PV power may partly reflect these associated variables.

4. Cloud Cover and Solar Radiation

Cloud cover is one of the most influential atmospheric variables affecting solar radiation availability. Clouds modify both the magnitude and spectral distribution of incoming solar radiation. They can block direct sunlight, scatter radiation, and increase the proportion of diffuse radiation.

ISSN: 2581-9429 Volume 6, Issue 1, June 2026 Impact Factor: 8.2

The effect depends strongly on cloud type, thickness, altitude, optical depth, coverage, and movement. Thick clouds produce greater attenuation, while thin high-altitude clouds may allow a substantial portion of solar radiation to pass through.

Cloud movement also produces rapid fluctuations in irradiance. This is especially important for grid-connected PV systems because rapidly changing PV generation can increase short-term variability and complicate grid management.

Table 3. Effect of different cloud conditions on PV generation

Cloud condition	Direct radiation	Diffuse radiation	PV output
Clear sky	Very high	Low–moderate	Very high
Thin cirrus	Relatively high	Moderate	High
Broken cumulus	Highly variable	Moderate–high	Highly variable
Thick cumulus	Low	Moderate	Low
Stratus/overcast	Very low	Relatively dominant	Low
Dense storm clouds	Extremely low	Low	Very low

Very-short-term PV forecasting research therefore frequently uses cloud information, satellite imagery, sky cameras, or cloud-motion information. Reviews have identified cloud modelling and image processing as important approaches for predicting short-term PV output.

5. Comparative Effect of Temperature, Humidity and Cloud Cover

The three climatic parameters do not affect PV output in the same way.

Table 4. Comparative assessment

Parameter	Primary mechanism	Impact on solar radiation	Impact on PV efficiency	Time scale
Temperature	Thermal effect on semiconductor	Usually indirect	Strong	Minutes to seasons
Humidity	Atmospheric moisture and surface moisture	Moderate/variable	Moderate	Hours to seasons
Cloud cover	Blocking and scattering of sunlight	Very strong	Indirect/strong through irradiance	Seconds to days
Combined effects	Coupled atmospheric processes	Strong	Strong	All time scales

Cloud cover generally has the most immediate influence on the amount of solar radiation available, while temperature has a particularly strong effect on the conversion efficiency of the PV module. Humidity often has a secondary but important influence and can become more significant when combined with condensation and soiling.

Alskaif et al. (2020) demonstrated the value of considering several meteorological variables together rather than relying on a single climatic variable for PV output estimation. Their analysis incorporated temperature, dew point, relative humidity, cloud cover, wind and other meteorological parameters in PV power estimation.

6. Effects on Seasonal PV Energy Generation

The effects of climatic variables change with season.

Table 5. Seasonal interpretation of climatic effects

Season	Temperature	Humidity	Cloud cover	Expected PV condition
Summer	High	Low–moderate in dry areas	Variable	High radiation but thermal losses

ISSN: 2581-9429 Volume 6, Issue 1, June 2026 Impact Factor: 8.2

Monsoon/rainy season	Moderate	High	High	Reduced irradiance and output
Autumn	Moderate	Moderate	Moderate	Generally favourable
Winter	Low	Moderate–high	Variable	Good efficiency but shorter solar duration
Spring	Moderate	Moderate	Variable	Generally favourable

In hot climates, high summer irradiance may be accompanied by high module temperature, producing a trade-off between resource availability and conversion efficiency. In humid or monsoon climates, increased cloud cover and atmospheric moisture can substantially reduce solar radiation availability.

7. Implications for PV Energy Prediction

Accurate PV forecasting requires meteorological information at an appropriate temporal and spatial resolution. Conventional regression models can incorporate temperature, humidity, cloud cover, irradiance, wind speed, and related variables. Machine-learning models can further identify nonlinear relationships among these parameters.

A systematic review of PV output forecasting found that studies have used combinations of solar irradiation, cloud cover, relative humidity, air temperature, wind speed, dew-point temperature, and other variables for short-term and day-ahead PV forecasting.

Table 6. Meteorological variables useful for PV prediction

Variable	Forecasting importance	Typical role
Solar irradiance	Very high	Main predictor of PV power
Cloud cover	Very high	Predicts rapid irradiance changes
Module/cell temperature	High	Determines thermal efficiency
Ambient temperature	High	Used to estimate module temperature
Relative humidity	Moderate	Atmospheric and moisture-related effects
Wind speed	Moderate	Module cooling
Dew point	Moderate	Moisture/condensation indicator
Precipitation	Context dependent	Cleaning and cloud/radiation effects

8. Mitigation and Optimization Strategies

The literature indicates several strategies for reducing climatic losses.

Table 7. Strategies for mitigating climatic impacts

Climatic problem	Possible mitigation
High module temperature	Natural ventilation, rear-side ventilation, active/passive cooling
High humidity	Improved encapsulation and moisture-resistant materials
Condensation	Proper module sealing and ventilation
Cloud variability	Advanced forecasting and energy-storage integration
Soiling under humid conditions	Appropriate cleaning schedules
Rapid irradiance fluctuations	Battery storage and grid-support strategies
Seasonal variation	Optimized system sizing and forecasting
High-temperature operation	Technology selection with suitable temperature coefficients

Hasan et al. (2022) emphasized ventilation, cooling, appropriate module design, moisture protection, and maintenance as approaches for reducing environmental losses.

Recent reviews further emphasize that PV systems should be designed according to local environmental conditions rather than assuming identical performance across climates. Bamisile et al. (2025) conclude that environmental conditions, including temperature and atmospheric conditions, must be considered in PV siting and productivity assessment.

III. CONCLUSION

This review demonstrates that temperature, humidity, and cloud cover are important climatic determinants of solar radiation availability and photovoltaic energy output. Temperature primarily affects the electrical conversion efficiency of PV modules, with increasing module temperature generally producing a reduction in power output. Humidity influences atmospheric radiation transmission, condensation, soiling, corrosion, and module durability, although its direct relationship with PV output is more complex. Cloud cover has a particularly strong short-term influence because it controls the amount of direct and diffuse solar radiation reaching the PV surface.

The most important conclusion is that these parameters should not be considered independently. Their interactions determine the actual operating environment of a PV system. Consequently, accurate PV performance assessment should combine irradiance measurements with temperature, humidity, cloud-cover information and, where possible, wind, precipitation, and soiling measurements. Such integrated models can improve PV system design, energy-yield estimation, forecasting, maintenance planning, and grid integration.

REFERENCES

1. Alskaif, T. A., Dev, S., Visser, L. R., Hossari, M., & van Sark, W. G. J. H. M. (2020). A systematic analysis of meteorological variables for PV output power estimation. *Renewable Energy, 153*, 12–22.
2. Bamisile, O., Acen, C., Cai, D., Huang, Q., & Staffell, I. (2025). The environmental factors affecting solar photovoltaic output. *Renewable and Sustainable Energy Reviews, 208*, 115073.
3. Dubey, S., Sarvaiya, J. N., & Seshadri, B. (2013). Temperature dependent photovoltaic (PV) efficiency and its effect on PV production in the world—A review. *Energy Procedia, 33*, 311–321.
4. Hasan, K., Yousuf, S. B., Tushar, M. S. H. K., Das, B. K., Das, P., & Islam, M. S. (2022). Effects of different environmental and operational factors on the PV performance: A comprehensive review. *Energy Science & Engineering, 10*(2), 656–675.
5. Mellit, A., & Kalogirou, S. A. (2008). Artificial intelligence techniques for photovoltaic applications: A review. *Progress in Energy and Combustion Science, 34*(5), 574–632.
6. Pelland, S., Remund, J., Kleissl, J., Oozeki, T., & De Brabandere, K. (2013). Photovoltaic and solar forecasting: State of the art. *International Energy Agency Photovoltaic Power Systems Programme, Report IEA-PVPS T14-01:2013*.
7. Skoplaki, E., & Palyvos, J. A. (2009a). On the temperature dependence of photovoltaic module electrical performance: A review of efficiency/power correlations. *Solar Energy, 83*(5), 614–624.
8. Skoplaki, E., & Palyvos, J. A. (2009b). Operating temperature of photovoltaic modules: A survey of pertinent correlations. *Renewable Energy, 34*(1), 23–29.
9. Sobri, S., Koohi-Kamali, S., & Rahim, N. A. (2018). Solar photovoltaic generation forecasting methods: A review. *Renewable and Sustainable Energy*
10. Wan, C., Zhao, J., Song, Y., Xu, Z., Lin, J., & Hu, Y. (2015). Photovoltaic and solar power forecasting for smart grid energy management. *CSEE Journal of Power and Energy Systems, 1*(4), 38–46.