



Performance Analysis of Photovoltaic System for Tourism Accommodation Load in Bali Using MATLAB/Simulink and PVGIS Dataset

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Abstract. Bali's tourism sector drives significant electricity demand across small-scale accommodation facilities, yet dependence on fossil-fuel generation remains high. This study presents a simulation-based performance analysis of a photovoltaic (PV) system for tourism accommodation load in Bali, Indonesia, using MATLAB/Simulink 2025a and PVGIS-ERA5 irradiance data. Solar irradiance and ambient temperature data were extracted for Denpasar (8.65°S, 115.22°E) from the PVGIS-ERA5 open-access dataset, with December 18, 2023 identified as the peak clear-sky day, reaching a maximum irradiance of 1059.9 W/m². The simulated system comprises a CS6K-250P-FG PV array by Canadian Solar Inc. configured in 3 parallel strings of 2 series modules (1500W rated), a DC-DC boost converter, and a Perturb and Observe (P&O) Maximum Power Point Tracking (MPPT) controller. Simulation at five irradiance operating points yielded output power ranging from 297.7W at 200 W/m² to 1499.0W at 1000 W/m², with MPPT tracking efficiency of 99.99–100.00% across all conditions. Daily energy yield on the selected clear day was estimated at 11.87 kWh. Load analysis revealed a temporal mismatch between peak PV generation at midday and peak villa energy demand in the evening, indicating that battery storage integration is essential for maximizing renewable energy utilization. These findings demonstrate the technical feasibility of PV adoption for small-scale tourism accommodation in tropical irradiance conditions.

Keywords: Bali, Energy Yield, MATLAB/Simulink, MPPT, Photovoltaic, PVGIS, P&O, Tourism Accommodation

1 Introduction

Bali is one of Indonesia's most energy-intensive provinces, driven by a tourism sector that accounts for a significant share of electricity demand across hospitality facilities. Despite abundant solar resources, the province remains heavily dependent on fossil-fuel generation, with renewable energy contributing a small fraction of the total energy mix (Giriantari et al., 2016; Veldhuis, 2013). The transition toward distributed solar photovoltaic (PV) generation represents a viable pathway for reducing this dependence, particularly for small-scale accommodation facilities that operate independently of the main grid.

Photovoltaic systems require accurate solar resource data to support reliable performance analysis and system sizing. Open-access satellite-derived databases have emerged as practical tools for this purpose, with the Photovoltaic Geographical Information System (PVGIS) developed by the European Commission Joint Research Centre providing hourly irradiance and temperature data at global coverage (Kenny et al., 2006). Studies have demonstrated that PVGIS-ERA5 data offer sufficient accuracy for PV performance estimation, with annual energy prediction errors typically within 5% of measured values (AlFaraj et al., 2024). The reliability of such satellite-derived datasets makes them particularly valuable in tropical regions where ground-based meteorological stations are sparse.

The Perturb and Observe (P&O) algorithm is one of the most widely implemented Maximum Power Point Tracking (MPPT) techniques in photovoltaic systems due to its simplicity and low computational requirements (Ibrahim et al., 2015; Ranjan & Kumar, 2016). MATLAB/Simulink provides a standard simulation environment for evaluating PV system performance (Malla, 2012), enabling analysis of MPPT behavior under varying irradiance and temperature conditions without requiring physical prototypes (Shakoor & Taha, 2022).

Existing studies on PV system performance in Bali have focused primarily on grid-connected utility-scale installations (Giriantari et al., 2016, Santoso et al., 2025), leaving a gap in simulation-based analysis of small-scale systems for tourism accommodation. This study addresses that gap by presenting a performance analysis of a 1500W PV array with P&O MPPT control, driven by PVGIS-ERA5 irradiance data for Denpasar, Bali. The objective is to quantify output power, MPPT tracking behavior, and daily energy yield under representative tropical irradiance conditions, providing an evidence base for PV adoption in Bali's tourism accommodation sector.

2 Methodology

2.1 System Configuration

The photovoltaic (PV) system modeled in this study consists of a CS6K-250P-FG photovoltaic array manufactured by Canadian Solar Inc., configured in 3 parallel strings of 2 series-connected modules, yielding a total rated power of 1500W at standard test conditions (STC: 1000 W/m², 25°C). Key electrical parameters of the array are summarized in Table 1.

Table 1. PV Array Electrical Parameters at STC

Parameter	Value
Module model	CS6K-250P-FG
Number of modules	6 (3P × 2S)
Rated power	1500W
Open-circuit voltage (Voc)	74.4V
Short-circuit current (Isc)	26.49A
Maximum power voltage (Vmp)	60.2V
Maximum power current (Imp)	24.9A

The PV array is connected to a DC-DC boost converter controlled by a Perturb and Observe (P&O) MPPT algorithm. The converter output feeds a resistive load of 10Ω , representing the daytime baseline consumption of a small tourism accommodation facility. The complete system was modeled and simulated in MATLAB/Simulink 2025a.

2.2 Irradiance Data

Accurate estimation of available solar radiation is essential for sizing photovoltaic systems (Rinchi, 2024). Solar irradiance and ambient temperature data were obtained from PVGIS-ERA5, an open-access hourly radiation dataset provided by the European Commission Joint Research Centre. Data were extracted for Denpasar, Bali (latitude: 8.65°S , longitude: 115.22°E , elevation: 34m), fixed-tilt installation at 10° slope and 0° azimuth, for the full year 2023. December 18, 2023 was identified as the peak clear-sky day, with a maximum global irradiance of 1059.9 W/m^2 , with a daily irradiation total of 7944 Wh/m^2 as shown in Figure 1.

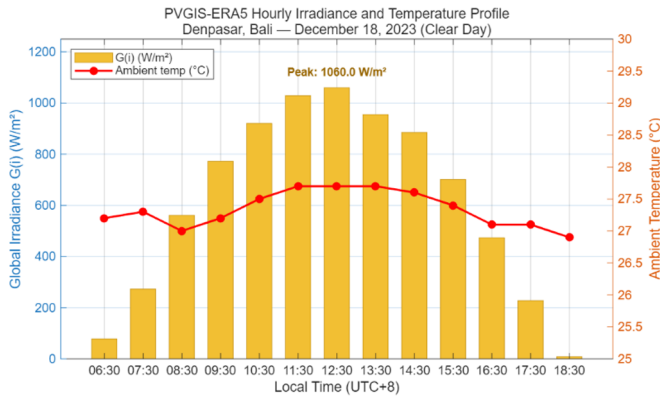


Figure 1. PVGIS_ERA5 Hourly Irradiance

The daylight window spans 06:30 to 18:30 local time (UTC+8), providing approximately 12 hours of solar generation potential. Monthly average daily irradiation values for Denpasar are presented in Table 2.

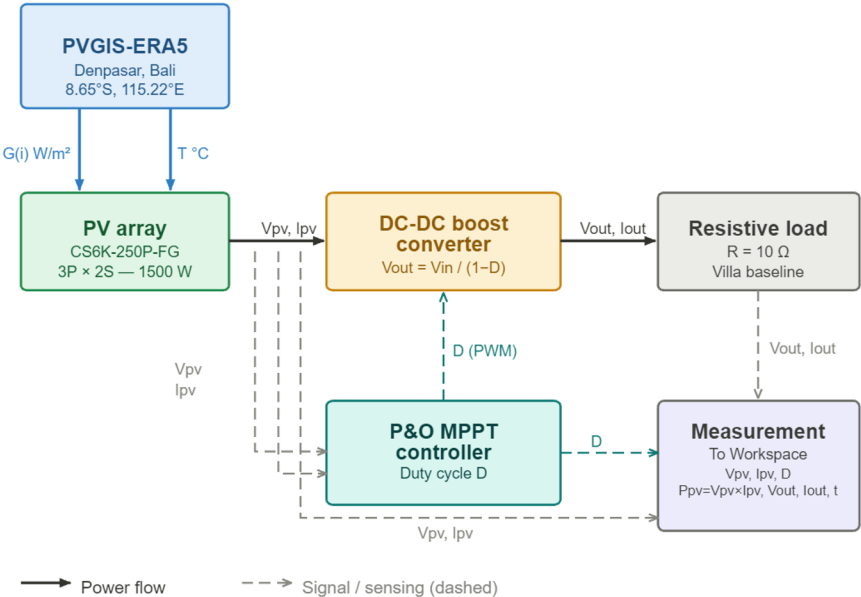
2.3 Simulation Approach

The complete simulation architecture of the photovoltaic system developed in MATLAB/Simulink is presented in Figure 2. The system comprises a CS6K-250P-FG PV array configured in 3 parallel strings of 2 series-connected modules, a DC-DC boost converter, and a P&O MPPT controller. Solar irradiance $G(i)$ and ambient temperature T derived from PVGIS-ERA5 are fed directly into the PV array block as time-varying inputs. The P&O MPPT controller receives PV-side voltage (V_{pv}) and current (I_{pv}) signals and generates a pulse-width modulated duty cycle signal D to regulate the boost converter switching, maintaining operation at the maximum power point. Output voltage (V_{out}) and current (I_{out}) at the resistive load, together with PV-side signals and duty cycle, are logged to the MATLAB workspace via To Workspace blocks for post-

simulation analysis. Grid inverter and utility interface components are outside the scope of this simulation, and the resistive load of $10\ \Omega$ represents the PV-side DC output prior to any inverter or storage interface.

Table 2. Monthly Average Daily Irradiation, Denpasar, Bali (PVGIS-ERA5, 2023)

Month	Avg. Daily Irradiation (Wh/m ² /day)
January	6164
February	4792
March	6196
April	4884
May	4803
June	4393
July	4282
August	5358
September	6272
October	7147
November	6897
December	6777



System scope: PV array — DC-DC boost converter — P&O MPPT controller — resistive load (no inverter / grid interface modeled)

Figure 2. Block Diagram of the Simulated Standalone Photovoltaic System in MATLAB/Simulink Showing Power Flow (Solid Lines) and Signal/Sensing Connections (Dashed Lines)

System performance was evaluated at five discrete irradiance operating points (200, 400, 600, 800, and 1000 W/m²) at the ambient temperature corresponding to each level from the PVGIS clear-day profile. For each operating point, the PV Array block parameters were configured accordingly and the model was simulated for 2 seconds of simulation time, sufficient to reach steady-state output. Output voltage and current were recorded at steady state, and output power was computed as their product. Daily energy yield was estimated by interpolating the power-irradiance relationship across the 13-hour PVGIS hourly irradiance profile using the trapezoidal integration method.

The P&O algorithm operates by comparing successive power measurements to determine the perturbation direction of the duty cycle that can be denoted as follows:

$$\Delta P = P(k) - P(k-1) \begin{cases} \text{If } \Delta P > 0 \ \& \ \Delta V > 0 \rightarrow D(k) = D(k-1) + \Delta D \\ \text{If } \Delta P > 0 \ \& \ \Delta V < 0 \rightarrow D(k) = D(k-1) - \Delta D \\ \text{If } \Delta P < 0 \ \& \ \Delta V > 0 \rightarrow D(k) = D(k-1) - \Delta D \\ \text{If } \Delta P < 0 \ \& \ \Delta V < 0 \rightarrow D(k) = D(k-1) + \Delta D \end{cases} \quad (1)$$

where D is the duty cycle and ΔD is the perturbation step size (Shakoor & Taha, 2022). The DC-DC boost converter output voltage is governed by:

$$V_{\text{out}} = V_{\text{in}} / (1 - D) \quad (2)$$

where V_{in} is the PV array output voltage and D is the duty cycle controlled by the MPPT algorithm (Ibrahim et al., 2015).

3 Result and Discussion

3.1 PV Array Output Power vs. Irradiance

The simulation was conducted at five irradiance levels derived from the PVGIS-ERA5 clear-day profile for Denpasar, Bali, on December 18, 2023. Table 3 presents the steady-state output voltage, current, and power at each operating point, with ambient temperature set to the corresponding PVGIS hourly value.

Table 3. Simulation Results at Five Irradiance Operating Points

Irradiance (W/m ²)	Temp (°C)	Vout (V)	Iout (A)	Pout (W)	Prated (W)
200	27.2	59.629	4.993	297.7	300
400	27.3	60.479	9.997	604.7	600
600	27.0	60.744	14.959	908.6	900
800	27.2	60.561	19.924	1206.6	1200
1000	27.7	60.200	24.900	1499.0	1500

The results show a consistent increase in output power with rising irradiance, as illustrated in Figure 3, confirming expected PV array behavior under uniform irradiance conditions. Output voltage remained stable across all operating points, varying within a narrow band of 59.6–60.7V, which demonstrates effective MPPT control by the P&O algorithm. This voltage stability under varying irradiance is consistent with findings reported by Ibrahim et al. (2015) and Shakoor and Taha (2022), where P&O MPPT maintained output voltage close to the maximum power point voltage across a wide irradiance range.

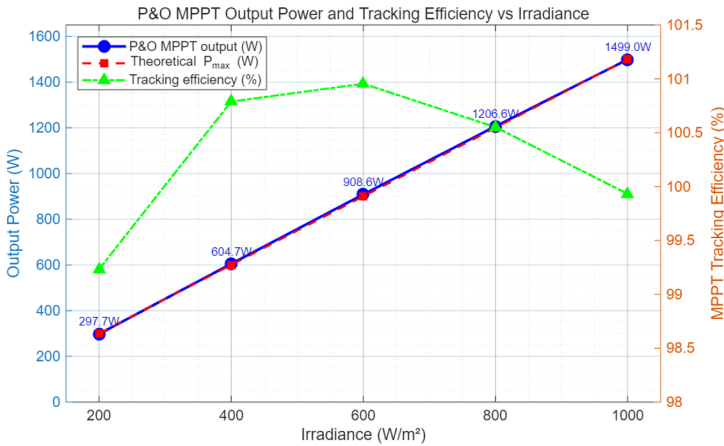


Figure 3. P&O MPPT Output Power and Tracking Efficiency vs Irradiance

The MPPT tracking efficiency was calculated as the ratio of simulated output power to the actual maximum power available from the P-V characteristic curve at each irradiance and temperature condition (Ibrahim et al., 2015). At 1000 W/m², the simulated output power of 1499.0W against an actual P_{max} of 1498.98W yields a tracking efficiency of 100.00%. Across all five operating points, MPPT tracking efficiency ranged from 99.99% to 100.00%, as illustrated in Figure 2. These near-ideal values reflect ideal component modeling in MATLAB/Simulink without parasitic losses, representing an upper-bound estimate of achievable MPPT performance in a physical system (Shakoor & Taha, 2022).

3.2 I-V and P-V Characteristics

Figure 4 presents the I-V and P-V characteristic curves of the CS6K-250P-FG array at five irradiance levels obtained from the PV Array block display tool in MATLAB/Simulink.

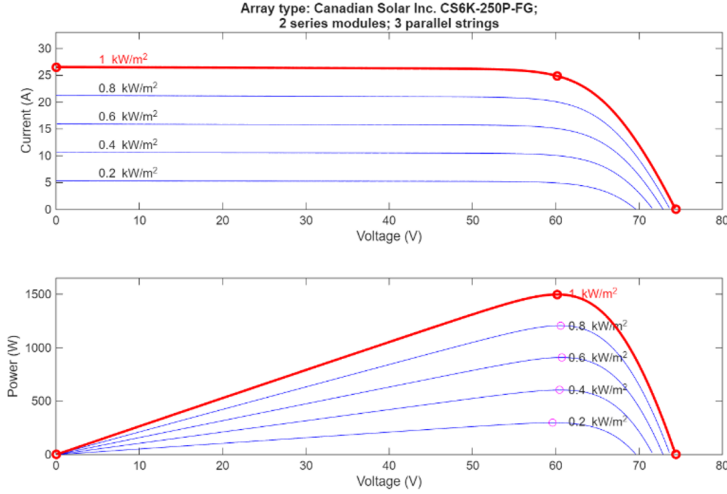


Figure 4. I-V and P-V Curves at Five Irradiance Levels

The curves demonstrate the non-linear relationship between voltage and current, with maximum power points shifting with irradiance as expected for crystalline silicon modules. At 27.7°C ambient temperature where the peak irradiance condition recorded in the PVGIS data, the array maximum power point voltage was 60.2V, consistent with the array V_{mp} of 60.2V calculated from the series configuration of two modules.

3.3 Daily Energy Yield Estimation

Daily energy yield was estimated by interpolating the simulated power-irradiance relationship across the 13-hour PVGIS hourly profile using the trapezoidal integration method. The estimated daily energy yield on the selected clear day was 11.87 kWh. This corresponds to a daily peak sun hour equivalent of approximately 7.9 hours, consistent with the high solar irradiation of Denpasar recorded at 7944 Wh/m² for December 18, 2023. This Trapezoidal energy yield can be denoted as follows:

$$E = (1/3600) \times \int P(t)dt \approx (1/3600) \times \Sigma[(P_k + P_{t_{k+1}})/2 \times (t_{t_{k+1}} - t_k)] \quad (3)$$

where P_k is the output power at hour k derived from simulation and t_k is the corresponding time in seconds.

It should be noted that the daily energy yield of 11.87 kWh represents an ideal DC-side estimate based on steady-state simulation without accounting for real-system losses including wiring resistance, dust soiling, temperature derating, and inverter conversion losses. Based on typical system performance ratios of 0.75–0.80 for tropical PV installations (AlFaraj et al., 2024), the practical AC-side energy yield would be approximately 8.9–9.5 kWh per clear day. This limitation should be considered when applying these results to actual system design. Monthly average daily irradiation data from PVGIS-ERA5 (Table 2) indicate that October through December represents the highest irradiation period in Bali, with monthly averages exceeding 6700 Wh/m²/day,

while June and July represent the lowest irradiation months at approximately 4282–4393 Wh/m²/day. Annual variation in daily energy yield is therefore expected to range from approximately 8.6 kWh on low-irradiation days to 11.9 kWh on clear peak days.

3.4 Load Analysis for Tourism Accommodation

A representative small-scale Bali villa accommodation operates a load profile that varies significantly across the day. The major electrical loads include a water pump rated at 0.5 HP with electrical input power of approximately 450–530 W (operating during morning guest shower periods of 06:30–08:30 and evening onset at 17:30–18:30), a refrigerator (150 W continuous), pool circulation pump (150 W daytime), and standby electronics (100 W continuous). This yields a morning and evening peak load of approximately 850 W when the pump is running, and a midday baseline of approximately 400 W when the pump is off. This load profile is consistent with energy consumption patterns reported for small tourism accommodation facilities in tropical developing countries (Giriantari et al., 2016). Figure 5 illustrates the temporal relationship between estimated hourly PV generation and villa load demand across the 12-hour daylight window. At peak irradiance, the 1500W system output exceeds this daytime baseline by a factor of approximately 1.9–2.7, indicating significant surplus generation potential during midday hours.

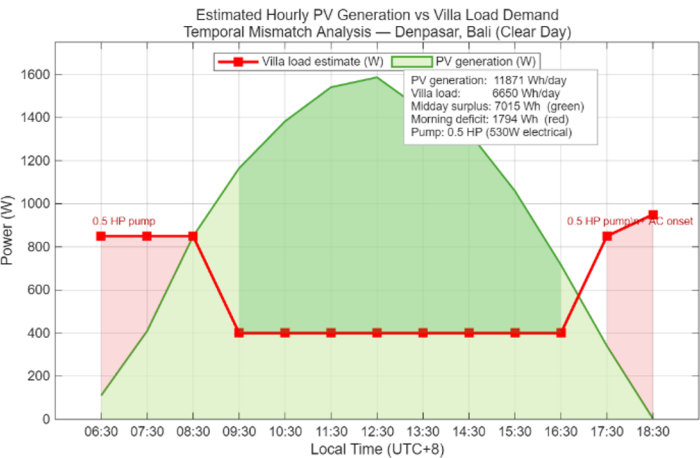


Figure 5. Estimated Hourly PV Generation Vs Villa Demand

Evening and nighttime loads, including air conditioning and lighting, which represent the dominant consumption period for tourism accommodation, are not covered by PV generation. This temporal mismatch between generation and peak demand highlights the need for battery storage integration to maximize self-consumption. An energy balance calculation based on the revised load profile yields a midday surplus (10:30–16:30 when pump is off and irradiance is high) of approximately 4.2 kWh, against evening load demand (18:00–23:00 for air conditioning and lighting) of approximately 8.5 kWh. A battery bank of 6–8 kWh capacity, accounting for a practical system performance ratio of 0.78 and round-trip

battery efficiency of 0.90, would offset approximately 45–55% of evening load demand. Full evening load coverage would require either a larger PV array or supplementary grid connection. This battery sizing recommendation should be validated with measured villa consumption data in future work, as the current estimate is based on a calculated energy balance using typical equipment ratings rather than empirical load measurements.

This study focuses on the PV array and MPPT controller performance analysis. Grid inverter and utility interface modeling are outside the scope of this work, and the resistive load used in simulation represents the PV-side output prior to any inverter or storage interface.

4 Conclusion

This study presented a simulation-based performance analysis of a 1500W photovoltaic system for tourism accommodation load in Bali, Indonesia, using MATLAB/Simulink and PVGIS-ERA5 irradiance data. The CS6K-250P-FG PV array configured in 3 parallel strings of 2 series modules, controlled by a Perturb and Observe MPPT algorithm with DC-DC boost converter, was evaluated at five irradiance operating points derived from the December 18, 2023 clear-day profile for Denpasar.

Results demonstrated output power ranging from 297.7W at 200 W/m² to 1499.0W at 1000 W/m², with MPPT tracking efficiency of 99.99–100.00% across all operating points. Daily energy yield on the selected clear day was estimated at 11.87 kWh (ideal DC-side), equivalent to approximately 8.9–9.5 kWh practical AC-side yield accounting for system losses. Load analysis incorporating a 0.5 HP water pump (530 W electrical input) revealed a temporal mismatch between peak PV generation at midday (surplus of approximately 4.2 kWh when pump is off) and peak villa energy demand in the morning and evening pump operation periods and nighttime air conditioning load. A battery bank of 6–8 kWh capacity is estimated to offset 45–55% of evening load demand, with full coverage requiring a larger array or grid supplementation.

These findings provide an evidence base for PV system adoption in Bali's tourism sector and demonstrate the viability of PVGIS-ERA5 satellite data for tropical PV performance simulation in regions with limited ground-based meteorological infrastructure.

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References

AlFaraj, J., Popovici, E., & Leahy, P. (2024). Solar irradiance database comparison for PV system design: A case study. *Sustainability*, 16(15), 6436. <https://doi.org/10.3390/su16156436>

- Giriantari, I. A. D., Ariastina, W. G., Kumara, I. N. S., & Sukerayasa, I. W. (2016). Selection of potential PV locations: A case study in Bali. *Journal of Engineering and Applied Sciences*, 11(9), 1886–1890.
- Ibrahim, O., Yahaya, N. Z., Saad, N., & Umar, M. W. (2015). MATLAB/Simulink model of solar PV array with perturb and observe MPPT for maximising PV array efficiency. *2015 IEEE Conference on Energy Conversion (CENCON)*, 254–258. <https://doi.org/10.1109/CENCON.2015.7409549>
- Kenny, R. P., Huld, T. A., & Iglesias, S. (2006). Energy rating of PV modules based on PVGIS irradiance and temperature database. *21st European Photovoltaic Solar Energy Conference*, 2088–2092.
- Malla, S. (2012). *Perturb and observe (P&O) algorithm for PV MPPT* [MATLAB Central File Exchange]. MathWorks. <https://www.mathworks.com/matlabcentral/fileexchange/39641>
- Ranjan, K., & Kumar, N. (2016). Modelling and simulation of perturb and observe algorithm on solar PV system using different converters in MATLAB/SIMULINK. *2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, 1–6. <https://doi.org/10.1109/ICPEICES.2016.7853373>
- Rinchi, B. (2024). A universal tool for estimating monthly solar radiation. *Energy Conversion and Management*, 300, 117900. <https://doi.org/10.1016/j.enconman.2024.117900>
- Santoso, M. V., Banjar-Nahor, K. M., & Hariyanto, N. (2025). Optimization of Nusa Penida electrical system: A simulation approach for cost and emission reduction. *ITB Graduate School Conference*, 4(1), 15–22.
- Shakoor, A. M., & Taha, H. H. (2022). Modelling and simulation of perturb and observe MPPT algorithm based on the PI controller for photovoltaic system. *Kurdistan Journal of Applied Research*, 7(2), 71–83. <https://doi.org/10.24017/Science.2022.2.6>
- Veldhuis, A. J. (2013). Reviewing the potential and cost-effectiveness of grid-connected PV in Indonesia. *Renewable and Sustainable Energy Reviews*, 27, 415–424. <https://doi.org/10.1016/j.rser.2013.03.060>

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