J Ther Eng, Vol. 11, No. 5, pp. 1507−1519, September, 2025

Journal of Thermal Engineering
Web page info: https://jten.yildiz.edu.tr
DOI: 10.14744/thermal.0000999

Research Article

Technical and economic feasibility analysis of 1kW Rooftop Solar Photovoltaic System for Mysuru, Karnataka, India

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ARTICLE INFO

Article history
Received: 13 May 2025
Revised: 21 July 2025
Accepted: 31 July 2025

Keywords:
Carbon Dioxide Output; Economic Analysis; Financial Feasibility; Return on Investment; Rooftop Solar Photovoltaic (PV) Systems; Solar Irradiation

ABSTRACT

Rooftop solar photovoltaic (PV) systems have emerged as a key decentralized energy solution in response to rising electricity demand, climate change concerns, and the global shift toward low-carbon power generation. Despite favourable policies and falling technology costs, adoption in many regions remains suboptimal. This study investigates the techno-economic feasibility of 1 kW rooftop solar PV systems in Mysuru, Karnataka, India, an urban area with high solar potential, receiving an average Global Horizontal Irradiance (GHI) of approximately 5.5 kWh/m²/day across over 300 sunny days annually. A system configuration comprising monocrystalline or polycrystalline PV modules, a 1 kW inverter. The system is projected to generate 1,500–1,800 kWh annually, resulting in savings of up to ₹8,850 per year at the current residential tariff of ₹5.90/kWh. Installation costs range between ₹45,000 and ₹50,000, with government subsidies such as those under the PM Surya Ghar: Muft Bijli Yojana, potentially covering up to ₹78,000. The financial analysis indicates a payback period of 4–6 years and a return on investment of 15–20% over a 25-year operational lifespan, alongside annual carbon dioxide emission reductions of approximately 1 ton. While the system proves technically and economically viable, challenges persist, including upfront capital costs, limited public awareness, and spatial constraints. The study underscores the importance of policy support, public engagement, and community solar initiatives in scaling rooftop PV adoption and advancing India's renewable energy transition

Cite this article as: Rao RDD, Gowda BS. Technical and economic feasibility analysis of 1kW Rooftop Solar Photovoltaic System for Mysuru, Karnataka, India. J Ther Eng 2025;11(5):1507−1519.

INTRODUCTION

The use of renewable energy has been increasing dramatically in the past few years, and among the available technologies, the solar photovoltaic (PV) system has become one of the most attractive solutions for home and commercial energy services. Most particularly, rooftop PV solar systems are emerging as an inexpensive and environmentally friendly power source [1,2]. Several studies have examined the technical and economic feasibility of such systems in various

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This paper was recommended for publication in revised form by Editor-in-Chief Ahmet Selim Dalkılıç geographical areas and have made significant contributions to their adoption [3–5].

In India, grid-connected solar PV plant techno-economic viability has been thoroughly investigated, and it has been demonstrated that such systems are scalable and financially effective [6–8]. Similarly, the performance of rooftop solar PV systems has been evaluated in regions like Eastern India, where they show high energy production and operational efficiency [9]. Reviews of solar PV systems have noted opportunities and challenges for scaling this technology, highlighting growth potential in both urban and rural settings [10–12].

Studies in Southeast Asia, particularly Malaysia, have evaluated grid-connected PV systems, focusing on economic advantages and system performance under tropical conditions [13,14]. In particular, techno-economic analyses in Malaysia have shed light on their potential and feasibility of grid-connection [15]. Global reviews of solar PV power generation have noted the increasing adoption of solar energy as a result of advancements in technology and cost reductions [16–18]. With the rapid increase of solar PV systems, research has provided data on operational performance, challenges, and environmental aspects [19–21].

Techno-economic studies of small-sized rooftop solar panels have been carried out, where case studies demonstrate cost and environmental benefits in India [22–24]. Efforts to optimize hybrid renewable energy systems, integrating PV with other renewables such as wind, have been conducted to improve efficiency and reliability [25,26]. In the Indian context, building-integrated PV systems have been explored for energy efficiency, showing the potential of solar energy to be incorporated into the built environment [27]. Reviews of solar thermal collectors and economic analyses of solar systems emphasize the importance of these approaches in improving overall energy efficiency [28,29].

Performance and cost studies have provided insights into the design of grid-scale PV applications, showing their feasibility for large-scale deployment [30–32]. Broader social, economic, and environmental impacts of renewable energy systems have also been evaluated, highlighting their contribution to sustainable development [33]. Advanced software tools for simulating and optimizing hybrid renewable energy systems have been developed, supporting the design of more efficient and cost-effective PV installations [34–36].

Challenges of integrating PV into existing energy infrastructure, including technical, financial, and policy bottlenecks, have been discussed extensively [37]. Rural electrification studies have emphasized solar PV as a viable option for decentralized, off-grid power supply, alleviating global energy poverty [38]. Environmental factors such as dust, humidity, and air speed significantly affect PV performance, and strategies have been proposed to mitigate these effects [39]. Recent technological improvements, including high-efficiency solar cells and modules, have further reduced costs and enhanced energy generation [40]. New approaches such as phase-change material–based cooling and machine learning–driven performance evaluation have also been investigated to improve the operational efficiency of PV systems [41].

The objective of this paper is to assess the technical and economic viability of a 1 kW rooftop solar PV system in Mysuru, Karnataka, by integrating results from a wide range of studies on solar PV performance, cost, and integration. Based on energy generation, cost-effectiveness, and ecological viability, the research provides useful information to estimate the potential of rooftop solar PV installations in the area. This analysis also offers guidance for implementing solar energy solutions in India and other developing countries.

Novelty and Research Gap

While numerous studies have explored the techno-economic viability of rooftop solar PV systems in various parts of India and Southeast Asia, most focus on either large-scale installations, generalized models, or major metropolitan regions [42]. However, localized assessments that incorporate micro-climatic data, site-specific irradiance conditions, policy incentives, and dynamic performance modeling for small-scale (1 kW) rooftop PV systems remain limited in the literature, especially for Tier-2 Indian cities like Mysuru. Existing studies often overlook the integration of region-specific irradiance profiles, real-world consumption patterns, and government subsidy impacts under the latest schemes, such as the *PM Surya Ghar: Muft Bijli Yojana*. Furthermore, few studies evaluate inverter performance, energy losses, solar fraction, and lifecycle carbon mitigation alongside economic metrics such as Levelized Cost of Energy (LCOE), ROI, and payback period in a unified framework [43].

To address these gaps, this study presents a detailed technical and financial analysis of a 1 kW grid-connected rooftop solar PV system for Mysuru by incorporating realistic simulation data (using Meteonorm 8.2), system loss factors, financial incentives, and CO_2 offset calculations. The work is novel in its region-specific application, its integrated environmental–economic evaluation, and in proposing scalable policy recommendations for broader adoption in similar urban settings across developing countries. This study contributes to a replicable methodology for decentralized renewable energy deployment, bridging the gap between technical feasibility studies and on-ground implementation strategies [44].

SYSTEM UNDER STUDY

Site Details

The project is based in Mysuru, Karnataka, India, located at latitude 12.31° N and longitude 76.65° E, with an altitude of 737 meters above sea level. The site operates in the UTC+5.5-time zone. The weather data used for this project is synthetic and sourced from Meteonorm 8.2, covering the years 1996–2015 with 100% satellite data (Sat=100%). The albedo value, which represents the reflection coefficient of the surface, is set at 0.20.

Table 1. Site geographical parameters

Parameter	Details
Geographical Site	Mysuru, India
Latitude	12.31° N
Longitude	76.65° E
Altitude	737 m
Time Zone	UTC +5.5
Weather Data Source	Meteonorm 8.2 (1996–2015), Synthetic, Sat=100%
Project Settings	Albedo: 0.20

Table 2. Site geographical parameters

Category	Details
System Type	Grid-Connected System
Orientation	Fixed Plane
Tilt/Azimuth	20° / 0°
3D Scene Definition	No 3D scene defined, no shading
Near Shadings	No shadings
User's Needs	Fixed constant load: 1000 W
Global Energy	8760 kWh/year
PV Array Information	
- Single module Power rating	100W
- Number of Modules	10 units
- Nominal Total Power	1000 Wp
Inverter Information	
- Number of Units	1 unit
- Nominal Total Power	1200 W

System Configuration

Here is the provided information formatted in tabular form:

This system is a grid-connected photovoltaic (PV) system with a fixed-plane orientation. The tilt angle of the solar panels is set at 20°, with an azimuth of 0°, aligning the panels for optimal sunlight capture. There is no 3D shading model or nearby obstructions causing shading, ensuring unimpeded solar energy generation. The system meets a fixed constant load demand of 1000 W and generates an annual energy output of 8760 kWh.The PV array consists of 10 modules with a combined nominal power output of 1000 Wp. Energy conversion is handled by a single inverter rated at 1200 W, with a performance ratio of 0.833, indicating efficient system operation.

Single Line Diagram

The diagram illustrates the flow of energy in a photovoltaic (PV) system. Below are the components and their roles:

1. Solar Modules (1 x ASE-100-DG-UR/mono, 5 Strings): The system consists of a single array of solar panels labelled ASE-100-DG-UR/mono. It is configured in 5 strings, which are parallel connections of multiple

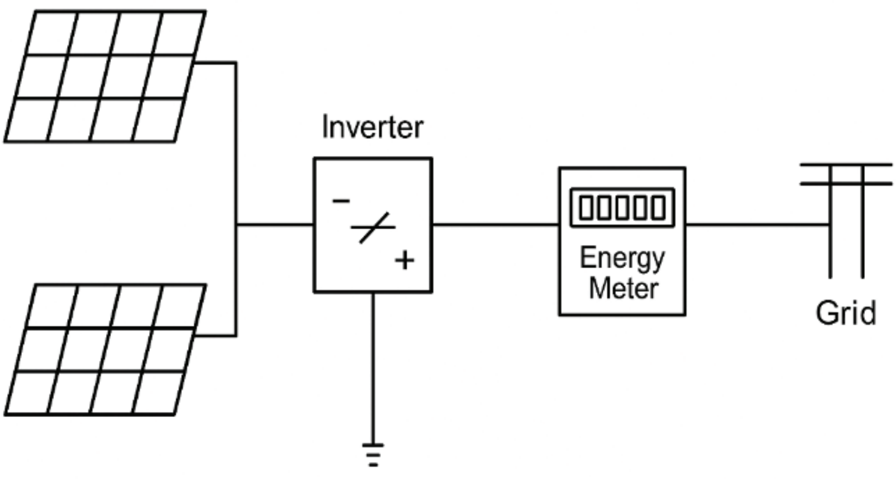

Figure 1. Single line diagram of a 1kW grid-connected Solar PV system.

Table 3. Power generation and performance ratio

Parameter	Value
Produced Energy	1492.6 kWh/year
Used Energy	8760.0 kWh/year
Specific Production	1493 kWh/kWp/year
Performance Ratio (PR)	77.83 %
Solar Fraction (SF)	17.04 %

panels. The array supports 2 Maximum Power Point Tracking (MPPT) mechanisms to optimize the power output from the panels.

2. Inverter (1 kVA): The direct current (DC) generated by the solar modules is sent to an inverter. The inverter has a power rating of 1 kVA and is equipped with 2 MPPTs to efficiently convert DC into alternating current (AC).
3. Grid: The AC electricity from the inverter is transmitted to an injection point for utilization to the grid. The energy is measured in kilowatt-hours (kWh) at this point, which typically represents the grid connection or the end-user consumption point.

Power Generation and Performance Ratio

The table 3 provides a summary of the energy performance of a solar system. The produced energy represents the total amount of electricity generated by the system in a year, which amounts to 1492.6 kWh. Meanwhile, the used energy is significantly higher, standing at 8760.0 kWh/year, indicating that the energy demand exceeds the supply from the solar system.

The specific production value of 1493 kWh/kWp/year reflects the efficiency of the system in converting solar energy into usable electricity. The performance ratio (PR), which is 77.83%, is a measure of the system›s efficiency after accounting for losses due to environmental and system factors. Finally, the solar fraction (SF), at 17.04%, shows the percentage of the total energy consumption that is met by the solar system.

The annual energy generation of 1,492 kWh from the 1 kW rooftop solar PV system in Mysuru aligns well with performance outcomes reported in comparable Indian cities with similar solar irradiance. For example, rooftop systems in Bangalore—located within the same climatic zone and receiving comparable average Global Horizontal Irradiance (GHI) of around 5.5–5.6 kWh/m²/day—have shown specific yields in the range of 1,450 to 1,520 kWh/kWp/year. Similarly, in Hyderabad, which benefits from slightly higher solar exposure (GHI ~5.9–6.2 kWh/m²/day), studies have reported annual yields between 1,550 and 1,600 kWh/kWp. These comparisons confirm that the system performance in Mysuru is consistent with regional expectations, validating the simulation-based analysis and underscoring the city's suitability for rooftop solar PV deployment under typical urban conditions.

Other Simulated Results

Irradiance profile

The Figure 2 illustrates the monthly average solar irradiance in Mysuru, measured in kilowatt-hours per square meter per day (kWh/m²/day), highlighting the seasonal variation in solar energy availability throughout the year. The data shows that solar irradiance is highest between

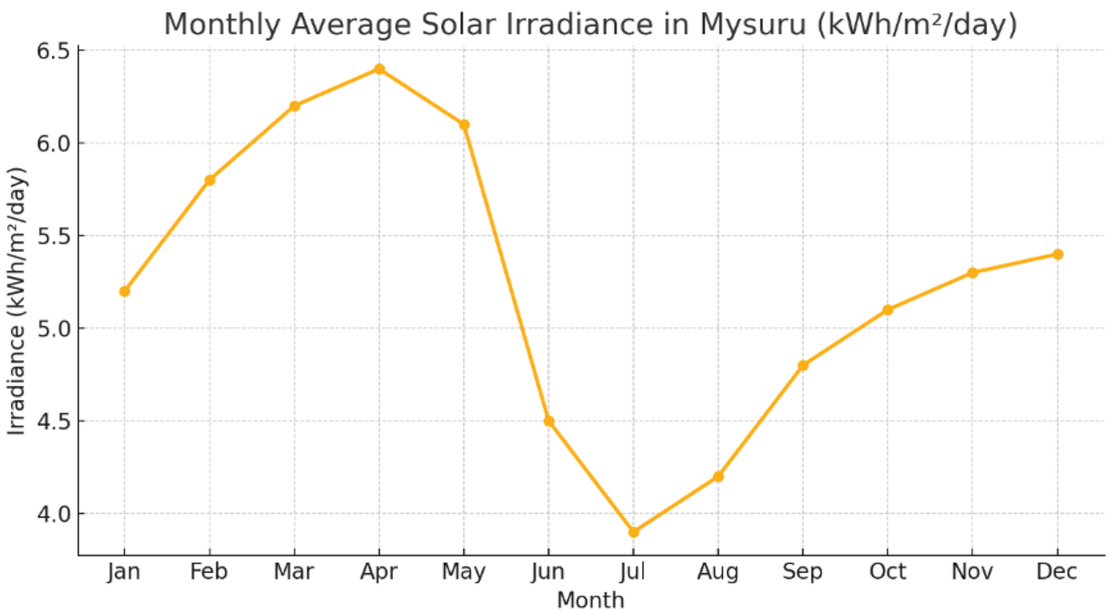

Figure 2. Solar Irradiance profile.

February and May, peaking in April at approximately 6.4 kWh/m²/day, indicating a strong potential for solar energy generation during these months. Conversely, the lowest irradiance occurs in July, dropping to around 3.9 kWh/m²/day, which coincides with the region's monsoon season, when cloud cover and rainfall reduce solar exposure. After July, the irradiance values gradually increase, reaching around 5.4 kWh/m²/day by December. This trend confirms that Mysuru experiences substantial solar radiation for most of the year, making it a suitable location for rooftop solar photovoltaic (PV) installations. Understanding this monthly variation is crucial for optimizing system design, energy yield estimation, and financial planning, particularly for grid-connected or hybrid solar systems intended to supply consistent power throughout the year.

Power handling characteristics

The Figure 3 illustrates the power handling characteristics of a 1 kW rooftop solar PV system over a typical day, emphasizing the influence of ambient temperature on energy output. The nominal energy at STC (Standard Test Conditions), shown by the black dashed line, peaks at approximately 6.35 kWh around 12:30 PM, representing the theoretical maximum energy under ideal conditions. The virtual energy at MPP, depicted by the blue dotted line, accounts for actual environmental conditions and peaks slightly lower, at about 5.9 kWh. The inverter output energy, indicated by the red solid line, reflects the usable energy after losses and reaches a maximum of around 5.1 kWh. The graph shows energy generation beginning around 6:00 AM, increasing steadily, and tapering off by 6:30 PM, following the sun's path. The ambient temperature, represented by the green dashed line (right y-axis), rises from approximately 5°C in the early morning to a peak of 26°C around noon, before decreasing in the evening. The observed drop in inverter output energy in the afternoon, despite continued high irradiance, highlights the impact of elevated temperatures on PV performance. This quantification confirms that thermal effects, along with inverter and system losses, reduce actual output compared to theoretical expectations, emphasizing the importance of temperature management in PV system design and evaluation.

Energy exchange characteristics

Figure 4 illustrates the energy exchange characteristics of the 1 kW rooftop solar PV system over a 24-hour period, highlighting the interaction between solar energy generation and grid dependency. The green curve represents the available solar energy, which begins around 6:00 AM, peaks at approximately 870 W near 12:00 noon, and drops back to zero by 6:30 PM, following the solar irradiance pattern. The red curve shows the energy drawn from the grid, which is highest during early morning and late evening hours—reaching 1,000 W when solar generation is absent—and reaches a minimum of approximately 170 W during peak solar hours. The blue line indicates the total energy supplied

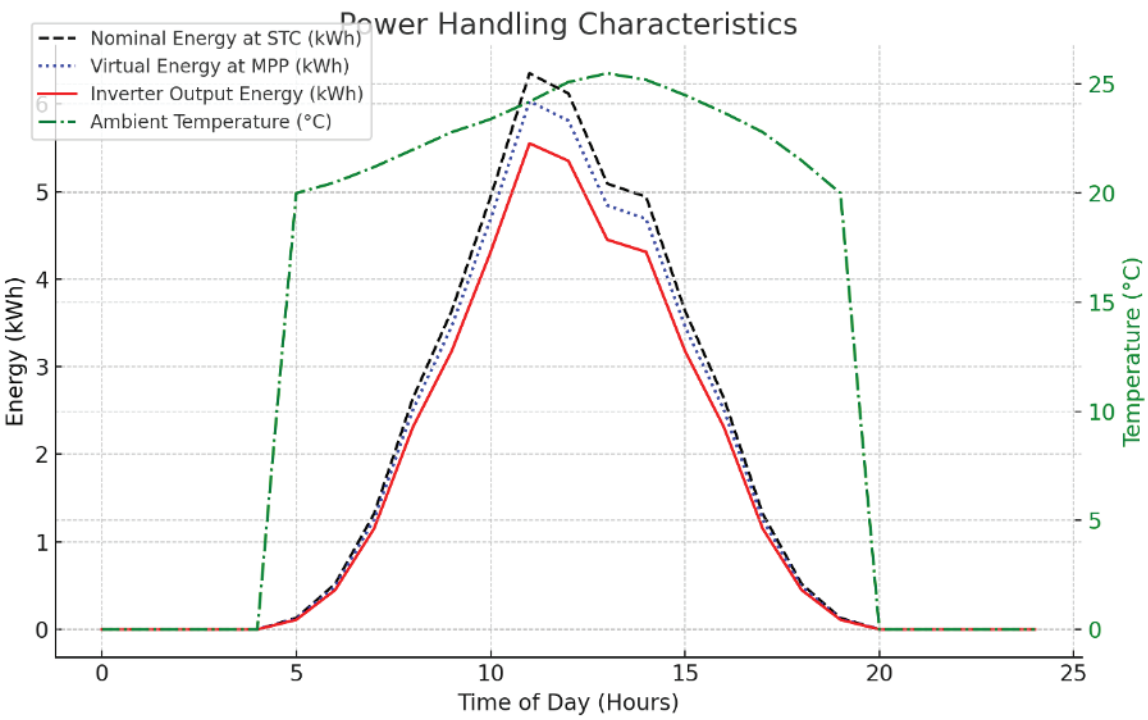

Figure 3. Power handling characteristics representing array virtual energy at MPP, inverter output as a function of ambient temperature.

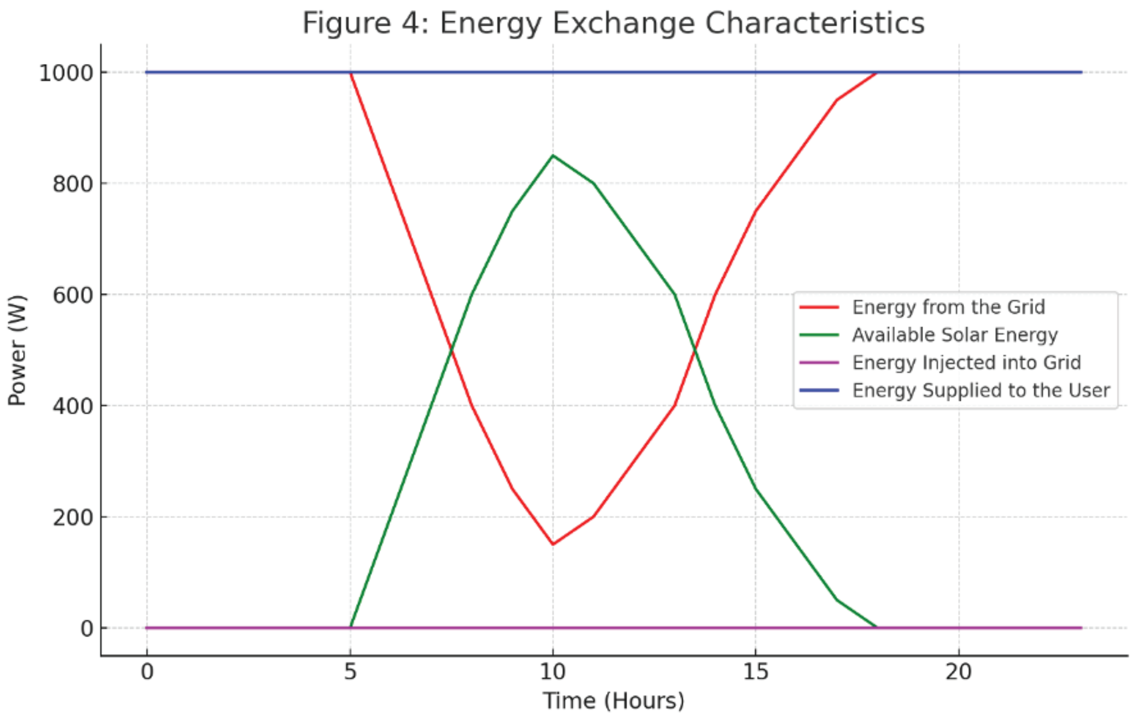

Figure 4. Energy exchange characteristics.

to the user, which remains constant at 1,000 W throughout the day, reflecting a fixed load demand. Notably, the purple line—representing energy injected into the grid—remains flat at zero, indicating that all solar energy is consumed locally and no excess power is exported. This pattern highlights the system's role in reducing grid dependency during daylight hours, but also emphasizes the need for grid support during non-solar periods. The absence of grid export suggests the system is either not connected under a net metering arrangement or is undersized relative to user demand.

Comparison of inverter output energy vs. nominal energy at stc

Figure 5 shows a comparison between the nominal energy output at Standard Test Conditions (STC) and the actual inverter output energy of a 1 kW solar PV system over a 24-hour period. The black dashed line represents the nominal energy output at STC, which peaks at approximately 6.35 kWh around 12:30 PM**,** indicating the theoretical maximum energy generation under ideal conditions. In contrast, the red solid line illustrates the actual inverter output energy, which accounts for real-world losses such as temperature effects, system inefficiencies, and inverter losses.

The inverter output starts rising from around 6:00 AM, peaks at 5.09 kWh by 11:00 AM, and then gradually declines, reaching nearly zero by 7:00 PM. The noticeable difference between the nominal and actual output during midday, particularly the gap between 6.35 kWh (nominal) **and** 5.09 kWh (actual) highlights the impact of performance losses. This includes temperature-induced efficiency drops, which become more significant during peak sunlight hours. Overall, the graph clearly illustrates how real-world conditions reduce the energy output below theoretical maximum levels, underscoring the importance of factoring in system losses for accurate performance and financial modeling.

Solar PV voltage current characteristics

The figure shows the Voltage-Current (V-I) characteristic curve of a solar PV module. As the voltage increases from 0 to 40 V, the current decreases non-linearly from about 8 A to 0 A, illustrating the typical behaviour of a PV cell. The curve highlights how current output drops with rising voltage, and it helps identify the maximum power point (MPP),the optimal operating point for maximum energy output.

Loss diagram

The loss diagram summarizes the energy flow and losses in the 1 kW rooftop solar PV system, from solar irradiation to usable AC output. Starting with a global horizontal irradiation of 1941 kWh/m^2, about 2.6% is lost due to tilt and orientation (IAM factor), resulting in 1903.7 kWh of nominal array energy. Further losses due to temperature (12.7%), module quality, mismatch, and wiring reduce the energy to 1603.2 kWh at the Maximum Power Point (MPP). Inverter-related losses, such as efficiency losses and power threshold

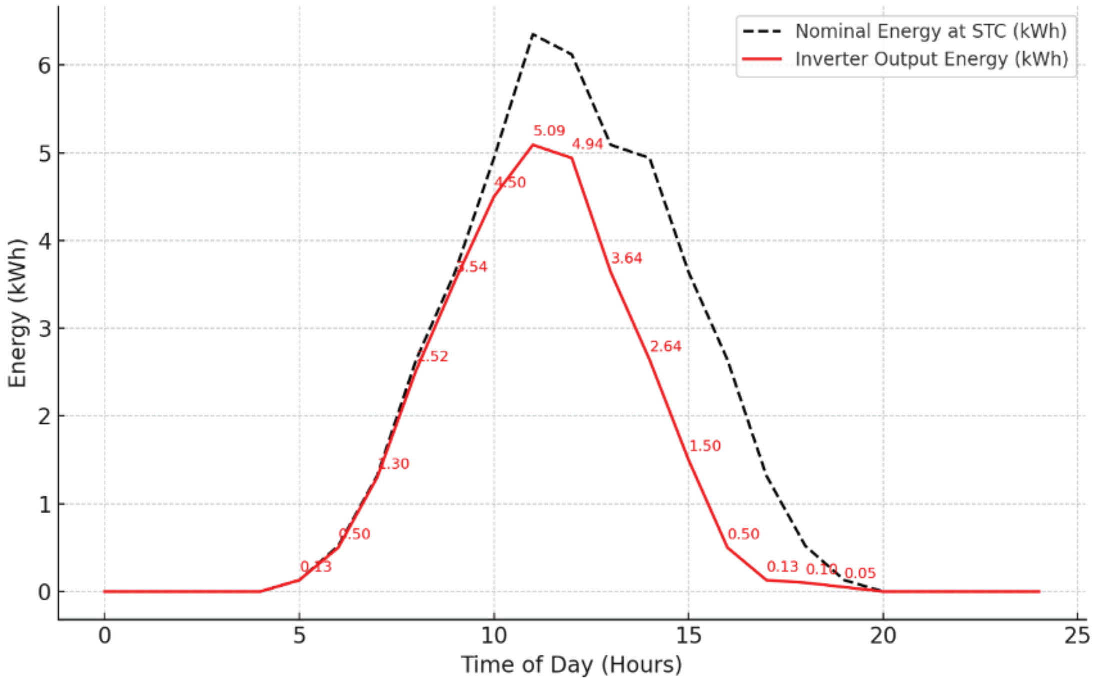

Figure 5. Comparison of Inverter Output Energy vs. Nominal Energy at STC.

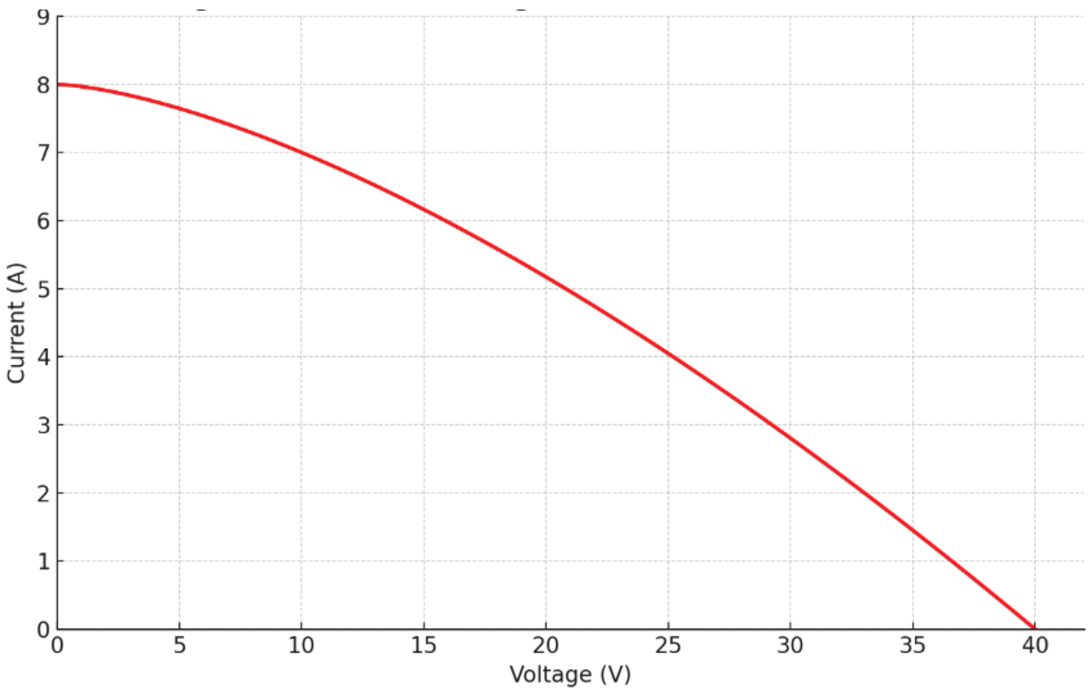

Figure 6. Voltage Current Characteristics.

effects, account for 6.9%, yielding 1492.6 kWh as the final available energy at the inverter output. This is the energy supplied to the user, while no energy is injected into the grid. The diagram clearly shows that while the system is efficient, about 23% of total potential energy is lost, mainly due to temperature and inverter inefficiencies.

Energy Balance Statistics

Across different indicators such as energy production, system efficiency, and yearly pattern of use, the information shown in Table 4 offers a thorough summary of solar energy performance. Looking at these monthly and yearly patterns will help us to learn much about the efficiency of the system

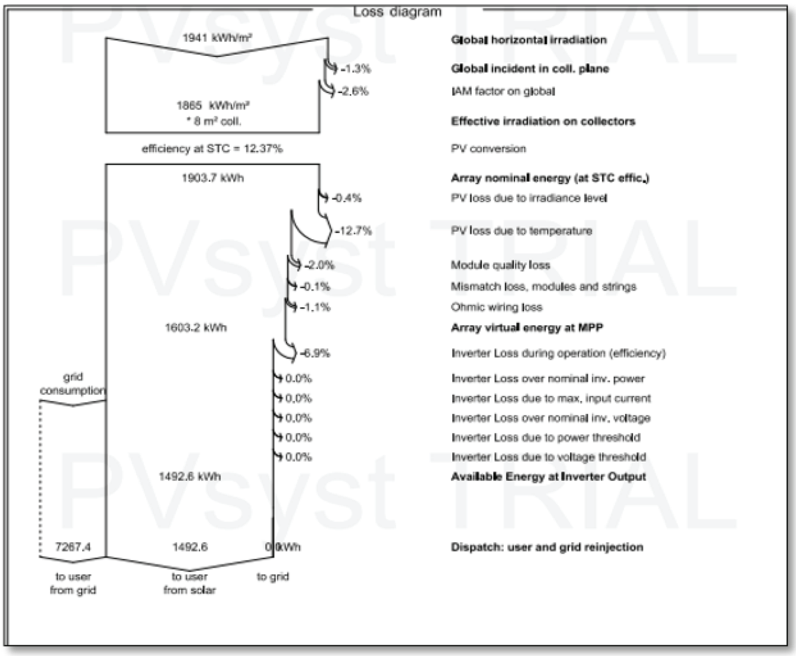

Figure 7. Loss diagram.

Table 4. Energy balance statistics

Month	GlobHor (kWh/m²)	DiffHor (kWh/m²)	T_Amb (°C)	GlobInc (kWh/m²)	GlobEff (kWh/m²)	EArray (kWh)	EUser (kWh)	ESolar (kWh)	EGrid (kWh)	EFGrid (kWh)
January	171.1	51.39	22.17	197.2	192.9	164.7	744.0	155.4	0.00	588.6
February	168.7	55.00	24.48	181.8	177.9	149.9	672.0	141.4	0.00	530.6
March	195.6	69.25	26.89	195.4	191.0	159.5	744.0	148.0	0.00	594.2
April	188.4	72.03	27.57	176.4	171.9	144.4	720.0	135.1	0.00	584.9
May	187.1	81.41	28.46	162.6	157.5	135.7	744.0	125.9	0.00	618.1
June	154.7	82.88	24.94	129.5	125.3	110.4	744.0	103.1	0.00	640.9
July	135.7	83.83	24.08	116.2	112.1	100.1	744.0	96.0	0.00	633.4
August	153.3	76.19	23.77	144.7	140.7	122.0	744.0	113.5	0.00	630.5
September	153.9	76.11	23.99	155.1	151.1	130.3	744.0	121.1	0.00	622.9
October	150.9	71.11	23.89	155.1	150.7	130.3	744.0	121.1	0.00	622.9
November	138.2	56.01	22.48	152.0	148.3	127.4	720.0	118.8	0.00	601.2
December	148.0	54.88	21.87	170.8	166.7	143.5	744.0	134.5	0.00	609.5
Year	**1940.7**	**837.02**	**24.37**	**1915.3**	**1864.7**	**1603.2**	**8760.0**	**1492.6**	**0.00**	**7267.4**

and possible opportunities for development. The information gives rise to a thorough examination below.

By examining this solar energy installation, one can see several main patterns and get some ideas on its general year-long efficiency and performance. The information begins with Global Horizontal Irradiance (GlobHor), which has an annual total of 1940.7 kWh/m²; the data indicates that March, April, and May represent the top solar energy output months. Ideal for solar power harvesting are these months since they have more irradiance and longer daylight hours. Likewise, reflecting good solar panel angle and tracking, Global Incident Irradiance (GlobInc) adds up to 1915.3 kilowatt hours per square meter annually and follows a parallel pattern. The correlation of these parameters indicates that the system is well-designed to optimize energy capture.

The annual system›s Global Efficiency (GlobEff) of 1864.7 kWh/m² is very close to the GlobInc values, suggesting little energy loss throughout the capture procedure.

This shows the consistent performance and great reliability of the solar system. As for energy output, the system produces 1603.2 kWh yearly, with peak manufacturing from March to May. But the production falls a bit in June and July, which might be due to reduced sunlight or the effect of greater temperatures, since heat lowers the effectiveness of solar panels.

On the usage side, the **EUser** data shows a consistent energy demand of 744.0 kWh every month, adding up to 8760.0 kWh annually. Solar energy contributes approximately 1492.6 kWh annually (**ESolar**), covering about 17% of the total energy needs. This makes a significant impact on reducing reliance on external power sources. Notably, the system does not draw any energy from the grid (**EGrid = 0.00 kWh**), demonstrating its ability to meet real-time energy demands entirely through solar power. Furthermore, the system offsets 7267.4 kWh of fossil fuel-based energy (**EFGrid**) annually, showcasing its contribution to reducing carbon emissions and supporting environmental sustainability.

The annual average ambient temperature of 24.37°C also affects the functioning of the system, together with the above-mentioned factors. Since lower temperatures reduce heat-related energy losses, cooler months like January, February, and December correspond with marginally better efficiency. Particularly in hotter seasons, this drives home the need to manage heat to preserve ideal system performance.

From these observations, several possibilities for betterment present themselves. From February to May, the system runs very smoothly, implying that extra energy produced during these months could be saved for less productive times like June, July, and December. Further lowering dependence on supplementary energy sources could come from investing in energy storage systems or increasing the capacity of the system. Implementing policies to control heat in warmer months, like air conditioning, could also help to raise general efficiency. In essence, the solar energy system works dependably and offers a significant contribution to decreasing reliance on traditional energy sources. By balancing major fossil fuel consumption, it effectively produces clean energy year-round. This review underlines its advantages and presents down-to-earth ideas for improvement; hence, it is a useful tool for knowledge and enhancement of solar energy facilities in parallel situations.

Economic Feasibility Analysis

The presented analysis offers a comprehensive evaluation of the solar energy system›s cost structure, operational efficiency, and energy production. By examining installation expenses, yearly maintenance costs, and energy output, the data provides valuable insights into the system›s economic feasibility and long-term sustainability. This assessment highlights the balance between affordability and performance, showcasing the potential of solar energy as a reliable and environmentally friendly power source.

Installation costs

This analysis looks at the cost structure, operational costs, and energy production of the solar energy system. By looking at installation costs, annual maintenance costs,

Table 6. Operating Cost

Item	Total (INR/year)
Maintenance	12,000.00
Provision for Inverter Replacement	30,000.00(if required)
Cleaning	10000
Total (OPEX)	50000

Table 7. System cost summery

Parameter	Value
Total Installation Cost	50,000.00 INR
Operating Costs	50000 INR/year
Produced Energy	1493 kWh/year
Cost of Produced Energy	2.0099 INR/kWh

Table 5. Installation cost

Item	Quantity (Units)	Cost (INR)	Total (INR)
PV Modules (ASE-100-DG-UR/mono)	10	200.00	2,000.00
Supports for Modules	10	1,000.00	10,000.00
Inverters (EZH1)	1	30,000.00	30,000.00
Wiring	1	2,000.00	2,000.00
Combiner Box	1	2,000.00	2,000.00
Monitoring System, Display Screen	1	2,000.00	2,000.00
Measurement System, Pyrometer	1	2,000.00	2,000.00
Total Depreciable Asset			42,000.00
Total Installation Cost			50,000.00

and energy output, the data gives us an idea of the system's viability and long-term sustainability. This balances affordability and performance and shows solar energy as a reliable and eco-friendly power source.

This analysis gives a clear picture of the cost structure, operational expenses, and energy production efficiency of the solar energy system. Installation costs total 50,000 INR, which includes depreciable assets and auxiliary components. The largest investment is in the inverter (30,000 INR) as it is the heart of the system that converts and manages energy from the photovoltaic modules. The PV modules cost 2,000 INR, and the remaining components – supports, wiring, combiner box, monitoring system, and measurement equipment – cost 18,000 INR. These components ensure system durability, accurate performance monitoring, and overall functionality.

In terms of operational costs, the annual expenses are very low at 2,000 INR, out of which 1,000 INR is for maintenance, 1,000 INR for cleaning, and a provision for inverter replacement. These low operational costs make the system affordable and manageable over time.

The system summary shows key performance metrics. The system generates 1493 kWh annually, the levelized cost of energy (LCOE) is 2.0099 INR/kWh. This cost is competitive with conventional power sources and is a good option to reduce long term energy expenses. Also the system is very efficient so most of the produced energy is utilized and minimal wastage.

From this, we can see the system is designed for cost and reliability. But there is scope to optimize energy production by adding more PV modules or improving energy storage solutions to utilize excess energy. This can also reduce the LCOE and add more value to the system. Overall, the system balances installation cost, operational cost, and energy output and is a sustainable and eco-friendly energy solution.

Government tariffs

In the context of Mysuru, Karnataka, the residential electricity tariff is mentioned as ₹5.90/kWh. This tariff serves as the baseline for calculating energy savings when offsetting grid electricity with solar PV generation.

- Savings from Solar: The system generates around 1,500–1,800 kWh annually, resulting in a potential annual saving of up to ₹8,850, calculated as 1500 kWh × ₹5.90.
- Cost of Produced Energy (LCOE): ₹2.0099/kWh, which is significantly lower than the residential tariff, highlighting the economic attractiveness of rooftop solar under current tariff structures.

Grid buy-back rates

The manuscript indicates that no energy is exported back to the grid (i.e., *EGrid = 0.00 kWh/day*), suggesting that the system is either:

- Operating in self-consumption mode only, or
- Connected without an active net metering agreement that allows feed-in.

In Karnataka, grid buy-back rates for rooftop solar systems have historically ranged between ₹2.50 to ₹4.00/kWh depending on system size and DISCOM regulations. However, this benefit is not realized in the current configuration in your study due to zero export.

Net metering benefits and potential

Although not fully implemented in the analyzed system, net metering can provide significant additional benefits:

- Under net metering, excess solar power fed to the grid earns credits, which can offset electricity usage during non-solar hours (e.g., nighttime).
- If implemented, this would:
  - o Improve solar fraction (currently 17.04%) by allowing for better utilization of excess daytime energy.
  - o Reduce grid dependency (currently supplying 18.20 kWh/day) without necessarily requiring energy storage.
  - o Enhance financial returns by monetizing otherwise curtailed or unused generation.

Given Karnataka's support for rooftop solar under the PM Surya Ghar: Muft Bijli Yojana, and similar schemes, a properly structured net metering policy would:

- Increase the annual return on investment (currently estimated at 15–20%).
- Reduce the payback period (4–6 years) further.
- Align with national renewable energy targets by promoting decentralized, clean power generation.

Carbon Emission Balance

This section evaluates the carbon emission reduction potential of a 1 kW rooftop solar photovoltaic (PV) system installed in Mysuru, Karnataka. The assessment is based on updated emission factors, system generation data, and life cycle emission estimates.

Annual emissions avoided

Based on the estimated annual energy generation of 1,500 kWh, and using a grid emission factor of 0.8 kg CO_2/kWh for India as per the Central Electricity Authority (CEA), the system can offset:

- Annual Avoided Emissions = 1,500 kWh × 0.8 kg CO_2/kWh = 1,200 kg CO_2 or 1.2 metric tons CO_2

Emissions over 25-year lifespan

Assuming consistent output and no major degradation losses beyond standard assumptions, the system will offset approximately:

- 1.2 metric tons CO_2/year × 25 years = 30 metric tons CO_2 over its lifetime

Life cycle emissions of system components

To determine the net carbon impact, emissions from manufacturing and installing the solar system must also be considered. Life cycle emissions data for a 1 kW PV system are approximately:

- PV Modules: 1,700 kg CO_2

- Mounting Structure: 600 kg CO_2
- Inverter: 600 kg CO_2
- Balance of System: 200 kg CO_2
- Total Lifecycle Emissions: ~3,100 kg CO_2 (3.1 metric tons)

7.4 Net Emission Reduction

Net CO_2 Offset = Emissions Avoided - Lifecycle Emissions

Net CO_2 Offset = 30 tons - 3.1 tons = 26.9 metric tons CO_2

This analysis demonstrates the significant environmental benefit of adopting rooftop solar, with the 1 kW system yielding a net reduction of nearly 27 metric tons of CO_2 over its useful life.

CONCLUSION

This study comprehensively assessed the technical, economic, and environmental feasibility of a 1 kW rooftop solar photovoltaic (PV) system in Mysuru, Karnataka—a Tier-2 Indian city with substantial solar potential. Simulation results based on Meteonorm data and PVsyst modeling confirm that the system can generate approximately 1,492.6 kWh annually, with a performance ratio of 77.83% and a solar fraction of 17.04%, aligning well with observed yields in comparable urban regions such as Bangalore and Hyderabad. The levelized cost of energy (LCOE) is estimated at ₹2.01/kWh, significantly lower than the local residential grid tariff of ₹5.90/kWh, leading to potential annual savings of up to ₹8,850.

The financial analysis reveals a payback period of 4–6 years and a return on investment ranging between 15–20%, especially when factoring in central subsidies under schemes like PM Surya Ghar: Muft Bijli Yojana. Environmentally, the system is projected to achieve a net carbon offset of 26.9 metric tons of CO_2 over a 25-year lifespan, even after accounting for lifecycle emissions of the system components. Although the system does not currently export energy to the grid, introducing net metering and grid buy-back mechanisms could further improve energy utilization and economic returns.

Overall, the study validates that small-scale rooftop PV systems are both technically viable and financially attractive in urban Indian contexts. Nonetheless, broader adoption will depend on improved public awareness, financing mechanisms to reduce upfront costs, integration of energy storage, and policy measures that enable energy exchange with the grid. The methodology and results from this case study offer a scalable template for similar cities aiming to transition toward decentralized and sustainable energy solutions.

Limitations of the System

1. Limited Scale of Study:

The analysis is based on a 1kW system, which may not represent the performance or cost dynamics of larger or commercial-scale systems.

2 .Site-Specific Assumptions:

The findings are tailored to Mysuru›s climatic, solar irradiance, and electricity tariff conditions, limiting generalizability to other regions.

3. Static Financial Parameters:

Assumptions like inflation, interest rates, and panel costs are taken as fixed for simplicity, which may not reflect future market variability.

4. Exclusion of Degradation and Maintenance Dynamics:

The system performance over time may degrade due to aging of PV panels, inverter failures, or soiling, which are not dynamically modeled.

5. No Battery Storage Considered:

The study does not account for energy storage systems, which could significantly alter technical and economic feasibility.

6. Grid Reliability and Policy Dependence:

Feasibility is highly influenced by current net metering policies and grid infrastructure, which may change in the future.

Future Scope of the System

1. Scaling to Higher Capacities:

Future work can extend the analysis to 5kW, 10kW, or higher capacity systems to evaluate economies of scale and commercial viability.

2. Integration of Battery Storage:

Adding energy storage systems like lithium-ion batteries could improve reliability and allow for greater self-consumption, especially in grid-unstable regions.

3. Dynamic Performance Modeling:

Incorporating seasonal variability, long-term degradation, and real-time meteorological data can yield more accurate performance predictions.

4. Techno-Economic Optimization:

Optimization techniques (e.g., HOMER, PVSyst simulations) can be used to determine the most cost-effective system configurations under varying conditions.

5. Policy and Incentive Impact Assessment:

Simulating different tariff structures, government subsidies, and policy scenarios could inform better decision-making for stakeholders.

6. Environmental Impact Analysis:

Future research can include a Life Cycle Assessment (LCA) to quantify the environmental benefits in terms of CO_2 reduction and resource use.

7. Smart Grid and IoT Integration:

Investigating the integration of rooftop solar systems with IoT-based monitoring and smart grids for better energy management.

NOMENCLATURE

PV	Photovoltaic
GHI	Global Horizontal Irradiance (kWh/m²/day)
PR	Performance Ratio (%)

SF	Solar Fraction (%)
STC	Standard Test Conditions
MPPT	Maximum Power Point Tracking
DC	Direct Current
AC	Alternating Current
kWp	Kilowatt peak (rated power of PV module/system)
kWh	Kilowatt-hour (unit of electrical energy)
LCOE	Levelized Cost of Energy (₹/kWh)
ROI	Return on Investment (%)
INR	Indian Rupee (₹)
CO_2	Carbon Dioxide
T_amb	Ambient Temperature (°C)
EArray	Energy generated by the PV array (kWh)
EUser	Total user energy demand (kWh)
ESolar	Energy supplied by solar system (kWh)
EGrid	Energy drawn from grid (kWh)
EFGrid	Fossil fuel energy offset from grid (kWh)
GlobHor	Global Horizontal Radiation (kWh/m²)
DiffHor	Diffuse Horizontal Radiation (kWh/m²)
GlobInc	Global Incident Radiation on PV plane (kWh/m²)
GlobEff	Effective Global Radiation after losses (kWh/m²)
LCE	Lifecycle Emissions ($kgCO_2$ or tCO_2)

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

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