ISSN 2616-5902 Vol.2, Issue 2: 6-13, DOI: 10.25236/AJBM.2020.020202

Investment decision-making model for distributed Photovoltaic based on the multi-level coordinated evaluation theory

Xiaoxu Fu*, Caixia Tan, Liling Huang, Zhongfu Tan

School of Economics and Management, North China Electric Power University, Beijing 102206, China;
**Correspondence: 183758841@qq.com*

ABSTRACT. *With the development of photovoltaic (PV) industry, installing small-scale PV systems which are integrated into the buildings becomes popular. Therefore, it is important to make optimal investment decisions for investors and consumers. This paper proposes an improved group decision-making method which integrates the cumulative prospect theory and Choquet integral for the investment options of small-scale PV systems. From the perspective of sustainability, the alternatives are evaluated by four criteria, including economic benefits, solar energy condition, carbon emissions and social benefits. Since the performances of criteria are given by decision makers as linguistic variables, the proposed method measures the criteria values by intuitionistic trapezoidal fuzzy numbers. Then the alternatives are evaluated and ranked to determine the optimal option. Finally, the proposed method is implemented in a case study to illustrate its feasibility and effectiveness.*

KEYWORDS: *investment options; small-scale photovoltaic systems; cumulative prospect theory; Choquet integral; intuitionistic trapezoidal fuzzy numbers*

1. Introduction

In recent years, the growing demand for electrical energy requires the renewable energy resources to be developed because of their sustainability and low carbon emissions around the world [1]. Solar photovoltaic (PV) energy is one of the potential industries that offer clean and renewable energies[2] , and therefore the installed global PV capacity has increased dramatically to 230 GW in 2015. Investors prefer to install small-scale PV systems because they can be integrated into the structure of the building to transform solar radiation directly into clean energy [3,4]. Therefore, the optimal decision options of small-scale PV systems become increasingly important to investors and consumers.

To select the optimal option of investment projects, some works in the literature utilized multi-objective decision-making methods and intelligent optimization algo-

ISSN 2616-5902 Vol.2, Issue 2: 6-13, DOI: 10.25236/AJBM.2020.020202

rithms. Abdallah *et al* [5] presented a novel location model based on green supply chain that minimized the costs of the mounting solar PV systems on facility rooftops, which also considered carbon emission credits. In Ref.[6], a new optimization model based on heuristic cost-benefit analysis was proposed to obtain the optimal distributed generation's sizing and siting that met the peak demand forecast. Kucuksari *et al* [7] proposed a framework to integrate GIS, optimization model, and simulation modules to determine the optimal location and the size of PV units annually for the next 20 years based on a campus area environment. Koo *et al* [8] proposed an integrated multi-objective model to select the optimal location in implementing rooftop PV system, which was yet in absence of the sustainable aspect for cites and society. From the above literature, it can be seen that various aspects including economy, environment and sustainability should all be considered to make rooftop PV investment decisions.

To evaluate alternatives from various aspects, a different decision-making tool, namely multi-criteria decision making (MCDM) method, has also been developed to identify the optimal decision to install a PV system. Xiao *et al* [9] established an optimal model for site selection of desert PV plants, combining an AHP (analytic hierarchy process) method and GIS (geographic information system) technology and tested the model by a typical desert area in China. Aragone´ s beltra´n *et al* [10] applied the ANP method to the selection of PV solar investment projects based on the risk minimization. The influence between the elements of the network was identified and analyzed. Lee *et al*[11] designed a two-stage framework for evaluating the suitable plant site alternatives of renewable energy. Rezaei *et al* [12] proposed TOPSIS (technique for order preference similarity to an ideal solution) for the evaluation and selection of optimal locations for wind-solar plants. We can see from these studies that the MCDM method can involve influence factors from various aspects which include economic influence, and has more advantages than other methods.

Installing an effective PV system at a suitable location requires a comprehensive evaluation system. This paper proposes an improved group decision-making method to evaluate the potential locations and determine the optimal option. The main contributions of this paper are presented as follows:

1) In order to evaluate the alternatives comprehensively, the perspectives of economic profits, solar energy conditions, carbon emissions and social benefits are considered as evaluation criteria for long-term planning.

2) To eliminate the subjective preference of decision makers, this paper proposes a group decision-making method integrating the cumulative prospect theory [13,14] and Choquet integral.

3) In the proposed method, the values of criteria are expressed as linguistic variables and measured by intuitionistic trapezoidal fuzzy numbers, and the weights of decision makers are determined by maximum deviation.

4) This method is implemented in a case study in Hebei, China to determine the optimal option of rooftops for investors.

ISSN 2616-5902 Vol.2, Issue 2: 6-13, DOI: 10.25236/AJBM.2020.020202

2. Methodology

Suppose there are m alternatives $A=\{A_1,A_2,\cdots,A_m\}$ in the decision-making problem. The performances of n criteria are denoted as $C=\{C_1,C_2,\cdots,C_n\}$, where C_i has l_i possible states $\{s_1,s_2,\cdots,s_{l_j}\}$ and p_{jt} represents the probability of C_j in the state s_t. Since the values of criteria are linguistic variables, they will be determined by the expert panel with l decision makers $\{d_1,d_2,\cdots,d_l\}$ whose weights are $W=(\omega_1,\omega_2,\cdots,\omega_l)$. For d_k, the value of C_j of alternative A_i in the state of s_t is x_{ijt}^k, which is expressed by an intuitionistic trapezoidal fuzzy number. Besides, the reference point of C_j is r_{j0}. The specific decision-making steps of the proposed method are as follows.

Step 1 Normalize the initial decision matrix.

After the experts evaluate the criteria according to their professional knowledge, the decision matrix of expert d_k is obtained and indicated as $\boldsymbol{D}^k=(x_{ij}^k)_{m\times n}$ where x_{ij}^k represents the intuitionistic trapezoidal fuzzy prospect of alternative A_i with respect to C_j which is determined by x_{ijt}^k. Then we normalize the decision matrix by Eqs. (1)-(2).

Suppose $x_{ijt}^k=([a_{ijt}^1,a_{ijt}^2,a_{ijt}^3,a_{ijt}^4];\mu_{ijt},\upsilon_{ijt})$ and the normalized matrix is $\boldsymbol{D}^{k'}=(x_{ij}^{k'})_{m\times n}$, where $x_{ij}^{k'}$ is the normalized intuitionistic trapezoidal fuzzy prospect and $x_{ijt}^{k'}=([b_{ijt}^1,b_{ijt}^2,b_{ijt}^3,b_{ijt}^4];\mu_{ijt},\upsilon_{ijt})$.

For cost criteria, which means the smaller the better,

$$b_{ijt}^q=\frac{\max\limits_{i,t}(a_{ijt}^4)-a_{ijt}^{5-q}}{\max\limits_{i,t}(a_{ijt}^4)-\min\limits_{i,t}(a_{ijt}^1)},\ q=1,2,3,4 \tag{1}$$

For benefit criteria, which means the larger the better,

$$b_{ijt}^q=\frac{a_{ijt}^q-\min\limits_{i,t}(a_{ijt}^1)}{\max\limits_{i,t}(a_{ijt}^4)-\min\limits_{i,t}(a_{ijt}^1)},\ q=1,2,3,4 \tag{2}$$

Step 2 Determine the reference point.

Generally, the intermediate point, the worst point and the optimal point are referred to as the reference point. Managers tend to determine the reference point r_{j0}

ISSN 2616-5902 Vol.2, Issue 2: 6-13, DOI: 10.25236/AJBM.2020.020202

of C_j according to their own risk preference and subjective thoughts. After the normalization, r_{j0} is transformed into r'_{j0}.

Step 3 Obtain the prospect value matrix.

According to Eq. (3), we compute the prospect value $z_{ij}^k = V(x_{ij}^{k'})$ of A_i with respect to C_j determined by expert d_k.

$$z_{ij}^k = \sum_{i=k_j+1}^{l_j} \pi_{ij(t)}^{k+} \upsilon(\Delta x_{ij(t)}^{k'}) + \sum_{i=1}^{k_j} \pi_{ij(t)}^{k-} \upsilon(\Delta x_{ij(t)}^{k'}) \tag{3}$$

where υ is the value function and π is the weight function. $\Delta x_{ijt}^{k'}$ computed by Eq. (4) represents the deviation between $x_{ijt}^{k'}$ and r'_{j0}, and $x_{ij(t)}^{k'}$ means the value after $\Delta x_{ijt}^{k'}$ is ranked.

$$\Delta x_{ijt}^{k'} = \begin{cases} d(x_{ijt}^{k'}, r'_{j0}) & x_{ijt}^{k'} \geqslant r'_{j0} \\ -d(x_{ijt}^{k'}, r'_{j0}) & x_{ijt}^{k'} \wedge r'_{j0} \end{cases} \tag{4}$$

Now the normalized decision matrix $\boldsymbol{D}^k$ of expert d_k is converted to the prospect matrix $\boldsymbol{Z}^k = (z_{ij}^k)_{m \times n}$.

Step 4 Compute the alternative prospect value of experts.

The prospect values of alternative A_i are integrated by using Choquet integral and then the prospect value z_i^k of A_i of expert d_k is obtained.

$$z_i^k = \sum_{j=1}^{n} z_{i(j)}^k [g(A_{(j)}) - g(A_{(j+1)})] \tag{5}$$

where $A_{(j)} = (c_{(j)}, \cdots, c_{(n)})$ and $A_{(n+1)} = \varnothing$. $z_{i(j)}^k$ means the prospect value after z_{ij}^k is ranked by $z_{i(1)}^k \leqslant z_{i(2)}^k \leqslant \cdots \leqslant z_{i(n)}^k$.

Step 5 Determine the expert weights.

According to the prospect value z_i^k, the weights of experts $W = (\omega_1, \omega_2, \cdots, \omega_l)$ can be calculated by Eq. (6) based on the method of maximizing deviations.

ISSN 2616-5902 Vol.2, Issue 2: 6-13, DOI: 10.25236/AJBM.2020.020202

$$\omega_k = \frac{\sum_{i=1}^{m}\sum_{l=1}^{m} | z_i^k - z_l^k |}{\sum_{k=1}^{n}\sum_{i=1}^{m}\sum_{l=1}^{m} | z_i^k - z_l^k |} \tag{6}$$

Step 6 Rank the alternatives according to the integrated prospect value.

Combining with the expert weights, we calculate the integrated prospect value z_i of alternative A_i using Eq. (7).

$$z_i = \sum_{k=1}^{l} \omega_k z_i^k \tag{7}$$

Rank z_i and then the alternative with the maximum integrated prospect value is considered as the optimal alternative.

3. Case Study

A PV generation service company located in Shanghai, China intends to invest in a 3.5kWp rooftop PV system in Hebei, China. After investigation and information collection, alternatives $\{A_1, A_2, A_3\}$ are identified which are located in Baoding city. The manager invites three experienced experts $\{d_1, d_2, d_3\}$ to evaluate the alternatives from four aspects: economic profits c_1, solar energy condition c_2, carbon emissions c_3 and social benefits c_4. c_1 and c_4 have four states: excellent s_1, good s_2, medium s_3 and bad s_4, while c_2 and c_3 have three, excellent s_1, good s_2 and medium s_3.

Three experts provide the performances of criteria using intuitionistic trapezoidal numbers according to their experience and the statistical data. Then the criteria are normalized where c_3 is the cost criteria while c_1, c_2 and c_4 are benefit criteria. Suppose the reference points given by the decision makers are $r_{10} = ([3,4,5,6]; 0.6,0.2)$, $r_{20} = ([2,3,4,7];0.6,0.2)$, $r_{30} = ([2,3,4,5]; 0.7,0.1)$ and $r_{40} = ([2,4,5,6];0.7,0.1)$ that are transformed into r'_{j0} after the normalization.

After the normalization, we obtain the prospect matrix shown in Table 1.

ISSN 2616-5902 Vol.2, Issue 2: 6-13, DOI: 10.25236/AJBM.2020.020202

Table 1 The prospect matrix

		c_1	c_2	c_3	c_4
d_1	A_1	−0.18	−0.18	−0.33	−0.35
	A_2	−0.19	0.02	−0.32	−0.41
	A_3	−0.04	−0.10	0.02	−0.24
d_2	A_1	−0.43	0.11	−0.04	−0.50
	A_2	0.16	−0.01	−0.22	−0.04
	A_3	−0.01	−0.16	−0.17	−0.26
d_3	A_1	−0.11	−0.06	−0.44	−0.55
	A_2	−0.43	0.05	−0.18	−0.35
	A_3	−0.43	0.18	−0.28	−0.61

Assume that the fuzzy measurements of criteria are $g(c_1)=0.2$, $g(c_2)=0.35$, $g(c_3)=0.25$ and $g(c_4)=0.4$. Then the fuzzy measurements among the criteria are calculated. $g(c_1,c_2)=0.52$, $g(c_1,c_3)=0.43$, $g(c_1,c_4)=0.57$, $g(c_2,c_3)=0.56$, $g(c_2,c_4)=0.69$, $g(c_3,c_4)=0.61$, $g(c_1,c_2,c_3)=0.72$, $g(c_1,c_2,c_4)=0.83$, $g(c_2,c_3,c_4)=0.87$, $g(c_1,c_2,c_3,c_4)=1$. Then we employ the Choquet integral to integrate the prospect values of criteria and obtain the prospect values of alternatives of each expert shown in Table 2.

Table 2 The prospect values of alternatives

	A_1	A_2	A_3
d_1	−0.257 6	−0.204 1	−0.098 4
d_2	−0.178 7	−0.021 0	−0.160 0
d_3	−0.281 7	−0.184 7	−0.235 4

Based on the above results, we compute the weights of experts by maximizing deviations and obtain that $W=(0.384\,6, 0.381, 0.234\,4)$. Then the integrated prospect values of three alternatives are calculated and the results are $z_1=-0.233\,2$, $z_2=-0.129\,8$, $z_3=-0.154$. Therefore, it is proved that $A_2 \vee A_3 \vee A_1$ and A_2 is the optimal area to install a small-scale PV system.

ISSN 2616-5902 Vol.2, Issue 2: 6-13, DOI: 10.25236/AJBM.2020.020202

4. Conclusion

In this work, the optimal investment option for small-scale PV systems was studied by using an improved group decision-making method which integrated the cumulative prospect theory and Choquet integral. From the perspective of sustainability, the alternatives were evaluated by four criteria including economic benefits, solar energy condition, carbon emissions and social benefits. Since the performances of criteria were given by decision makers as linguistic variables, the proposed method measured the criteria values by intuitionistic trapezoidal fuzzy numbers. Then the alternatives were evaluated and ranked to determine the optimal option. Finally, the proposed method was implemented in a case study to illustrate its feasibility and effectiveness.

References

[1] Hoggett R. Technology scale and supply chains in a secure, affordable and low carbon energy transition [J]. Applied Energy, 2014, 123: 296-306.

[2] Jia F, Sun H, Koh L. Global solar photovoltaic industry: An overview and national competitiveness of Taiwan [J]. Journal of Cleaner Production, 2016, 126: 550-562.

[3] Grossmann W D, Grossmann I, Steininger K W. Distributed solar electricity generation across large geographic areas, Part I: A method to optimize site selection, generation and storage [J]. Renewable and Sustainable Energy Reviews, 2013, 25: 831-843.

[4] Eltawil M A , Zhao Z M. Grid-connected photovoltaic power systems: Technical and potential problems—A review [J]. Renewable and Sustainable Energy Reviews, 2010, 14(1): 112-129.

[5] Abdallah T, Diabat A, Rigter J. Investigating the option of installing small scale PVs on facility rooftops in a green supply chain [J]. International Journal of Production Economics, 2013, 146(2): 465-477.

[6] El-Khattam W, Bhattacharya K, Hegazy Y , et al. Optimal investment planning for distributed generation in a competitive electricity market [J]. IEEE Transactions on Power Systems, 2004, 19(3): 1674-1684.

[7] Kucuksari S, Khaleghi A M, Hamidi M, et al. An Integrated GIS, optimization and simulation framework for optimal PV size and location in campus area environments [J]. Applied Energy, 2014,113: 1601-1613.

[8] Koo C, Hong T, Lee M, et al. An integrated multi-objective optimization model for determining the optimal solution in implementing the rooftop photovoltaic system [J]. Renewable & Sustainable Energy Reviews, 2016, 57: 822-837.

[9] Xiao J H, Yao Z Y, Qu J J, et al. Research on an optimal site selection model for desert photovoltaic power plants based on analytic hierarchy process and geographic information system [J]. Journal of Renewable and Sustainable Energy, 2015, 5(2): 023132.

[10] Aragonesbeltran P, Chaparrogonza´lez F, Pastorferrando J P ,et al. An ANP-based approach for the selection of photovoltaic solar power plant investment projects [J]. Renewable and Sustainable Energy Reviews, 2010, 14(1):

ISSN 2616-5902 Vol.2, Issue 2: 6-13, DOI: 10.25236/AJBM.2020.020202

249-264.
[11] Lee A H I, Kang H Y, Lin C Y, et al. An integrated decision-making model for the location of a PV solar plant [J]. Sustainability, 2015, 7(10): 13522-13541.
[12] Rezaei M, Mostafaeipour A, Qolipour M, et al. Investigation of the optimal location design of a hybrid wind-solar plant: A case study [J]. International Journal of Hydrogen Energy, 2018, 43(1): 100-114.
[13] Wilton E, Delarue E. D'haeseleer W, et al. Reconsidering the capacity credit of wind power: Application of cumulative prospect theory [J]. Renewable Energy, 2014, 68: 752-760.
[14] Michalska E, Dudzinska-Baryla R. Comparison of the valuations of alternatives based on cumulative prospect theory and almost stochastic dominance [J]. Operation Research and Decision, 2012, 3(5): 23-36.