Research Note

Analysing exergy efficiency on a grid connected PV power plant via different solar exergy models in Samsun - Turkey

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KEYWORDS
Power conversion efficiency; PV exergy efficiency; solar exergy models; PV power plant.

Abstract. In this study, power conversion efficiency and the analysis of exergy of a grid-connected photovoltaic (PV) power plant was done by comparing solar exergy models for 12 months. Statistical analysis was used to evaluate the PV exergy efficiency related to solar exergy models. First, solar exergy models proposed by Petela, Spanner and Parrott and the mean of solar exergy-to-solar radiation energy ratio were calculated, and the PV exergy efficiency was analyzed. The results indicate that the average solar exergy-to-solar radiation energy ratio for the Samsun region was 0.93 which are related to Petela and Spanner's model. The ratio for Parrott's model was calculated as 0.99. The results confirm that the power conversion efficiency is in the range of 6.15 - 8.87%. While PV exergy efficiency related to Parrott's model is seen to vary between 4.85% and 7.09% during 12 months, but in Petela's and Spanner's model it changes from 5.19% to 7.60%.

1. Introduction
Solar panel technology is one of the fast-developing devices for collecting solar irradiation, which is unlimited and free for all people in the world [1, 2].

The thermodynamic analysis of a closed system was differently based on quantization theory, exergy or available energy; in other words, exergy is the one that can be described theoretically in terms of usable maximum work of a thermodynamic system [3]. Dincer has discussed the relationship between energy transformation, exergy and sustainable development from a scientific point of view [4]. The exergy efficiency of a system is used to analyze the performance with respect to the corresponding performance in reversible conditions or the system's effectiveness in practical working circumstances [5]. An evaluation method was recommended to ensure that the policies of sustainable development, economic and environmental impacts of renewable energy systems form the optimization and performance analysis of the design of solar PV systems [5–11]. Thus, the exergy efficiency is achieved by precise engineering and scientific installation designs by taking into account the different environmental parameters of regions [12].

It is known that the performance of PV panel is negatively affected by many environmental parameters such as partial or full shading, dust, paint, reflection, etc. [2]. In the other words these parameters will significantly adversely affect the PV exergy and exergy efficiency.

Generally, the exergy efficiency analysis of PV systems is discussed in two basic steps; the solar exergy of the area where the PV plant is designed and then the exergy efficiency of the PV system related to it.

The optimization of the design of solar devices such as solar energy collectors and PV systems, and the evaluation of their performance requires accurate and realistic data about the solar energy potential in that region. In practice, solar radiation exergy includes qualitative and quantitative data of regional solar radiation that will give the maximum possible work output that can be produced while considering the properties of the regional solar radiation [13–15]. As it is known, the upper limit of the solar energy conversion, which can be used by considering the environmental parameters of the solar radiation falling on the area where the PV system will be installed, or the upper limit of the conversion is defined as the exergy of solar radiation.
There are several studies on solar radiation exergy, that is very important in efficiency evaluation of solar-powered power systems, theoretically in chronological order; Petela [16], Spanner [17], Parrott [18], Jeter[19], Bejan [20], Alta et al. [21], Hepbasli and Alsuhaibani [22], Jamil and Bellos [23], korasanizadeh and Sepehrinia [24], etc.

Petela [16] formulated the available energy called exergy with the determinant parameters, the surface temperature of the area where the sunbeams hit on the earth and the temperature of the sun's surface. In the same year as Petela, Spanner [17] suggested that the exergy of solar radiation would be equal to the work potential of the system. Parrott [18] developed the suggested solar exergy model of Petela by adding the geometry of the sun-earth axis motion of the incoming radiation of the sun, that is, the half-angle of the cone formed. Jeter [19], on the other hand, applied Spanner's work with a different point of view, namely the Carnot heat engine model to solar radiation exergy. Bejan [20] examined Petela, Spanner and Jeter's theories and concluded that they were individually correct. All the three theories are the result of a high-temperature isotropic radiation source that has a heat input from a high-temperature heat reservoir. Alta et al. [21] mapped the monthly average solar radiation exergy using the solar radiation data of 152 meteorological stations in different geographical locations in Turkey. In this study, mean exergy value of solar radiation was at 13.5 ± 1.74MJm⁻²day⁻¹, with a mean annual exergy-to-energy ratio of 0.93. Hepbasli and Alsuhaibani [22] studied the solar exergy models of Petela, Spanner and Jeter used in solar energy-related applications, and determined the solar exergetic values for some regions of Saudi Arabia and Turkey. The values found are close to each other. Jamil and Bellos [23] developed empirical models of the solar radiation exergy potential in different cities of India. In this study, the exergy data of direct and diffuse solar radiation were calculated and they were correlated to obtain the exergy of global exergy efficiency factor. Beam and diffuse exergy efficiencies were in the range of 0.9286- 0.9365 and 0.7189-0.7499 respectively. korasanizadeh and Sepehrinia [24] studied solar exergy potential with five experimental models linear, quadratic, cubic, exponential, and power functional forms that depend only on relative sunlight duration, using solar and metrological data of eight cities in Iran. The results show that the ratio of exergy to energy can be considered 0.87 for the whole Iran.

As seen from the studies of the reviewed literature, they concluded that the results of all theories such as Petela [16], Spanner [17], and Jeter [19] are close to each other and they can be considered to be correct. Besides this, most of the engineering calculations of the exergy efficiency of thermodynamic systems have been based on the solar exergy models of Petela and Spanner.

The energy and exergy analysis (thermodynamic analysis) of PV and PVT systems have been performed by many researchers, such as Sahin et al.[25], Akyüz et al.[26], Bayrak et al. [27-29], Sopian et al. [30], Kumar et al. [31], Kallio and Siroux [32], Kim et al. [33], Miskat and Rashedi [34], Hasan et al. [35], Manjunatha et al [36], etc.

Sahin et al. [25] examined the thermodynamic properties of solar PV cells depending on exergy. In their study, the output exergy was calculated depending on the physical and chemical components of the solar cell. The exergy efficiencies was ranged from 2% to 8%. Akyüz et al. [26] proposed a new computer calculation approach to determine the maximum amount of exergy that can be taken from the sun. In their study, they used the experimental data obtained from a PV system installed in Turkey and they applied it to a conventional photovoltaic system in order to formulate the exergy efficiency of the system. Bayrak et al. [27] designed an experimental setup to investigate the electrical performance and thermodynamic analysis of a 75 W photovoltaic panel under different shading ratios. The energy and exergy efficiencies for non-shading panel was found 8.19% and 8.05%, respectively. In another study of Bayrak et al. [28], energy and exergy analysis was carried out by applying different wing parameters (length, arrays) to PV panels in the climatic conditions of Elazig, Turkey. They concluded that temperature was not distributed homogeneously and the values of panel was calculated as 11.55%, and 10.91%, respectively. In addition, Bayrak et al. [29] investigated the effects of static and dynamic shading on the thermodynamic and electrical performance of PV panels. The results showed that the lowest and the highest efficiency values of the panel with dynamic shading was 0.86% and 10.27%, respectively. Sopian et al. [30] carried out experimental and computational studies to improve the electrical and exergy efficiency of PVT systems under outdoor conditions in Bangi, Malaysia, using two cooling techniques. As a result of their study, they reported that cooling with nano liquids and Nano-PCM-based nano liquid cooling are more efficient than conventional water-based cooling. Results showed for nanofluid and nanofluid with nano-PCM, achieved highest electrical exergies of 73 and 74.52 respectively. Kumar et al. [31] compared water-based photovoltaic (WPV) to traditional land-based photovoltaic (LPV) installations. They found that the exergy efficiency of SPV is 3.07% higher than the FPV and 43.65% higher than LPV installation methods, respectively. Kallio and Siroux [32], studied the energy and exergy of a PVT collector, and compared to a photovoltaic (PV) panel under two different European climate conditions. The total exergy in Strasbourg was 1.27% higher than that in Tampere. Kim et al. [33] conducted an energy and exergy analyses of the inlet flow, radiation intensity and PV module back the temperature of the air-type PVT collector with outdoor experiments. They found that the total exergy efficiency of the air-type PVT collector with perforated baffles was about 20% difference. Miskat and Rashedi [34] determined the solar exergetic map and the environmental cost of solar PV system in Nepalese cities; city of Janakpur carries the highest amount of solar PV exergy efficiency of 36.27% during a year. Hasan et al. [35] investigated effects of different environmental and operational factors on the PV performance. In their study, it found that dust allocation and soiling effect are crucial, along with the humidity and temperature that largely affect the performance of PV module. Manjunatha et al. [36] analyzed energy and exergy performance of 50w solar photovoltaic panel. An experimental study performed for investigation the electrical, thermal and exergy output of solar PV panel.

In this study, the basic three solar exergy models of Petela, Spanner and Parrot were analyzed theoretically and experimentally by taking measurements of a grid-connected PV power plant in real weather conditions on a clear and sunny day for 12 months of the year in the city of Samsun/Turkey. Finally, exergy efficiencies were realized by considering environmental conditions such as wind speed and solar cell temperature.

2. Materials and Methods
2.1. PV array power plant
The grid-connected PV plant has a maximum capacity of 114 kW and was built on an area of 10000 m². The PV power plant consists of 440 poly-crystalline panels each with maximum output of 260 W and the electric current generated from the sun is controlled by 4 inverters of 30 kW. One array with 124 panels were used for the analysis. This PV plant was installed with the
support of the European Union project. Image of the solar power plant is illustrated in Figure.1, mounted at 41° 17’ 15.00” N and 36° 20’ 0.60” E.

2.2. Methods

The analysis of the PV array was investigated in Ondokuz Mayis Universitesi Teknopark’ and performed under weather conditions in Samsun city, Turkey. The data for this study were collected on different clear and cloudless days between June 2019 and May 2020. The data of this study were obtained in the province of Samsun over a period of 12 months.

The solar exergy and their parameter analysis of this study are; solar irradiation, ambient wind speed (v), outdoor air temperature (T_a), and generated open-circuit voltage (V_{oc}), short circuit current (I_{sc}) of the system, output voltage (V) and output current (I). The energy, solar exergy and exergy analysis of the PV plant were done by applying the following steps:

- Instantaneous output electrical power generation (P) data were obtained from the inverter.
- The total solar radiation incident on the surface of the photovoltaic (I_{s}) was measured with a Kipp & Zonen Pyranometer.
- Wind speed (v) was measured with Wellhise HT-380 digital anemometers.
- Ambient temperature (T_a) and cell temperature (T_{cell}) data were measured by using the T-type thermocouples.
- By using the obtained data for each month, the solar exergy and PV system exergy efficiency by using Petela, Spanner and Parrott’s model were analysed.
- The obtained results related to Petela, Spanner and Parrott’s model were compared for solar exergy and PV exergy efficiency analysis.

3. Theoretical Analysis

The efficiency analysis of a PV power plant can be made based on the first and the second laws of thermodynamics which include energy, entropy and exergy balance.

3.1 Energy analysis

The first law of thermodynamics discusses the energy analysis of the PV system. Solar irradiation (I_{s}) is the sun’s radiant energy incident on a surface of unit area, expressed in units of W/m^2. Incident solar power is given as:

\[ P_{sun} = I_{s} \times A \]  

By reaching solar radiation on the surfaces of panels, PV device converts it into usable electricity. Maximum electrical output power of the PV panel is given by:

\[ P = V_{m} I_{m} \]  

PV power conversion efficiency is the percentage of incident solar energy that is converted into electricity;

\[ \eta_{pce} = \frac{V_{m} I_{m}}{I_{s} A} \]  

where \((I_{m}), (V_{m})\) and \((A)\) represent the maximum current, the maximum voltage and the photovoltaic panel area, respectively. In this study, the PV array surface is 201 m^2.

3.2 Exergy analysis

The exergy efficiency \(\Psi_{pv}\) of any system can be expressed as the ratio of output exergy \(\dot{E}_{x_{out}}\) to input exergy \(\dot{E}_{x_{in}}\); then for calculating exergy efficiency, input exergy and output exergy should be examined:

\[ \Psi_{pv} = \frac{\dot{E}_{x_{out}}}{\dot{E}_{x_{in}}} \]  

Calculation of solar radiation exergy was mainly made and proposed by Petela, Parrott and Spanner. According to Petela’s theorem, the net input exergy of a PV panel including solar radiation intensity is given by [16]:

\[ \dot{E}_{x_{in}} = A I_{s} \left[ 1 - \frac{4}{3} \left( \frac{T_{a}}{T_{s}} \right) \right] + \frac{1}{3} \left( \frac{T_{a}}{T_{s}} \right)^{3} \]  

where \(T_{s}\) is surface temperature of sun, which is about 5800 K.

In Spanner’s model, the input exergy of a PV is calculated as work potential [17]:

\[ \dot{E}_{x_{in}} = A I_{s} \left[ 1 - \frac{4}{3} \left( \frac{T_{a}}{T_{s}} \right) \right] \]
Being different from previous studies, we also calculated the input exergy of a solar photovoltaic array by considering the geometry of the incoming radiation (Parrott’s model) [17]:

\[
\dot{E}_{\text{in}} = AI_s \left[ 1 - \frac{4}{3} \left( \frac{T_a}{T_s} \right) (1 - \cos \sigma)^\frac{1}{2} + \frac{1}{3} \left( \frac{T_a}{T_s} \right)^3 \right] \quad (7)
\]

where \( \sigma \) is the half-angle of the cone subtended by the sun’s disc. The calculated \( \sigma \) values have been observed to change from 0.0046 (July) to 0.0047 (January). These limit values correspond to the minimum (July) and maximum (January) distances of the earth to the sun. In this study using Parrott’s model (Eq. 7), the approximate value of \( \sigma \) is given 0.005 [18].

The ratio of solar radiation exergy to solar radiation energy (exergy to energy ratio) can be calculated related to the Petela (Eq. 8) [16], Spanner (Eq. 9) [17] and Parrott’s model (Eq. 10) [18] as follow:

\[
\Phi_{\text{pet}} = 1 - \frac{4}{3} \left( \frac{T_a}{T_s} \right) + \frac{1}{3} \left( \frac{T_a}{T_s} \right)^3 \quad (8)
\]

\[
\Phi_{\text{span}} = 1 - \frac{4}{3} \left( \frac{T_a}{T_s} \right) \quad (9)
\]

\[
\Phi_{\text{par}} = 1 - \frac{4}{3} \left( \frac{T_a}{T_s} \right) (1 - \cos \sigma)^\frac{1}{2} + \frac{1}{3} \left( \frac{T_a}{T_s} \right)^3 \quad (10)
\]

Where \( \Phi_{\text{pet}}, \Phi_{\text{span}} \) and \( \Phi_{\text{par}} \) indicate the ratio of solar radiation exergy to solar radiation energy related to the Petela, Spanner and Parrott respectively.

The output exergy (\( \dot{E}_{\text{out}} \)) for a PV system is equal to the electrical exergy (\( \dot{E}_{\text{electrical}} \)) (electrical energy produced by the system) minus thermal exergy (\( \dot{E}_{\text{ther}} \)) as heat loss:

\[
\dot{E}_{\text{out}} = \dot{E}_{\text{electrical}} + \dot{E}_{\text{ther}} \quad (11)
\]

The electrical exergy of a PV array is given by:

\[
\dot{E}_{\text{electrical}} = I_m V_m \quad (12)
\]

The heat loss from the PV surface to the environment can be express as thermal exergy:

\[
\dot{E}_{\text{ther}} = Q \left[ 1 - \left( \frac{T_a}{T_{\text{cell}}} \right) \right] \quad (13)
\]

where

\[
Q = h_{ca} A (T_{\text{cell}} - T_a) \quad (14)
\]

and

\[
h_{ca} = 5.7 - 3.8v \quad (15)
\]

where \( T_{\text{cell}} \) is the temperature of the cell, \( h_{ca} \) is the heat transfer coefficient and \( v \) is the wind velocity.

By using Eqs. 12 and 13 the output exergy can be written as:

\[
\dot{E}_{\text{out}} = I_m V_m - \left[ 1 - \left( \frac{T_a}{T_{\text{cell}}} \right) \right] h_{ca} A (T_{\text{cell}} - T_a) \quad (16)
\]

By taking into account the solar exergy models (Petela, Parrot, Spanner) which have a different amount of input exergy in Eq. 5, the exergy efficiency of a PV system will be calculated separately for each model and compared.

By putting Eq. 5 (Petela’s input exergy model) and Eq. 16 in Eq. 4, the exergy ratio of the PV system related to Petela’s model will be analysed as:

\[
\Psi_{\text{PV}} = \frac{I_m V_m - \left[ 1 - \left( \frac{T_a}{T_{\text{cell}}} \right) \right] h_{ca} A (T_{\text{cell}} - T_a)}{AI_s \left[ 1 - \frac{4}{3} \left( \frac{T_a}{T_s} \right) + \frac{1}{3} \left( \frac{T_a}{T_s} \right)^3 \right]} \quad (17)
\]

In the same way, exergy efficiency of the PV system by using the Spanner’s model (Eq. 18) and Parrott’s models (Eq. 19) are given as below:
Spanner and Parrott were compared theoretically and experimentally in terms of the radiation from the sun does not directly increase the exergy output of the system. The power conversion and exergy efficiency values of the analysed PV power system are installed greatly affect the output power generation, but the input exergy directly depends on the ambient temperature and PV cell temperature related to the output exergy and thermal exergy for different months are shown in Figure 3.

The average solar radiation exergy is obtained as 14.62 MJ/m² day for summer, 6.41 MJ/m² day for autumn and 7.67 MJ/m² day for winter seasons. The annual mean exergy value of solar radiation in the Samsun region is calculated as 10.97 MJ/m² day related to Petela and Spanner’s model. The ratio of solar radiation exergy to solar radiation energy related to Petela and Spanner’s approach for the Samsun region are found to be 0.93. These results are in line with the results reported by Alta et al. [21]. The ratio of solar radiation exergy to solar radiation energy related to Parrott’s model reached up to 0.99. The mean solar radiation exergy in Parrott’s model is approximately 6% higher than Spanner and Petela’s model for each month.

The variation of solar exergy and electrical exergy values of the PV array for the different months are given in Figure 3. The electrical exergy is significantly less than the energy that could be extracted. These losses are due to the system’s irreversibility. The ambient temperature and PV cell temperature related to the output exergy and thermal exergy for different months are shown in Figure 4.

As illustrated in Figure 4, the value of PV exergy changes from 2122.40 W in February 2020 to 4889.61 W in June 2019. That is, the increase in ambient temperature increases cell temperature and thermal exergy of PV array, PV exergy is dependent on thermal exergy.

Wind speed is another effective parameter for analyzing the convective coefficient heat loss that is used to calculate the thermal exergy of a PV module. The average wind speeds for the installation place vary between 2.22 m/s to 3.77 m/s during a year.

The variation of power conversion and exergy efficiencies for different months are illustrated in Figure 5. The value of power conversion efficiency (η_{pce}) changes from 8.87% in June 2019 to 6.15% in February 2020 and exergy ranged from 4.87% to 7.60% for all models. From the evaluation of result as shown in Figure 5, it is clear that Exergy efficiency (ψ) related to the solar exergy models is lower than the power efficiency (η_{pce}). It is seen that environmental factors of the region where the PV power system is installed greatly affect the output power generation, but the intensity of the radiation from the sun does not directly increase the exergy output of the system. The power conversion and exergy efficiency values of the analysed PV power system are close to those published by Bayrak et al. [27-29].

Figure 6, shows the exergy efficiency comparison between Parrott, Spanner and Petela’s model of a grid connected PV for the different months.

As illustrated in Figure 6, the exergy efficiency related to Spanner and Petela’s model is higher than Parrott’s model for each month. The exergy efficiency is about 7.60% in June 2019 to 5.19% in February 2020 related to Spanner and Petela’s model, in Parrott’s solar exergy model it changes from 7.09% to 4.85% for the same months. The exergy efficiency related to the solar
exergy models, where the increase (~6%) in input exergy for Parrott’s model causes a decrease (6%) in exergy efficiency. The exergy efficiency using Parrot’s model is approximately 6% less than Spanner and Petela’s model for each month.

5. CONCLUSIONS

In conclusion, using the first and second laws of thermodynamics power conversion efficiency, solar exergy and exergy efficiency of a grid-connected photovoltaic power plant were analysed for 12 months, and the exergy efficiency related to the solar exergy models of Parrott, Spanner and Petela were calculated and compared. Initially, energy/exergy calculations were done by taking measurements using a single solar panel on a clear and sunny day. For the whole study, 12 months of a year, data were collected in real weather conditions of a grid-connected PV power plant and the solar exergy calculations were done by considering the three solar exergy models. Finally, the exergy efficiencies have been realized, taking into account the wind speed and solar cell temperature. This study was performed for a realistic view to the industrial and scientific community.

The results are summarized below:

- The average solar exergy-to-solar radiation energy ratio for the Samsun region are found to be 0.93 and this is related to Petela and Spanner’s model. This ratio for Parrott’s model is reached up to 0.99.
- The average exergy value of solar radiation in the Samsun region is obtained as 10.97 MJ/m²·day related to Petela and Spanner’s model. This value for Parrott’s model which is calculated at 11.62 MJ/m²·day for the Samsun region.
- The increase in the ambient temperature will increase the PV cell temperature, in other words, PV exergy efficiency is adversely affected PV cell temperature.
- Environmental factors have a notable impact on the exergy efficiency of the PV power system.
- The PV exergy efficiency using Parrott’s solar exergy model varied between 4.85% and 7.09% during 12 months of the year. In Petel’s and Spanner’s solar exergy model changes from 5.19% to 7.60%.
- Exergy efficiency of the system related to Parrot’s model is approximately 6% less than Spanner and Petela’s model.
- PV exergy efficiency data is more detailed when considering the geometry of the incident solar radiation for Parrott’s solar exergy model.

References


Figures captions

Figure 1. Satellite image of the solar power plant.
Figure 2. Effect of the solar radiation on the input exergy models for different months.
Figure 3. The electrical exergy and input exergy models for 12 months.
Figure 4. The effects of ambient and solar cell temperature on output exergy and thermal exergy.
Figure 5. The variation of power conversion and exergy efficiencies related to Spanner, Petela and Parrott's model for 12 months.
Figure 6. Exergy efficiency comparison related to Parrott, Spanner and Petela’s models for different months.

Figures

Figure 1. Image of the solar power plant.
Figure 2. Effect of the solar radiation on the input exergy models for different months.

Figure 3. The electrical exergy and input exergy models for 12 months.

Figure 4. The effects of ambient and solar cell temperature on output exergy and thermal exergy.
Figure 5. The variation of power conversion and exergy efficiencies related to Spanner, Petela and Parrott’s model for 12 months.

Figure 6. Exergy efficiency comparison related to Parrott, Spanner and Petela’s models for different months.

Biographies

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Vedat Keskin received his PhD degree in Physics from Gebze Technical University in Turkey in the year of 2013, MSc degree and BSc degree in Physics Education from Marmara University, Istanbul in Turkey in 2009 and 1992. He is currently an academic member as Assistant Professor at Civil Aviation College of Samsun University. His research interests include solar power systems, exergy analysis in photovoltaic and photovoltaic power systems, thin film photovoltaics, magnetic multilayered thin films and civil aviation.

Nomenclature

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>A</td>
<td>Area ($m^2$)</td>
</tr>
<tr>
<td>$\dot{E}_x$</td>
<td>Exergy ($W$)</td>
</tr>
<tr>
<td>$h_{cw}$</td>
<td>Heat Transfer Coefficient</td>
</tr>
<tr>
<td>I</td>
<td>Current ($A$)</td>
</tr>
<tr>
<td>$I_S$</td>
<td>Solar Radiation ($W/m^2$)</td>
</tr>
<tr>
<td>$P$</td>
<td>Electrical Power ($W$)</td>
</tr>
<tr>
<td>$T$</td>
<td>Temperature ($K$)</td>
</tr>
<tr>
<td>V</td>
<td>Voltage ($v$)</td>
</tr>
</tbody>
</table>
\( v \) \hspace{1cm} \text{Wind Speed (m/s)}

**Greek symbols**

\( \eta_{pce} \) \hspace{1cm} \text{Power Conversion Efficiency}

\( \Psi \) \hspace{1cm} \text{Exergy Efficiency}

\( \sigma \) \hspace{1cm} \text{Angle (rad)}

\( \Phi \) \hspace{1cm} \text{Solar Exergy to Solar Energy Ratio}

**Subscripts**

\( a \) \hspace{1cm} \text{Ambient}

\( \text{cell} \) \hspace{1cm} \text{Cell}

\( m \) \hspace{1cm} \text{Maximum}

\( \text{in} \) \hspace{1cm} \text{Input}

\( \text{out} \) \hspace{1cm} \text{Output}

\( PV \) \hspace{1cm} \text{Photovoltaic}

\( \text{Ther} \) \hspace{1cm} \text{Thermal}

\( S \) \hspace{1cm} \text{Sun}

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**Conflict of interest**

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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\textbf{Signature} \hspace{1cm} \textbf{Corresponding Author’s Full Name:}

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Seyed Hamed Pour Rahmati Khalejan