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Experimental Performance Analysis of a Grid-Connected Photovoltaic System under the Climatic Conditions of Abbasabad, Mazandaran

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Abstract

This study presents an experimental and simulation-based performance analysis of a grid-connected Photovoltaic (PV) system operating under the climatic conditions of Abbasabad, Mazandaran, a humid and forest-influenced region in northern Iran. Meteorological data were obtained through the Meteonorm database integrated within PVsyst, and the system configuration consisted of three 270-W polycrystalline silicon modules, a 1.8-kW IMC inverter, and auxiliary components including a 25-A charge controller and two 150-Ah batteries. The PV modules exhibited a short-circuit current of 9.06 A, an open-circuit voltage of 37.2 V, and a maximum power point voltage and current of 31.2 V and 8.25 A, respectively. Simulation results indicate that the system experiences array losses of 0.81 kWh/kWp/day and inverter-related losses of 0.17 kWh/kWp/day. The average useful energy delivered to the grid is 4.67 kWh/kWp/day, yielding an annual Performance Ratio (PR) of approximately 0.827. Seasonal variations in irradiation, humidity, temperature, and wind speed significantly influence system behavior, with the highest PR values observed during winter months due to lower module temperatures and reduced thermal losses. Overall, the findings confirm that despite the region's high humidity, dense vegetation, and frequent cloud cover, the PV system maintains acceptable performance and can reliably contribute to residential-scale electricity generation. The results provide a practical reference for PV deployment in similar coastal and humid climates.

Keywords: Photovoltaic system, Photovoltaicsyst, Performance ratio, Solar energy, Abbasabad climate, Grid-connected Photovoltaic, Polycrystalline silicon.

1 | Introduction

The global transition toward sustainable energy systems has intensified the demand for clean, renewable, and environmentally responsible electricity generation technologies. Among these, Photovoltaic (PV) systems have emerged as one of the most promising solutions due to their modularity, low maintenance requirements,

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and ability to operate in diverse geographical conditions [1–3]. The increasing environmental concerns associated with fossil-fuel consumption-such as greenhouse gas emissions, air pollution, and resource depletion-have further accelerated the adoption of solar energy technologies worldwide [4].

Iran, despite its substantial fossil-fuel reserves, possesses exceptional solar potential, with annual global horizontal irradiation ranging between 1800 and 2200 kWh/m². However, the deployment of PV systems in the northern coastal regions of the country presents unique challenges. Areas such as Abbasabad in Mazandaran Province experience high humidity, dense vegetation, frequent cloud cover, and seasonal dust transport, all of which can significantly influence PV performance [5], [6]. These climatic characteristics necessitate localized performance assessments to ensure accurate system sizing, reliable operation, and economic feasibility.

This study focuses on the experimental and simulation-based evaluation of a grid-connected PV system installed in Abbasabad. By integrating meteorological data from Meteonorm into PVsyst and analyzing system behavior across seasonal variations, the research aims to quantify Performance Ratio (PR), energy yield, and system losses. The results contribute to a deeper understanding of PV operation in humid coastal climates and provide practical insights for optimizing residential-scale solar installations in similar regions.

2 | Literature Review

The rapid expansion of PV technologies over the past three decades has been driven by the global need to reduce greenhouse gas emissions, diversify energy resources, and transition toward sustainable electricity generation [4]. Early research on solar energy in Iran dates back to 1969, when the University of Shiraz initiated the first systematic studies on solar radiation and thermal systems. Shortly thereafter, Sharif University of Technology established advanced laboratories dedicated to solar energy conversion, marking the beginning of structured PV research in the country. These foundational efforts laid the groundwork for subsequent developments in PV module fabrication, performance assessment, and system optimization.

Internationally, the first comprehensive evaluation of PV system performance using the PR metric was conducted in Switzerland in 1998, establishing PR as a universal indicator for comparing PV systems across different climates. Since then, numerous studies have examined the influence of environmental parameters-including irradiance, temperature, humidity, dust deposition, and wind speed-on PV efficiency [5], [7–11]. For instance, Wittkopf et al. [1] demonstrated that commercial PV arrays typically convert only 13-19% of incident solar radiation into electrical energy, with thermal losses and spectral mismatch being the dominant limiting factors. Similarly, Kazem et al. [6] highlighted the significant impact of shading duration and shadow geometry on energy yield, particularly in regions with dense vegetation or complex terrain.

Recent global studies have increasingly focused on climate-specific performance modeling. Research conducted in humid subtropical regions (e.g., Southeast Asia, Brazil, and coastal Turkey) shows that high humidity and cloud cover reduce direct beam radiation, thereby lowering the effective irradiance on PV modules [1], [5]. Conversely, lower ambient temperatures in such climates can partially offset these losses by reducing module temperature and improving voltage output [5]. Kazem et al. [6] reported that solar tracking systems can increase energy yield by up to 50% in summer and 300% in winter, although their economic feasibility depends heavily on local climatic variability.

In Iran, most PV performance studies have concentrated on arid and semi-arid regions such as Yazd, Kerman, and Isfahan, where high solar irradiance and low humidity create favorable conditions for PV deployment. However, significantly fewer studies have examined PV behavior in humid coastal regions such as Mazandaran. This gap is critical because northern Iran experiences unique environmental stressors-including airborne biological particles, seasonal dust transport, and persistent cloud cover-that can substantially influence PV output.

The present study contributes to this research gap by providing a detailed performance assessment of a grid-connected PV system in Abbasabad. Using PVsyst simulations based on Meteonorm meteorological data

(*Table 1*), the study evaluates system losses, energy yield, and annual PR under real climatic conditions. By integrating local environmental characteristics with global performance models, this research offers a comprehensive understanding of PV behavior in humid forest-coastal climates and provides a benchmark for future installations in similar regions.

Table 1. Meteorological data for the abbasabad site.

Month	Relative Humidity (%)	Linke Turbidity (–)	Wind Velocity (m/s)	Temperature (°C)	Dh (kWh/m²)	Gh (kWh/m²)
January	63.7	3.488	1.70	0.8	31.5	80.2
February	58.7	4.057	2.10	3.0	36.2	96.2
March	46.7	5.122	2.49	8.4	56.6	139.0
April	51.8	6.504	2.39	12.7	69.8	170.7
May	42.9	6.481	2.40	18.4	71.3	206.7
June	34.6	6.281	2.50	23.7	72.0	222.0
July	33.0	6.895	2.40	26.7	80.0	218.5
August	33.0	5.752	2.20	25.8	66.4	203.9
September	36.0	4.803	2.09	21.3	52.0	168.4
October	45.0	4.690	1.80	15.3	38.3	126.9
November	59.0	3.935	1.60	7.1	34.0	87.6
December	65.2	3.490	1.60	2.6	27.3	72.9
Annual	47.5	5.125	2.10	13.8	635.4	1792.9

3 | Methodology

The methodological framework of this study integrates experimental data acquisition, climate-based modeling, and performance simulation using PVsyst to evaluate the behavior of a grid-connected PV system installed in Abbasabad, Mazandaran. The methodology is structured into four main components: 1) collection of meteorological data, 2) system configuration and parameter extraction, 3) simulation modeling in PVsyst, and 4) performance assessment through energy yield and loss analysis.

3.1 | Meteorological Data Acquisition

Meteorological inputs were obtained from the Meteonorm database embedded within PVsyst, which provides long-term hourly averages of Global Horizontal Irradiance (GHI), Diffuse Horizontal Irradiance (DHI), ambient temperature, wind speed, and relative humidity. These parameters are essential for accurately modeling PV performance, particularly in humid coastal climates where atmospheric moisture and cloud cover significantly influence beam radiation. According to *Table 1* of the thesis, the Abbasabad site exhibits substantial seasonal variability, with higher humidity and cloudiness during spring and autumn, and relatively clearer skies during summer. These variations directly affect the incident irradiance and module operating temperature.

3.2 | System Configuration and Electrical Parameters

The PV system consists of three polycrystalline silicon modules rated at 270 W each, yielding a total installed capacity of 810 W. The electrical characteristics of the modules, extracted from *Table 2*, include:

I. Short-circuit current: 9.06 A

II. Open-circuit voltage: 37.2 V

III. Maximum power point voltage: 31.2 V

IV. Maximum power point current: 8.25 A

V. Module efficiency: 18.28%

Table 2. Electrical specifications of the polycrystalline PV module (270 W).

Parameter	Value
Rated power (Pmax)	270 W
Short-circuit current (Isc)	9.06 A
Open-circuit voltage (Voc)	37.2 V
Maximum power point voltage (Vmp)	31.2 V
Maximum power point current (Imp)	8.25 A
Module efficiency	18.28%
Module type	Polycrystalline silicon

The inverter used in the system is an IMC grid-connected model with a nominal AC power of 1.8 kW, maximum DC voltage of 500 V, and conversion efficiency of 97.2% (*Table 3*). The system also includes a 25-A charge controller and two 150-Ah batteries, although the primary analysis focuses on grid-connected operation.

Table 3. Electrical specifications of the IMC Grid-Connected inverter.

Parameter	Value
Nominal AC Power	1.8 kW
Maximum DC Voltage	500 V
Maximum Module Voltage	200 V
AC Output Voltage	200 V
Frequency	50 Hz
Conversion Efficiency	97.2%
Charge Controller Rating	25 A
Battery Bank	2 × 150 Ah

3.3 | Simulation Modeling in Photovoltaicsyst

The PVsyst software was employed to simulate system performance under real climatic conditions. The modeling procedure included:

I. Importing Meteonorm climate data for Abbasabad

II. Defining module and inverter specifications

III. Configuring system topology (series/parallel arrangement)

IV. Setting module tilt equal to the site's latitude, as recommended for fixed-tilt systems

V. Incorporating horizon profile *Fig. 1* to account for shading from surrounding terrain and vegetation

VI. Running annual simulations to compute energy yield, system losses, and PR

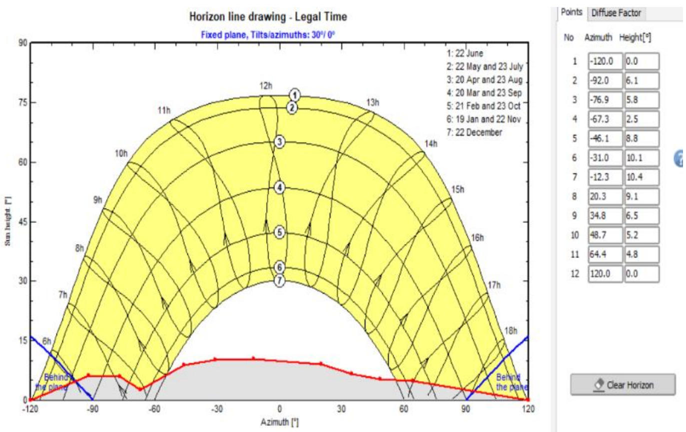

Fig. 1. Horizon profile at the abbasabad site.

The software calculates array losses (thermal, ohmic, mismatch, and irradiance-related losses) and system losses (inverter losses, wiring losses, and AC losses). These outputs form the basis for evaluating system efficiency and identifying performance-limiting factors.

3.4 | Performance Assessment Metrics

The primary performance indicators used in this study include:

I. Energy yield (kWh/kWp/day): Total useful energy delivered to the grid per unit of installed capacity.

II. PR: A dimensionless metric representing the ratio of actual system output to the theoretical output under standard test conditions [9], [12].

III. Array and system losses: Quantification of energy losses due to temperature, shading, inverter inefficiency, and wiring.

According to the simulation results, the system exhibits array losses of 0.81 kWh/kWp/day and inverter losses of 0.17 kWh/kWp/day, resulting in a net useful output of 4.67 kWh/kWp/day and an annual PR of approximately 0.827.

4 | Experimental and Simulation Setup

This section describes the physical characteristics of the study site, the configuration of the PV system, and the simulation procedures implemented in PVsyst. The setup integrates geographical, environmental, and technical parameters to ensure accurate modeling of system performance under the climatic conditions of Abbasabad, Mazandaran.

4.1 | Site Description

The experimental site is located in Abbasabad, situated in the western part of Mazandaran Province, Iran. The region is characterized by a humid subtropical climate with dense vegetation, high annual precipitation, and significant seasonal variability in cloud cover. These environmental conditions influence the availability of direct beam radiation and contribute to fluctuations in PV module temperature and shading patterns. Meteorological data extracted from Meteonorm *Table 1* indicate:

I. High humidity levels throughout the year

II. Moderate wind speeds, particularly during spring and autumn

III. Seasonal dust and pollen transport due to surrounding forests

IV. Variable solar irradiance, with peak values occurring in summer months

These climatic factors make Abbasabad an ideal case study for evaluating PV performance in humid coastal environments.

4.2 | Panel Tilt and Orientation

The PV modules were installed with a fixed tilt angle equal to the site's latitude, following standard recommendations for maximizing annual energy yield in fixed-tilt systems. According to *Fig. 2* in the thesis, the optimal tilt angle ensures that the modules receive maximum annual irradiance while minimizing seasonal shading effects. The azimuth angle was set to true south (0° deviation), which is the optimal orientation for PV installations in the Northern Hemisphere.

4.3 | Solar Path Analysis

A detailed solar path analysis was conducted using PVsyst's sun-path diagram (*Fig. 2*). The analysis revealed:

I. High solar altitude during summer months, resulting in increased irradiance

II. Lower solar elevation in winter, but with reduced module temperature and improved voltage output
III. Potential partial shading during early morning and late afternoon due to surrounding vegetation

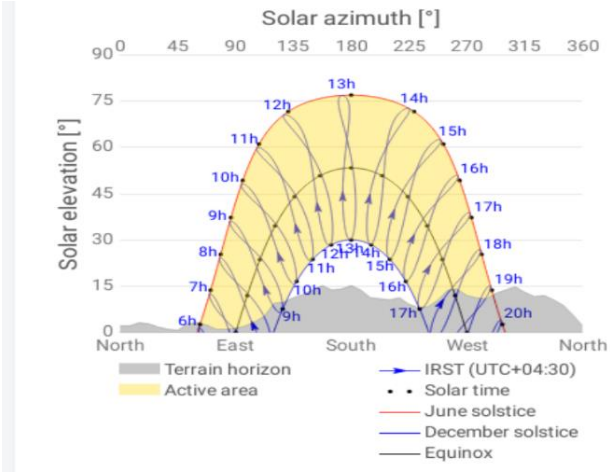

Fig. 2. Sun path analysis at the abbasabad site.

This analysis was essential for determining the effective irradiance on the module surface and for quantifying shading-related losses.

4.4 | Photovoltaic Module and Inverter Specifications

The system consists of three polycrystalline silicon modules rated at 270 W each. The electrical characteristics (*Table 2*) include:

I. Pmax: 270 W
II. Voc: 37.2 V
III. Isc: 9.06 A
IV. Vmp: 31.2 V
V. Imp: 8.25 A
VI. Module efficiency: 18.28%

The inverter used is an IMC grid-connected model with specifications (*Table 3*):

I. Nominal AC power: 1.8 kW
II. Maximum DC voltage: 500 V
III. Maximum module voltage: 200 V
IV. AC output voltage: 200 V
V. Frequency: 50 Hz
VI. Inverter efficiency: 97.2%

These specifications were directly imported into PVsyst to ensure accurate simulation of electrical behavior.

4.5 | Horizon Profile and Shading Analysis

The horizon profile for the site *Fig. 4* was incorporated into PVsyst to account for shading from nearby trees, buildings, and terrain. The horizon line shows:

I. Moderate shading during early morning hours

II. Minimal shading during midday

III. Increased shading during late afternoon due to forest density

This step is critical because shading significantly reduces the effective irradiance and can cause mismatch losses within the PV array.

4.6 | Simulation Procedure in Photovoltaicsyst

The simulation process consisted of the following steps:

I. Importing Meteonorm climate data for Abbasabad

II. Defining module and inverter parameters

III. Configuring the system layout (series/parallel arrangement)

IV. Setting tilt and azimuth angles

V. Importing the horizon profile

VI. Running annual simulations to compute:

- *Global incident energy*
- *Effective irradiance on the array*
- *Array losses (thermal, ohmic, mismatch, irradiance)*
- *System losses (inverter, wiring, AC losses)*
- *Monthly and annual energy yield*
- *PR*

The simulation results indicated:

I. Array losses: 0.81 kWh/kWp/day

II. Inverter losses: 0.17 kWh/kWp/day

III. Useful AC energy delivered: 4.67 kWh/kWp/day

IV. Annual PR: ~0.827

These values demonstrate that despite the humid climate and shading effects, the system maintains acceptable performance.

5 | Results and Discussion

This section presents the simulation outcomes of the grid-connected photovoltaic system installed in Abbasabad and provides a detailed analysis of energy production, system losses, and PR. The results are interpreted in the context of local climatic conditions and compared with findings from recent global studies.

5.1 | Monthly and Annual Energy Production

According to the PVsyst simulation results *Table 4*, the system delivers an average of 4.67 kWh/kWp/day of useful AC energy to the grid. Monthly variations in energy production closely follow the seasonal distribution of solar irradiance:

I. Highest production occurs during June–August, corresponding to higher solar altitude and reduced cloud cover.

II. Lowest production is observed in December–January, primarily due to shorter daylight hours and increased atmospheric moisture.

Table 4. Monthly, annual, and daily energy production at the abbasabad site.

Month	GlobHor (kWh/m²)	DiffHor (kWh/m²)	T_Amb (°C)	GlobInc (kWh/m²)	GlobEff (kWh/m²)	EArray (kWh)	E_Grid (kWh)	PR (Ratio)
January	80.2	31.47	0.81	127.1	121.8	192.4	185.9	0.903
February	96.2	36.23	3.01	135.2	130.4	202.4	195.5	0.893
March	139.0	56.59	8.35	167.6	161.0	241.3	232.9	0.858
April	170.7	69.79	12.69	182.7	174.9	256.9	248.0	0.811
May	206.7	71.30	18.36	197.3	194.8	267.1	261.0	0.811
June	222.0	72.01	23.68	207.7	199.0	274.5	265.0	0.811
July	218.5	66.27	26.67	209.5	202.7	272.3	264.7	0.775
August	201.9	66.38	25.78	210.9	202.7	274.1	264.7	0.775
September	168.4	51.83	21.30	196.9	187.3	262.3	253.4	0.795
October	127.8	38.26	15.27	167.9	159.3	235.7	226.4	0.871
November	87.6	34.03	7.64	131.7	126.4	185.4	178.5	0.871
December	72.9	27.34	2.64	118.1	114.0	177.8	171.7	0.897
Year	1792.9	635.37	13.87	2060.4	1978.6	2859.0	2760.7	0.827

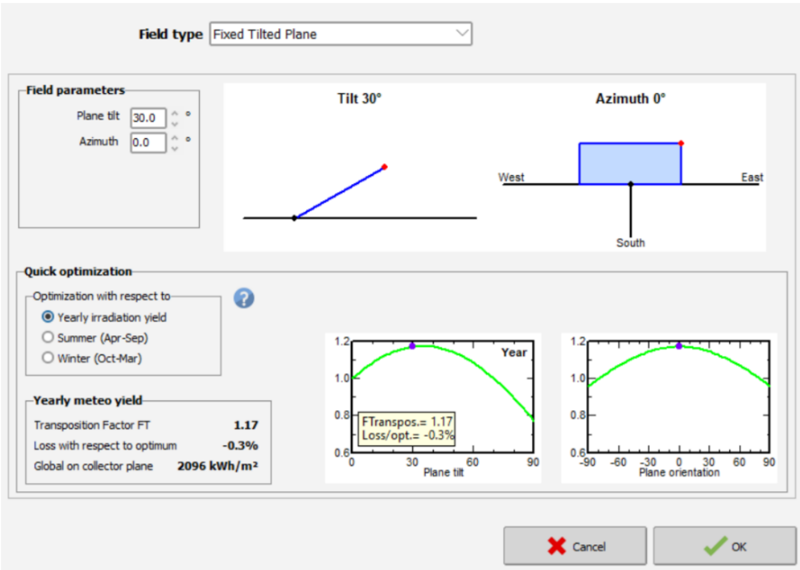

Fig. 2. Determination of panel tilt angle in PVsyst.

Fig. 2 of the thesis illustrates the monthly dispersion of energy yield, showing a clear correlation between irradiance availability and system output. Despite the humid climate, the system maintains stable performance throughout the year, demonstrating the suitability of polycrystalline modules for coastal environments.

5.2 | Performance Ratio Analysis

The annual PR of the system is approximately 0.827, which is consistent with PR values reported for similar climates in Southeast Asia and coastal Turkey (typically 0.78–0.85). The relatively high PR indicates:

I. Effective system design

II. Low mismatch and wiring losses

III. High inverter efficiency (97.2%)

IV. Moderate thermal losses due to the region's mild temperatures

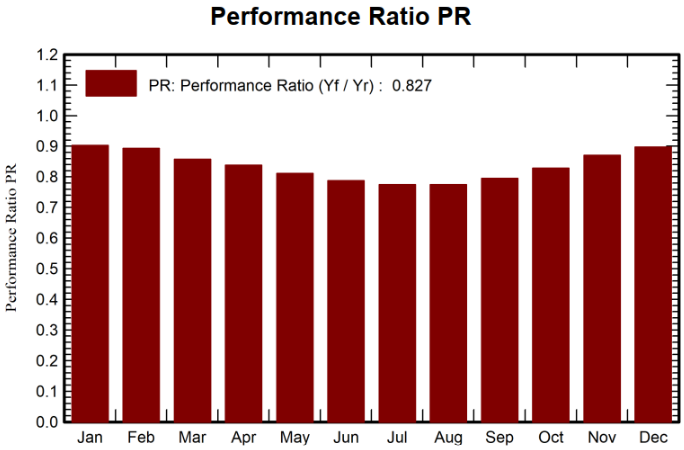

Fig. 3. Average PR of the grid-connected system at the abbasabad site.

Fig. 3 of the thesis shows monthly PR values, with the highest PR occurring in winter months. This trend aligns with global findings that lower module temperatures improve voltage output and reduce thermal derating.

5.3 | Array and System Losses

The PVsyst loss diagram *Fig. 4* provides a detailed breakdown of energy losses from incident irradiance to AC output.

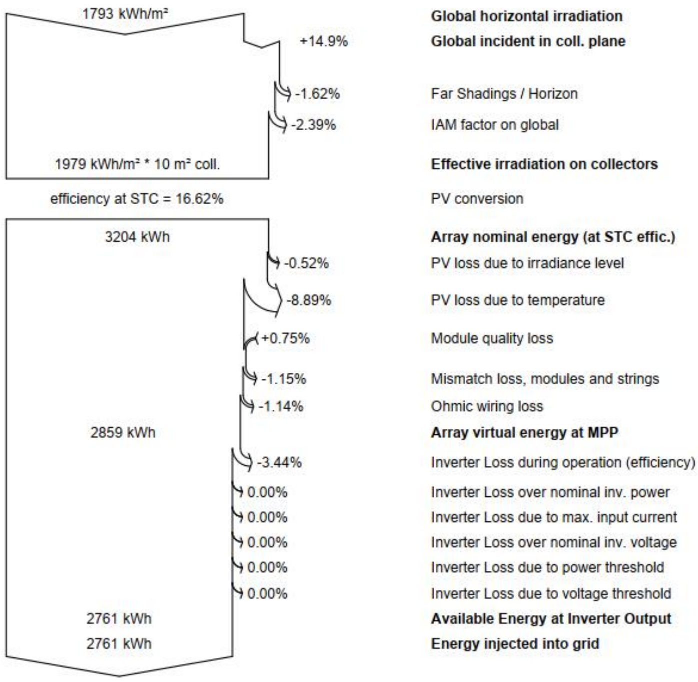

Fig. 4. Total PV panel losses from irradiance to grid injection.

Key findings include:

5.3.1 | Array losses

I. Thermal losses: Significant during summer due to elevated module temperatures.

II. Irradiance losses: Caused by diffuse radiation dominance during cloudy seasons.

III. Mismatch losses: Minimal, reflecting proper module configuration.

IV. Total array losses: 0.81 kWh/kWp/day

These values are consistent with studies conducted in humid climates, where diffuse radiation and moisture reduce effective irradiance.

5.3.2 | System losses

I. Inverter losses: 0.17 kWh/kWp/day, consistent with the inverter's 97.2% efficiency.

II. Wiring and AC losses: Minor, indicating proper system installation.

III. Shading losses: Present during early morning and late afternoon due to surrounding vegetation (*Fig. 1*).

Overall, the system demonstrates low electrical losses, confirming the reliability of the selected components.

5.4 | Influence of Climatic Conditions

The climatic characteristics of Abbasabad significantly influence system performance:

I. Humidity and cloud cover: High humidity reduces beam radiation and increases diffuse irradiance, lowering the effective irradiance on the module surface. This effect is most pronounced in spring and autumn [13], [14].

II. Temperature: Moderate temperatures in winter improve module efficiency, resulting in higher PR values despite lower irradiance.

III. Wind speed: Seasonal winds help cool the modules, reducing thermal losses during warm months.

IV. Dust and biological particles: The presence of pollen and forest-generated particulates can reduce transmittance of the module surface, although the impact is less severe than in arid regions.

These findings align with global studies showing that humid coastal climates exhibit lower irradiance but benefit from reduced thermal losses.

5.5 | Comparison with International Studies

When compared with similar PV installations worldwide:

I. The annual PR of 0.827 is higher than typical values reported for tropical humid regions (0.75–0.80).

II. The energy yield of 4.67 kWh/kWp/day is comparable to coastal installations in Turkey and Brazil.

III. Loss patterns closely resemble those reported in studies from Malaysia and Thailand, where diffuse radiation dominates.

6 | Conclusion

This study conducted a comprehensive performance assessment of a grid-connected PV system operating under the humid subtropical climatic conditions of Abbasabad, Mazandaran. Using long-term meteorological data from Meteonorm and detailed system modeling in PVsyst, the research quantified the influence of local environmental factors-including humidity, diffuse radiation, shading, and seasonal temperature variations-on system behavior.

The results demonstrate that despite the region's high atmospheric moisture and dense vegetation, the PV system maintains a strong annual PR of 0.827, which is comparable to or higher than values reported for similar coastal and humid regions worldwide. The system delivers an average of 4.67 kWh/kWp/day of useful AC energy, confirming its suitability for residential-scale electricity generation. Loss analysis revealed that array losses (0.81 kWh/kWp/day) and inverter losses (0.17 kWh/kWp/day) are within acceptable ranges, with thermal losses being the most significant contributor during summer months.

The findings highlight the importance of incorporating accurate horizon profiles, climate-specific irradiance patterns, and temperature-dependent module behavior when designing PV systems in humid environments.

The study also underscores the potential of polycrystalline modules to perform reliably under diffuse-dominant radiation conditions.

Overall, this research provides valuable insights for optimizing PV deployment in northern Iran and similar coastal climates. Future work may include on-site experimental measurements, soiling impact quantification, and economic optimization to further enhance system performance and long-term reliability.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability

All data are included in the text.

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