Research Paper
Computational Methods for Differential Equations
http://cmde.tabrizu.ac.ir
Vol. *, No. *, *, pp. 1-9
DOI:10.22034/cmde.2025.66760.3151

Utilizing the fully fuzzy base-criterion method and the optimistic-pessimistic-natural procedure to evaluate solar panels deflection

Seyed Kazem Yekani[1,*], Tuhid Pashaee Golmarz[1], Mohammad Khazaeili[2], Mahdi Nami Khalilehdeh[1]
[1]Faculty of Mechanical Engineering, University of Tabriz, Tabriz, Iran.
[2]TM.co Research Center, Urmia, Iran.

Abstract

Solar energy systems are among the most widely used renewable energy sources. One of the most important things that may happen to any solar panel and affect their efficiency is deflection. To examine their effects on the deflection rate, the four significant variables including Angle, Area, Airflow Velocity, and Material are taken into consideration here. These parameters have been achieved using numerical simulation. The main issue is that these parameters are offered at intervals when a solar power plant is scheduled for implementation, which makes it extremely difficult for a decision-maker to select an accurate value from the given intervals to precisely model the system. To address this issue, a unique hybrid methodology based on the Optimistic-Pessimistic-Natural technique (OPN) and the completely (fully) fuzzy base-criterion method (FF-BCM) is proposed in this study. First, the weight value is determined using FF-BCM to infer the significance of the suggested parameters. Next, using the OPN approach, three spots within the recommended interval are selected using the attained weights. The deflection value for the optimistic technique is found 17.06 cm based on the realized data. Its value in the Natural strategy is 18.1 cm, indicating a 6.1% improvement. Ultimately, with a deflection of 24.34 cm, the Pessimistic strategy has the highest deviation, outperforming the ON (Optimistic and Natural) methods by 42.7% and 34.5%, respectively.

Keywords. Fully Fuzzy Base-Criterion Method, Triangular fuzzy numbers, Optimistic-Pessimistic-Natural technique, Solar panel, Deflection.
2010 Mathematics Subject Classification. 65C20, 90B50.

1. Introduction

Solar energy is one of the primary sources of sustainable power that is constantly available and does not produce abuse [12, 23]. The use of solar energy to generate power from sunshine has increased due to interest in low-cost energy. However, the continent estate—such as temperature and wind speed—largely determines the efficacy, utility, and lifespan of solar boards [2, 15, 18]. According to the obtained data, a solar system can convert between 15% and 20% of the sun's radiation into electricity, with the remaining energy being wasted as heat [6, 7, 21].

Numerous studies have been published about the composition of solar panels and how environmental factors affect these systems' productivity. Riffat and Ma [19] conducted a review and made several modifications to solar panels employing thermoelectric devices that could achieve high efficiency while lowering weight, dimension, and noise levels. Dai et al. [5] looked into the wind load on rooftop solar panels in a different study. The findings showed that, in general, lower-height buildings will result in more significant fluctuations in wind strain on solar panels. Novel solar panel system structures were investigated by Ayed et al. [4]. They demonstrated that conical structures had superior production using solar panels in the forms of pyramids, hexagons, and cones. Narayanan et al. [16] reported an investigation of sunlight-based energy assortment techniques to satisfy Australian house energy needs utilizing both sun-powered heat authorities and photovoltaic (PV) frameworks. Mathematical models were created for different framework arrangements and two distinct situations were examined in their exploration. Sharma et al. [22] worked

Received: 13 April 2025 ; Accepted: 18 July 2025.
∗ Corresponding author. Email: s.k.yekani@tabrizu.ac.ir.

on the angle of solar panels to harvest maximum efficiency. They employed various mathematical and statistical methodologies to obtain the optimum point. Hamdeh et al. [1] investigated pyramid-shaped solar panel systems. They studied air velocity changes' effect on the system efficiency. Salehi et al. [20] stated that solar energy systems generating electricity have a major challenge which is surface temperature enhancement made by ambient and operating temperature. This phenomenon decreases the solar photovoltaic systems' productivity. They declaimed that these panels' efficiency is reduced by 0.5% for every degree increase in ambient temperature. Therefore, they developed a new system including two main parts: solar panels and cooling units. They analyzed the system's performance by employing a thermoelectric module and natural cooling and compared the results.

The evaluated publications indicate that there is a dearth of study on the loads that solar panels encounter; hence, this is a worthwhile area that can be focused on. However, because external factors like velocity are introduced gradually, obtaining a precise value for them could induce undesired mistakes in the computation. Therefore, using interval bounds as natural, pessimistic, and optimistic viewpoints might produce more rational and logical outcomes. Thus, in order to accurately evaluate a solar panel system, the FF-BCM technique is applied here to apply the previously described parameter intervals. Additionally, a new OPN methodology is proposed in this study considering three points of view. This paper covers an explanation of FF-BCM in section 2, specifics of the OPN technique in section 3, the process of solving a case study in section 4, and finally a conclusion section in section 5 to clearly illustrate the strategy.

2. The Fully Fuzzy BCM

The BCM technique is one of the latest MCDM methods introduced to obtain the weight of the criteria. This method was introduced in 2020 by Haseli et al.[10]. The BCM method uses the pairwise comparison approach to obtain the weight of the criteria. Then, these authors [11] extended their method based on the fuzzy set theory due to the complexity as well as the uncertainty of the purpose and fuzziness of human thought and judgments. Some researchers also applied a completely fuzzy theory to the MCDM methods such as Lin et al. [14]. Herein, the implementation of BCM in the fuzzy ambiance is shown. These algorithm phases are represented as follows:

Phase 1. Decision criteria system creation: DM must choose an alternative on all basis of the criteria. Suppose the set of n criteria has this configuration: $\{c_1, c_2, \ldots, c_n\}$.

Phase 2. Base-criterion specification (appointive or preferential): According to the built decision criteria $\{c_1, c_2, \ldots, c_n\}$, one of them (preferential) is selected. Decision-maker selects this as the base criterion and does not perform any comparison.

Phase 3: The fuzzy base comparisons execution. The fuzzy reference comparison comprises of pairwise comparison between the base criterion and others. Equation (2.1) shows the resulting Base-to-Others. This process is led by a triangular fuzzy number. Table 1 shows the employed linguistic values in the fully fuzzy BCM.

$$\tilde{A}_B = (\tilde{a}_{B1}, \tilde{a}_{B2}, \ldots, \tilde{a}_{Bn}), \tag{2.1}$$

That $\tilde{A}_B$ represents the fuzzy base criterion over the other criteria vector, and $\tilde{a}_{Bj}$ represents the fuzzy preference of the base-criterion over the j criterion.

Phase 4. The ideal (optimum) fuzzy weights calculation: The optimal value of $\tilde{w}_B \% \tilde{w}_j$ is harvested from the elements of the comparison matrix $\tilde{w}_B \% \tilde{w}_j = \tilde{a}_{Bj}$. To achieve the optimal weights $(\tilde{w}_1^*, \tilde{w}_2^*, \ldots, \tilde{w}_n^*)$, minimizing the maximum absolute value of $|\widetilde{w}_B \%_0 \widetilde{w}_j \exists \widetilde{a}_{B_j}|$ for each j is vital. So, the addendum mathematical model ought to be solved.

$$\begin{aligned}
&\min \left\{\max\left(\widetilde{w}_B \% \widetilde{w}_j \exists \widetilde{a}_{B_j}\right)\right\}, \\
&\text{s.to:} \quad \sum_{j=1}^{n} \widetilde{w}_j = \widetilde{1}, \\
&\qquad\quad \widetilde{w}_j \geq \widetilde{0}, \quad j = 1, 2, \ldots, n,
\end{aligned} \tag{2.2}$$

where $\widetilde{1} = (1,1,1), \quad \widetilde{0} = (0,0,0)$.

TABLE 1. Employed linguistic values in the fully fuzzy BCM.

Linguistic term	Fuzzy number	Reciprocal TFNs
Just equal	(1, 1, 1)	$(1,\ 1,\ 1)\odot^{(-1)}$
Equally important	(1, 1, 3)	$(1,\ 1,\ 3)\odot^{(-1)}$
Weakly important	(1, 3, 5)	$(1,\ 3,\ 5)\odot^{(-1)}$
Strongly important	(3, 5, 7)	$(3,\ 5,\ 7)\odot^{(-1)}$
Very strongly important	(5, 7, 9)	$(5,\ 7,\ 9)\odot^{(-1)}$
Absolutely important	(7, 9, 9)	$(7,\ 9,\ 9)\odot^{(-1)}$

The linearized type of the numerical model is achieved:

$$\begin{aligned} &\min \widetilde{\lambda},\\ &\text{s.to:}\quad \widetilde{\lambda} \geq \widetilde{w}_B \exists \widetilde{w}_j \otimes \widetilde{a}_{B_j},\\ &\qquad\quad \widetilde{\lambda} \geq \widetilde{w}_j \otimes \widetilde{a}_{B_j} \exists \widetilde{w}_B,\\ &\qquad\quad \widetilde{\lambda} \geq \widetilde{0}, \quad j = 1, 2, \ldots, n. \end{aligned} \tag{2.3}$$

That $\widetilde{w}_j = \left(w_j^l, w_j^m, w_j^u\right), \quad \widetilde{w}_B = \left(w_B^l, w_B^m, w_B^u\right), \quad \widetilde{a}_{B_j} = \left(a_{B_j}^l, a_{B_j}^m, a_{B_j}^u\right), \quad \widetilde{\lambda} = \left(\lambda^l, \lambda^m, \lambda^u\right)$

Allahviranloo et al. [3] proposed a novel methodology to solve fully fuzzy linear programming problems using triangular fuzzy numbers. To transform the problem, a linear ranking function is utilized. So, it is used the following equation to transform this problem.

$$\tilde{A} = \left(z^l - \frac{1}{4}z^m + \frac{1}{4}z^u, -\frac{1}{4}z^l, \frac{1}{4}z^l\right), \tag{2.4}$$

Hence, mathematical model (2.3) may be written as follows:

$$\begin{aligned} &\min \left(\lambda^l - \tfrac{1}{4}\lambda^m + \tfrac{1}{4}\lambda^u\right),\\ &\text{s.to:}\\ &w_B^l - \tfrac{1}{4}w_B^m + \tfrac{1}{4}w_B^u - \left(\left(a_{Bj}^l + \tfrac{1}{4}(a_{Bj}^u - a_{Bj}^m)\right) w_j^l - \tfrac{1}{4}a_{Bj}^l w_j^m + \tfrac{1}{4}a_{Bj}^l w_j^u\right) \leq \lambda^l - \tfrac{1}{4}\lambda^m + \tfrac{1}{4}\lambda^u,\\ &w_B^l - \tfrac{1}{4}w_B^m + \tfrac{1}{4}w_B^u - \left(\left(a_{Bj}^l + \tfrac{1}{4}(a_{Bj}^u - a_{Bj}^m)\right) w_j^l - \tfrac{1}{4}a_{Bj}^l w_j^m + \tfrac{1}{4}a_{Bj}^l w_j^u\right) \geq -\left(\lambda^l - \tfrac{1}{4}\lambda^m + \tfrac{1}{4}\lambda^u\right),\\ &\sum_{j=1}^{n} \left(w_j^l - \tfrac{1}{4}w_j^m + \tfrac{1}{4}w_j^u\right) = 1, \quad w_j^l - \tfrac{1}{4}w_j^m + \tfrac{1}{4}w_j^u \geq 0,\\ &\lambda^l - \tfrac{1}{4}\lambda^m + \tfrac{1}{4}\lambda^u \geq 0, \quad w_j^m - w_j^l \geq 0, \quad w_j^u - w_j^m \geq 0, \quad \lambda^m - \lambda^l \geq 0, \quad \lambda^u - \lambda^m \geq 0. \end{aligned} \tag{2.5}$$

After solving the mathematical model (2.5), the most favorable content of the triangular fuzzy weights is achieved.

3. The Optimistic-Pessimistic-Natural technique (OPN)

In this section, Optimistic-Pessimistic-Natural Functions for factors (criteria) are introduced. Suppose $\{c_1, c_2, \ldots, c_N\}$ are N criteria and $c_j \in [L_j, U_j]$, that L_j , U_j are the upper and lower limits of the jth criterion, and w_j are the weight of the jth criterion, respectively.

For the decision-maker, three strategies including optimistic, pessimistic, and natural are considered. Also, the values of these strategies are explained in two states as follows:

State 1. Benefit criterion level: In this state, the value function is an ascending value function. Equation (3.1) represents the values of the criterion level, namely x_j^n, x_j^p, x_j^o as the optimistic - pessimistic - natural values. Figure 1 shows a schematic of this value function.

$$\begin{aligned}
x_j^o &= L_j - \rho \ln\left(1 - w_j\left(1 - e^{\frac{-(U_j-L_j)}{\rho}}\right)\right); && \rho = +\sqrt{\frac{U_j - L_j}{U_j + L_j}}, \quad j = 1, 2, \dots, N,\\
x_j^n &= L_j + w_j(U_j - L_j); && \rho = \pm\infty, \quad j = 1, 2, \dots, N\\
x_j^p &= L_j - \rho \ln\left(1 - w_j\left(1 - e^{\frac{-(U_j-L_j)}{\rho}}\right)\right); && \rho = -\sqrt{\frac{U_j - L_j}{U_j + L_j}}, \quad j = 1, 2, \dots, N,
\end{aligned} \tag{3.1}$$

where ρ is the expansion factor.

State 2. Non-Benefit Criterion Level: In this state, the value function is a descending value function. Equation (3.2) represents the values of the criterion level, namely x_j^n, x_j^p, x_j^o as the optimistic, pessimistic, and natural values. Figure 2 shows a schematic of this value function.

$$\begin{aligned}
x_j^o &= L_j - \rho \ln\left(1 - w_j\left(1 - e^{\frac{-(U_j-L_j)}{\rho}}\right)\right); && \rho = +\sqrt{\frac{U_j - L_j}{U_j + L_j}}, \quad j = 1, 2, \dots, N,\\
x_j^n &= L_j + w_j(U_j - L_j); && \rho = \pm\infty, \quad j = 1, 2, \dots, N,\\
x_j^p &= L_j - \rho \ln\left(1 - w_j\left(1 - e^{\frac{-(U_j-L_j)}{\rho}}\right)\right); && \rho = -\sqrt{\frac{U_j - L_j}{U_j + L_j}}, \quad j = 1, 2, \dots, N.
\end{aligned} \tag{3.2}$$

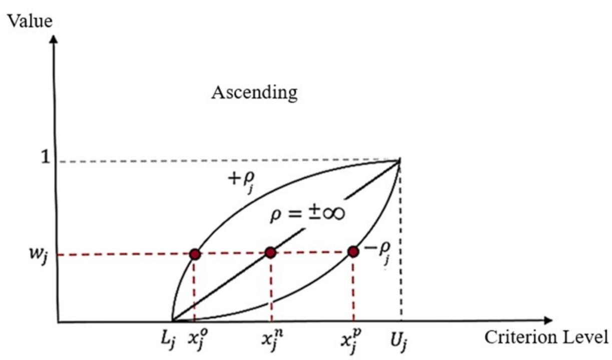


FIGURE 1. Ascending Value Function.

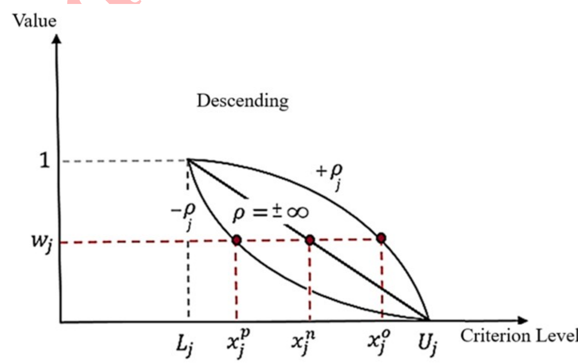


FIGURE 2. Descending Value Function.

4. Case Study (Solar Panels)

A solar board structure situated in a periodic stream field serves as the primary case study. The solar board in question is located inside a uniformly distributed display of boards that are facing a powerful oncoming wind. The flow pressure has allowed for the resolution of both the underlying relocation and the stream surrounding the board. It is anticipated that there will be enough boards positioned upstream and downstream of the main board based on Figure 3 for sporadic stream conditions to be relevant in the stream's streamwise direction.

There are two processes involved in this work: calculating the fluid flow domain at a speed of 25 m/s and examining how the fluid load affects the structure of the solar panel. After performing a numerical simulation, Figure 4 displays the flow streamlines surrounding the panel, and Figure 5 illustrates how the flow load causes the panel to deflect. It stands for the solar head's velocity.

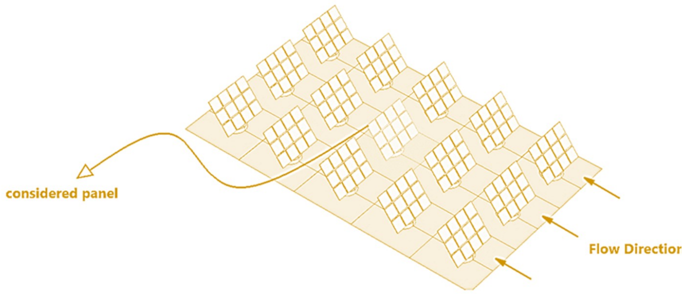


FIGURE 3. Investigated case study.

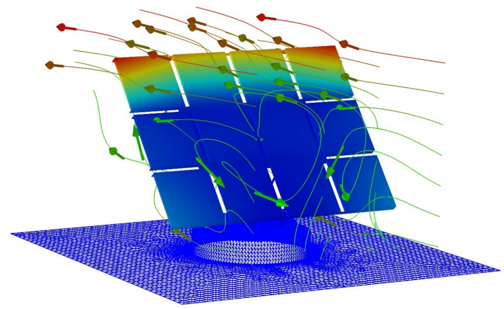


FIGURE 4. Flow streamlines around the panel.

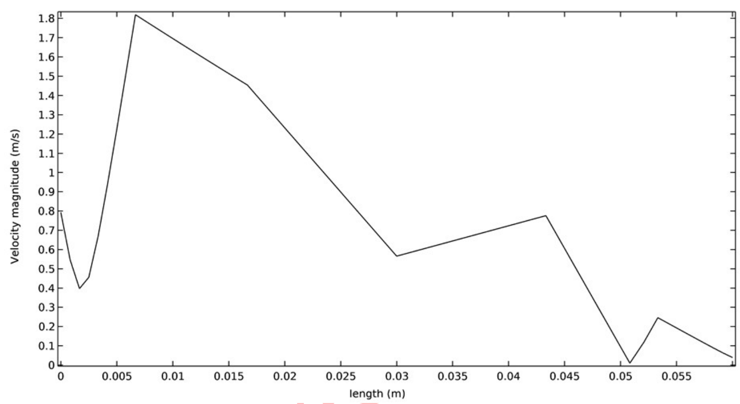


FIGURE 5. The velocity of the solar panel head.

TABLE 2. Initial values for studied factors.

Criteria	C_B (m/s)	C_2 (MPa)	C_3 (m^2)	C_4 (degree)
Interval value	**[24.20, 25.85]**	**[235.10, 260.00]**	**[1.10, 1.50]**	**[20, 45]**

Considering Figure 6, four factors (criteria) including Angle, Area, Airflow velocity, and Material can be effective on the displacement of the head edge of the solar panel. Figure 4 shows it clearly.

The most important parameter in Figure 6 is the flow velocity, which plays a notable role in the amount of deflection. Therefore, this parameter is considered the base criterion ($C_1 \equiv C_B$). In this manner, C_2 is the material strength, C_3 is the panel area, and ultimately, C_4 is the angle of the panel surface. Table 2[8, 9, 13, 17] represents initial interval values for the studied parameters.

The four stages of the suggested approach to solving this problem are criteria weighting, criteria detection by the decision-maker, strategies utilizing the OPN technique, and the use of three strategies to get triple deflection. The stages of the suggested strategy are depicted in the following diagram (Figure 7).

According to the second phase of the proposed approach and based on Table 1, the comparison of importance for factors is deduced in Table 3.

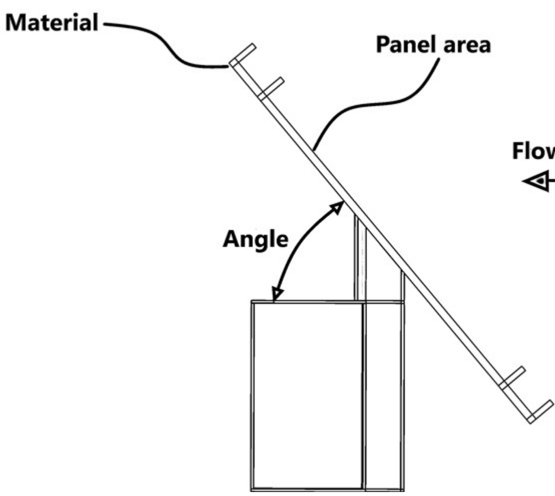


FIGURE 6. Four effective parameters on the deflection.

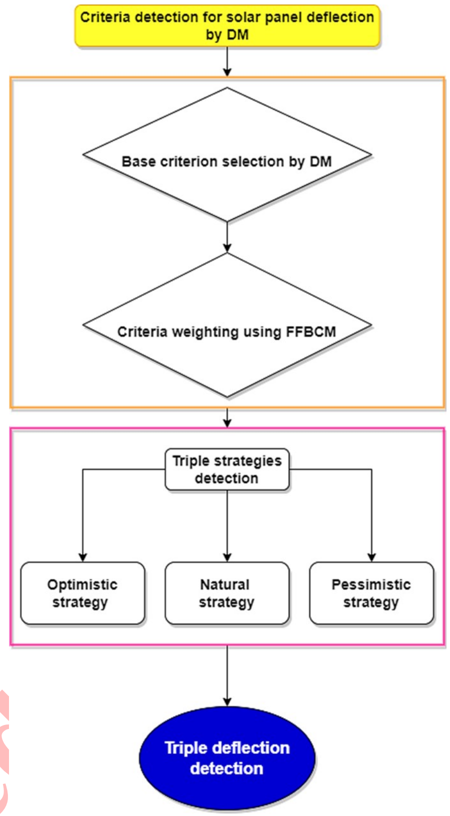


FIGURE 7. Proposed approach flowchart.

TABLE 3. Comparing the importance of factors.

Base criterion	C_B	C_2	C_3	C_4
C_B: Flow velocity	Just equal	Very strongly important	Weakly important	Strongly important
Fuzzy numbers	(1,1,1)	(5,7,9)	(1,3,5)	(3,5,7)

$$\min\left(\lambda^l-\frac{1}{4}\lambda^m+\frac{1}{4}\lambda^u\right),$$

s.to:

$$\begin{aligned}
&w_B^l-\frac{1}{4}w_B^m+\frac{1}{4}w_B^u-\left(\left(1+\frac{1}{4}(1-1)\right)w_1^l-\frac{1}{4}(1)w_1^m+\frac{1}{4}(1)w_1^u\right)\le\lambda^l-\frac{1}{4}\lambda^m+\frac{1}{4}\lambda^u,\\
&w_B^l-\frac{1}{4}w_B^m+\frac{1}{4}w_B^u-\left(\left(1+\frac{1}{4}(1-1)\right)w_1^l-\frac{1}{4}(1)w_1^m+\frac{1}{4}(1)w_1^u\right)\ge-\left(\lambda^l-\frac{1}{4}\lambda^m+\frac{1}{4}\lambda^u\right),\\
&w_B^l-\frac{1}{4}w_B^m+\frac{1}{4}w_B^u-\left(\left(5+\frac{1}{4}(9-7)\right)w_2^l-\frac{1}{4}(5)w_2^m+\frac{1}{4}(5)w_2^u\right)\le\lambda^l-\frac{1}{4}\lambda^m+\frac{1}{4}\lambda^u,\\
&w_B^l-\frac{1}{4}w_B^m+\frac{1}{4}w_B^u-\left(\left(5+\frac{1}{4}(9-7)\right)w_2^l-\frac{1}{4}(5)w_2^m+\frac{1}{4}(5)w_2^u\right)\ge-\left(\lambda^l-\frac{1}{4}\lambda^m+\frac{1}{4}\lambda^u\right),\\
&w_B^l-\frac{1}{4}w_B^m+\frac{1}{4}w_B^u-\left(\left(1+\frac{1}{4}(5-3)\right)w_3^l-\frac{1}{4}(1)w_3^m+\frac{1}{4}(1)w_3^u\right)\le\lambda^l-\frac{1}{4}\lambda^m+\frac{1}{4}\lambda^u,\\
&w_B^l-\frac{1}{4}w_B^m+\frac{1}{4}w_B^u-\left(\left(1+\frac{1}{4}(5-3)\right)w_3^l-\frac{1}{4}(1)w_3^m+\frac{1}{4}(1)w_3^u\right)\ge-\left(\lambda^l-\frac{1}{4}\lambda^m+\frac{1}{4}\lambda^u\right),\\
&w_B^l-\frac{1}{4}w_B^m+\frac{1}{4}w_B^u-\left(\left(3+\frac{1}{4}(7-5)\right)w_4^l-\frac{1}{4}(3)w_4^m+\frac{1}{4}(3)w_4^u\right)\le\lambda^l-\frac{1}{4}\lambda^m+\frac{1}{4}\lambda^u,\\
&w_B^l-\frac{1}{4}w_B^m+\frac{1}{4}w_B^u-\left(\left(3+\frac{1}{4}(7-5)\right)w_4^l-\frac{1}{4}(3)w_4^m+\frac{1}{4}(3)w_4^u\right)\ge-\left(\lambda^l-\frac{1}{4}\lambda^m+\frac{1}{4}\lambda^u\right),\\
&\sum_{j=1}^{4}\left(w_j^l-\frac{1}{4}w_j^m+\frac{1}{4}w_j^u\right)=1,\quad w_j^l-\frac{1}{4}w_j^m+\frac{1}{4}w_j^u\ge0,\quad j=1,2,3,4,\\
&\lambda^l-\frac{1}{4}\lambda^m+\frac{1}{4}\lambda^u\ge0,\quad w_j^m-w_j^l\ge0,\quad w_j^u-w_j^m\ge0,\quad\lambda^u-\lambda^m\ge0,\quad\lambda^m-\lambda^l\ge0.
\end{aligned}\tag{4.1}$$

The optimal solution for the weights and objective function of the mentioned mathematical model are as follows:

$$\tilde{w}_B^* = (0.000,\ 0.000,\ 1.590),\quad \tilde{w}_2^* = (0.072,\ 0.072,\ 0.072),\quad \tilde{w}_3^* = (0.000,\ 0.000,\ 1.590),$$
$$\tilde{w}_4^* = (0.000,\ 0.000,\ 0.530),\quad \tilde{\lambda}^* = (0.000,\ 0.000,\ 0.000)$$

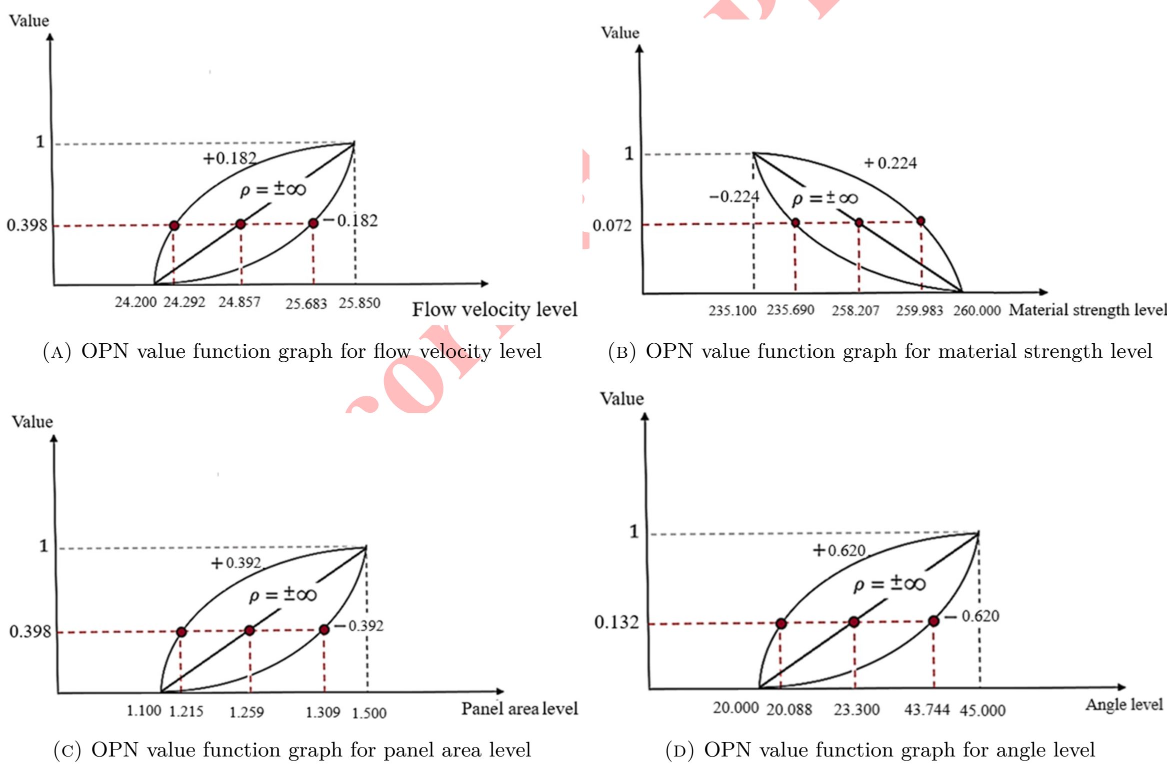
Crisp values of weight are represented as follows:

$$R(\tilde{w}_B^*) = 0.398,\quad R(\tilde{w}_2^*) = 0.072,\quad R(\tilde{w}_3^*) = 0.398,\quad R(\tilde{w}_4^*) = 0.132,\quad R(\tilde{\lambda}^*) = 0.000$$

As the third phase, utilizing the achieved results of the second phase and Equations (3.1) and (3.2) for triple strategies detection for DM, Table 4 consisting of the final results of the OPN technique for solar panels is deduced. Then, Figure 8 is represented to show the OPN value function graph for each criteria level. For the 4th phase of

Table 4. Final results of OPN technique for solar panels.

Criteria	Criterion level interval	ρ_j	x_j^o	x_j^n	x_j^p
C_B	[24.20, 25.85]	0.182	24.292	24.857	25.683
C_2	[235.10, 260.00]	0.224	259.983	258.207	235.690
C_3	[1.10, 1.50]	0.392	1.215	1.259	1.309
C_4	[20, 45]	0.620	20.088	23.300	43.744



(a) OPN value function graph for flow velocity level

(b) OPN value function graph for material strength level

(c) OPN value function graph for panel area level

(d) OPN value function graph for angle level

Figure 8. OPN value functions for criteria levels

the suggested approach, based on Table 4, triple deflection is detected and reported in Table 5. According to Table 5, it is obvious that the Optimistic strategy's deflection value is 17.06 cm. This is the most optimistic value in the present design, which will naturally have the lowest value. The value for Natural strategy is 18.1 cm, indicating a

6.1% increment to the optimistic state. Finally, with a deflection of 24.34 cm—42.7% and 34.5% greater than the ON strategies' value, respectively—the Pessimistic strategy has the biggest deviation.

Table 5. Triple deflection based on triple strategies

	Triple strategies		
Criteria	x_j^o	x_j^n	x_j^p
C_B	24.292	24.857	25.683
C_2	259.983	258.207	235.690
C_3	1.215	1.259	1.309
C_4	20.088	23.300	43.744
Deflection (cm)	**17.06**	**18.1**	**24.34**

5. Conclusion

In innovative energy systems, solar panels that produce free electricity are significant components. Deflection is one of the device's failure modes that can result in significant damage and lower system productivity. Numerous parameters can have an impact on the deflection rate. Four factors—Angle, Area, Airflow Velocity, and Material—are taken into consideration to examine their effects on the deflection rate based on expert investigations. The primary issue is that these parameters are offered at intervals when a solar power plant is scheduled for implementation, which makes it extremely difficult for a decision-maker to select a precise number from the given intervals to accurately model the system. To address this issue, a novel hybrid approach based on the Optimistic-Pessimistic-Natural (OPN) strategy and the Fully Fuzzy Base-Criterion Method (FF-BCM) is put forth. First, the weight value is determined using FF-BCM to infer the significance of the suggested parameters. Next, using the OPN approach, three spots within the recommended interval are selected using the attained weights. In order to derive a more dependable deflection amount through numerical simulation, the decision-maker is thus equipped with three clear values. Based on the obtained data, the base criterion velocity values for optimistic, natural, and pessimistic states are 24.292, 24.857, and 25.683 m/s, respectively. As is evident, there is nearly a 5.7% gap between optimistic and pessimistic responses. The differences are 10.3% for material strength, 7.7% for panel area, and 117.8% for panel angle. This demonstrates that the deflection value for the optimistic technique is 17.06 cm based on the realized data. Its value in the Natural approach is 18.1 cm. Finally, with a deflection of 24.34 cm—42.7% and 34.5% greater than the ON strategies' value, respectively—the Pessimistic strategy has the biggest deviation.

References

[1] N. H. Abu-Hamdeh, S. Khorasani, H. F. Oztop, and K. A. Alnefaie, *Numerical analysis on heat transfer of a pyramid-shaped photovoltaic panel*, J. Therm. Anal. Calorim., (2021), 1–12.

[2] D. M. Alghool, T. Y. Elmekkawy, M. Haouari, and A. Elomri, *Optimization of design and operation of solar assisted district cooling systems*, Energy Convers. Manag.: X, *6* (2020), 100028.

[3] T. Allahviranloo, F. H. Lotfi, M. K. Kiasary, N. A. Kiani, and L. Alizadeh, *Solving fully fuzzy linear programming problem by the ranking function*, Appl. Math. Sci., *2* (2008), 19–32.

[4] H. Ayed, H. Moria, F. Aldawi, N. Farouk, K. Sharma, M. M. Youshanlouei, I. Mahariq, and F. Jarad, *Thermal, efficiency and power output evaluation of pyramid, hexagonal and conical forms as solar panel*, Case Stud. Therm. Eng., *27* (2021), 101232. doi10.1016/j.csite.2021.101232

[5] S. F. Dai, H. J. Liu, J. H. Yang, and H. Y. Peng, *Wind loads on roof-mounted isolated solar panels of tall buildings through wind tunnel testing*, Sol. Energy, *231* (2022), 607–622.

[6] M. Emam, S. Ookawara, and M. Ahmed, *Performance study and analysis of an inclined concentrated photovoltaic-phase change material system*, Sol. Energy, *150* (2017), 229–245.

[7] E. Eroglu, *Discussing total electron content over the solar wind parameters*, Math. Probl. Eng., *2022* (2022), 9592008.

[8] A. R. Farivar, J. Farivar, and H. Farivar, *New method of control for solar panels and Sterling dish*, (2014).

[9] M. Farrizi and M. Jabbari, *Design and Construction of Cooling System using Solar Furnaces and Solar Panels*, IIOAB J., *7* (2016), 21–25.

[10] G. Haseli, R. Sheikh, and S. S. Sana, *Base-criterion on multi-criteria decision-making method and its applications*, Int. J. Manag. Sci. Eng. Manag., *15* (2020), 79–88.

[11] G. Haseli, R. Sheikh, and S. S. Sana, *Extension of base-criterion method based on fuzzy set theory*, Int. J. Appl. Comput. Math., *6* (2020), 54.

[12] M. Kaveh, H. Karami, and A. Jahanbakhshi, *Investigation of mass transfer, thermodynamics, and greenhouse gases properties in pennyroyal drying*, J. Food Process Eng., *43* (2020), e13446.

[13] M. Khazaeili and T. Pashaee Golmarz, *An Innovative Area Method for Resolving Fully Fuzzy Linear Programming Issues (Case Study: Transportation Logistics Network)*, Sahand Commun. Math. Anal., (2025).

[14] Z. Lin, H. Ayed, B. Bouallegue, H. Tomaskova, S. Jafarzadeh Ghoushchi, and G. Haseli, *An integrated mathematical attitude utilizing fully fuzzy bwm and fuzzy waspas for risk evaluation in a SOFC*, Mathematics, *9* (2021), 2328.

[15] C. Mata-Torres, P. Palenzuela, D.-C. Alarc'on-Padilla, A. Zurita, J. M. Cardemil, and R. A. Escobar, *Multi-objective optimization of a Concentrating Solar Power+ Photovoltaic+ Multi-Effect Distillation plant: Understanding the impact of the solar irradiation and the plant location*, Energy Convers. Manag.: X, *11* (2021), 100088.

[16] R. Narayanan, P. Parthkumar, and R. Pippia, *Solar energy utilisation in Australian homes: A case study*, Case Stud. Therm. Eng., *28* (2021), 101603.

[17] T. Pavlovic and Z. L. Pavlovic, *Determining optimum tilt angles and orientations of photovoltaic panels in Nis Serbia*, Contemp. Mater., *2* (2010), 151–156.

[18] C. G. Popovici, S. V. Hudişteanu, T. D. Mateescu, and N.-C. Cherecheş, *Efficiency improvement of photovoltaic panels by using air cooled heat sinks*, Energy Procedia, *85* (2016), 425–432.

[19] S. B. Riffat and X. Ma, *Thermoelectrics: a review of present and potential applications*, Appl. Therm. Eng., *23* (2003), 913–935.

[20] R. Salehi, A. Jahanbakhshi, M. R. Golzarian, and M. Khojastehpour, *Evaluation of solar panel cooling systems using anodized heat sink equipped with thermoelectric module through the parameters of temperature, power and efficiency*, Energy Convers. Manag.: X, *11* (2021), 100102.

[21] T. Semenou, D. R. Rousse, B. Le Lostec, H. F. Nouanegue, and P.-L. Paradis, *Mathematical modeling of dual intake transparent transpired solar collector*, Math. Probl. Eng., *2015* (2015), 942854.

[22] A. Sharma, M. A. Kallioğlu, A. Awasthi, R. Chauhan, G. Fekete, and T. Singh, *Correlation formulation for optimum tilt angle for maximizing the solar radiation on solar collector in the Western Himalayan region*, Case Stud. Therm. Eng., *26* (2021), 101185.

[23] U. Tesio, E. Guelpa, and V. Verda, *Integration of thermochemical energy storage in concentrated solar power. Part 1: Energy and economic analysis/optimization*, Energy Convers. Manag.: X, *6* (2020), 100039.