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Site Selection For solar PV Farm Using Elimination and Choices Translating Reality (ELECTRE) in Multi-Criteria Decision Making

Nurul Afiqah Sariman[1], Mohamad Shahiir Saidin[1,*]

[1] Department of Mathematical Sciences, Faculty of Science, Universiti Teknologi Malaysia, 81310 Skudai, Johor, Malaysia

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ABSTRACT

This research focuses on selecting the optimal site for a solar photovoltaic (PV) farm in Saudi Arabia using Multi-Criteria Decision Making (MCDM) methods. Method of Shannon Entropy for objective weighting and ELECTRE for alternative ranking is chosen to apply to the data. Five cities in Saudi Arabia are selected as potential site for Solar PV Farm. Five potential site, Riyadh, Jeddah, Abha, Dammam, and Al Ahsa were assessed based on five main criteria which are climatic, technical, economic, environmental, and social. In addition, for each criterion there were total of 16 sub-criteria that needs to be researched and evaluated. Some of the sub-criteria are solar irradiation, air temperature, temperature losses, payback period and population density. Each weight of sub-criteria will contribute in determining the ranking. In addition, method of CRITIC and TOPSIS are use as comparison for the result obtained. To validate the results between two methods, a sensitivity analysis was conducted using the Spearman Rank Correlation method to measure the degree of correlation between the rankings. Furthermore, this study highlights the effectiveness of integrating objective and subjective MCDM methods in addressing complex decision-making problems, such as solar PV farm site selection. The consistency of results across methods confirms the reliability of this hybrid approach in producing accurate and data-driven decisions.

Keywords:
Solar PV Farm; Shannon Entropy; CRITIC; ELECTRE; TOPSIS

1. Introduction

The growing of sustainable energy has led to increased global interest in renewable energy technologies, particularly solar photovoltaic (PV) systems. Solar PV systems directly convert sunlight into electricity and are considered among the most promising solutions for reducing reliance on fossil fuels and minimizing environmental impact based on Hassan *et al.,*[1]. As a country with abundant sunlight and high levels of solar radiation, Saudi Arabia holds significant potential for large-scale solar energy development explained by Zubair *et al.,* [2]. In line with its national energy strategy, Saudi Arabia is actively seeking to expand its electricity generation capacity through renewable sources, especially solar energy conducted by Orfanogiannaki *et al.,* [3].

* *Corresponding author.*
E-mail address: shahiir@utm.my

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However, selecting the most appropriate site for a solar PV farm involves complex decision-making due to the presence of multiple interrelated criteria. Factors such as climatic conditions, technical feasibility, economic costs, environmental impacts, and social considerations must all be carefully evaluated. To address this challenge, MCDM offer structured and systematic method to assess various alternatives based on a range of quantitative and qualitative factors based on Sorooshian *et al.,* [4]. In this study, two MCDM methods are employed: Shannon Entropy, which objectively calculates the weight of each sub-criterion based on data dispersion can be seen in review papers by Yi *et al.,* [5], and ELECTRE, which ranks alternatives through pairwise comparison using concordance and discordance indices based on reference from Govindan *et al.,* [6].

Solar photovoltaic (PV) systems represent one of the fastest-growing renewable energy technologies, capable of converting sunlight directly into electricity. Alongside other renewable sources such as wind, hydro, biomass, and geothermal, solar PV is widely regarded as a clean and sustainable solution to growing environmental challenges regarding to Govindan *et al.,* [7]. Since solar PV relies solely on sunlight, regions with high solar exposure are particularly well-suited for its implementation. Cities that receive substantial global horizontal irradiance (GHI) throughout the year are considered ideal for establishing solar PV installations based on Saracoglu *et al.,* [8]. In Saudi Arabia’s context, the government is working to enhance national electricity generation capacity based on Zell *et al.,* [9]. As part of this initiative, various renewable energy sources have been proposed for integration. Given the country's geographical location, which provides consistently high solar radiation, Saudi Arabia is particularly well-positioned to adopt solar PV systems as a primary energy source from Zubair *et al.,* [2].

Shannon Entropy is a method in MCDM to address uncertainty and variability among criteria. It was introduced by Claude Shannon in 1948; this method has been adapted in decision-making contexts to support objective weight determination. In MCDM, Shannon Entropy is particularly useful for quantifying the amount of information or variation present across different criteria. It was first used to reduce subjectivity in the weighing process, particularly when dealing with multiple and often conflicting objectives. Shannon Entropy makes it easier to assign weights in a clear and data-driven manner by evaluating the degree of dispersion in each criterion among options. This improves the entire decision-making process's dependability based on Yi et al., [5].

The ELECTRE method was developed to address decision-making problems involving a set of distinct alternatives. It works by conducting pairwise comparisons and utilizing concordance and discordance indices to establish a preference relation among the alternatives. This method is particularly effective when decision-makers need to choose not just the best alternative, but also a shortlist of acceptable alternatives under conflicting evaluation criteria based on reference from Govindan *et al.,* [6]. Due to its ability to accommodate both qualitative and quantitative data, ELECTRE I have been extensively applied across various fields in complex decision-making scenarios.

The Criteria Importance Through Criteria Correlation, CRITIC is an objective approach for determining the weight of criteria in decision-making. It evaluates both the variation of each criterion and its independence from others by analysing correlations. This makes CRITIC effective in identifying criteria that are both unique and impactful in the decision process. Its main strength lies in relying solely on data, which helps eliminate subjective. The Technique for Order of Preference by Similarity to Ideal Solution, TOPSIS method developed by Hwang and Yoon in 1981 [10], is another widely used MCDM technique. It ranks alternatives by comparing their distance from an ideal solution (best case) and a negative ideal solution (worst case). The most preferred option is the one closest to the ideal and farthest from the negative ideal. The results from the application of these two methods are used as a comparison to ensure the validity of the results obtained using Shannon-ELECTRE.

The main objectives of this study are : (1) to combine two method for evaluating the weights of primary criteria and sub-criteria using both objective (Shannon Entropy) and subjective (CRITIC) approaches, (2) to determine the most suitable site for grid-connected solar PV development in Saudi Arabia using the ELECTRE method, and (3) to compare the results of Shannon Entropy–ELECTRE with CRITIC–TOPSIS to evaluate the consistency and reliability of both decision-making approaches. In summarize, this study demonstrates the importance and effectiveness of integrating objective and subjective MCDM methods for solving complex site selection problems in renewable energy planning.

2. Methodology

2.1 ELECTRE Ranking Based on Shannon Entropy

The Shannon Entropy and ELECTRE method is a hybrid MCDM technique that combines the ELECTRE method for pairwise analysis of options with Shannon Entropy for objective weighting. Concordance and discordance matrices are used by ELECTRE to rank and assess alternatives, whereas Shannon Entropy allocates weights according to the variability of each criterion. When making decisions in complicated situations, like choosing a location for Solar PV Farm, this combination offers a methodical and trustworthy framework can be seen in review papers by several authors [11-12]. Steps used in this study are;

Step 1: Normalized decision matrix r_{ij}
Original decision matrix is transformed into a dimensionless matrix to eliminate the effects of different units of measurement across criteria. The normalization process depends on whether the criterion is beneficial or non-beneficial. The formula are given by:

for beneficial criteria

$$r_{ij} = \frac{x_{ij} - \min(x_j)}{max(x_j) - \min(x_j)}, \tag{1}$$

for non-beneficial criteria

$$r_{ij} = \frac{\max(x_j) - x_{ij}}{max(x_j) - \min(x_j)}, \tag{2}$$

$i = 1,2, \dots, m, \qquad j = 1,2, \dots, n,$

Step 2: Calculate entropy, E_i
The entropy of each criterion is calculated to measure the degree of uncertainty or disorder associated with it. Entropy helps in identifying the information provided by each criterion in differentiating between alternative. Entropy value is calculated using this equation:

$$E_i = -k \sum_{i=1}^{m} r_{ij} \ln(r_{ij}) \tag{3}$$

where,

$$k = \frac{1}{\ln(m)} \tag{4}$$

m is the number of alternatives.

Step 3: Determine degree of divergence, d_i

The degree of divergence is obtained by subtracting the entropy value of each criterion from one. This value reflects the contrast intensity of the criterion, or how informative it is across all alternatives. A higher divergence indicates greater discriminative power among alternatives for that specific criterion. It can be calculate using:

$$d_i = 1 - E_i \tag{5}$$

Step 4: Calculate weight, w_i

Weights are calculated by dividing each criterion's degree of divergence by the total sum of all divergences. This step produces objective weights that are proportional to each criterion's contribution to the decision process. These weights are used to emphasize criteria that exhibit more variability and influence among the alternatives. Following is the formula used:

$$w_i = \frac{d_i}{\sum_{i=1}^{n} d_i} \tag{6}$$

Step 5: Calculate weighted normalized decision, V_{ij}

Each element in the normalized decision matrix is multiplied by its corresponding weight to create the weighted normalized decision matrix. This process integrates both the magnitude and importance of each criterion into a single evaluation. The resulting matrix serves as the basis for concordance and discordance computations. The matrix is illustrated as:

$$V_{ij} = R \times W = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \cdots & \cdots & \ddots & \vdots \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix} \tag{7}$$

Step 6: Specify concordance, C_{ab} and discordance, D_{ab}

For each pair of alternatives, concordance and discordance sets are identified based on the weighted normalized matrix. The concordance set includes criteria where one alternative is better or equal to another, while the discordance set includes criteria where one alternative performs worse.

let $A = \{a, b, c, . . .\}$

$$C_{ab} = \{j \mid x_{aj} \geq x_{bj}\} \tag{8}$$

$$D_{ab} = \{j \mid x_{aj} < x_{bj}\} = J - C_{ab} \tag{9}$$

Step 7: Calculate concordance and discordance matrix

The concordance matrix is formed by summing the weights of criteria in the concordance set for each pair of alternatives. Likewise, the discordance matrix is built by finding the maximum deviation in discordance criteria between two alternatives. These matrices quantitatively represent the strength of preference or opposition between alternatives. The value are based on:

$$c(a,b) = \sum_{j \in C_{ab}} w_j \tag{10}$$

$$d(a,b) = \frac{\max |v_{aj} - v_{bj}|}{\max |v_{mj} - v_{nj}|} \tag{11}$$

Step 8: Determine the concordance, $\bar{c}$ and discordance, $\bar{d}$
The concordance and discordance index for each pair of alternatives is calculated based on the values from the concordance and discordance matrices. The concordance index represents the degree of overall agreement that one alternative is at least as good as another, while the discordance index reflects the extent of disagreement or opposition. Following is the given formula:

$$\bar{c} = \sum_{a=1}^{m} \sum_{b}^{m} \frac{c(a,b)}{m(m-1)} \tag{12}$$

$$\bar{d} = \sum_{a=1}^{m} \sum_{b}^{m} \frac{d(a,b)}{m(m-1)} \tag{13}$$

Step 9: Determine ranking
The final score is assigned to each alternative based on the number of times it dominates other alternatives across both concordance and discordance matrices. Alternatives are ranked from highest to lowest score, where a higher score indicates better overall performance.

$$H = E \times F \tag{14}$$

3. Results

3.1 Numerical Application

The data of this paper are taken from a case study by Ibrahim et al. 2023. The results of this method then are compared with TOPSIS method based on CRITIC. In this application there are 5 cities, $A = \{A_1, A_2, A_3, A_4, A_5\}$ to be evaluated against 16 sub-criteria. These sub-criteria are grouped into % main criteria, $C = \{C_1, C_2, C_3, C_4, C_5\}$.

Shannon Entropy is used to calculate weight of each sub-criteria. Value of local weight and global weight are important in this study to determine which sub-criteria have the greatest and least influence on the decision-making process. This approach helps ensure that every factor is fairly considered based on its relevance both within its group and in the overall evaluation. Table 1 display the value of local and global weight using Shannon Entropy.

Table 1
Value of local and global weight using Shannon Entropy

Criteria	Local Weight	Global Weight
C_{11}	0.14409	0.04620
C_{11}	0.27842	0.08926
C_{13}	0.24102	0.07727
C_{14}	0.21919	0.07027
C_{15}	0.11727	0.03760
C_{21}	0.38105	0.06397
C_{22}	0.25446	0.04272
C_{23}	0.36448	0.06119
C_{31}	0.21059	0.06399
C_{32}	0.18459	0.05609
C_{33}	0.21059	0.06399
C_{34}	0.18364	0.05580
C_{35}	0.21059	0.06399
C_{41}	0.56785	0.06399
C_{42}	0.43215	0.04870
C_{51}	1.00000	0.09496

The table shows values obtained after applying Shannon Entropy. Based on the table, the sub-criteria that has the greatest weight are C_{51}. The value with the least influence corresponds to C_{15}. This weight will subsequently be applied to determine the ranking of the alternatives.

The ELECTRE method employs both concordance and discordance approaches to perform pairwise comparisons among alternatives. The concordance matrix represents the extent to which an alternative A_i is preferred over another alternative A_j based on the weighted criteria that support this preference. Conversely, the discordance matrix captures the degree to which alternative A_i is less favourable than A_j, by highlighting the criteria where A_i significantly underperforms relative to A_j. Together, these matrices provide a comprehensive view of both the strengths and weaknesses of each alternative in relation to others. Using the defined formulas and coding implementation, the concordance and discordance matrices are generated to compare each pair of alternatives. The matrices below display the value of concordance and discordance matrix:

$$\boldsymbol{C} = \begin{bmatrix} - & 0.65256 & 0.67725 & 0.65956 & 0.67725 \\ 0.34744 & - & 0.61059 & 0.40863 & 0.71145 \\ 0.32275 & 0.42700 & - & 0.26747 & 0.41409 \\ 0.34044 & 0.62897 & 0.77013 & - & 0.68633 \\ 0.32275 & 0.28855 & 0.58591 & 0.31367 & - \end{bmatrix}$$

$$\boldsymbol{D} = \begin{bmatrix} - & 0.87450 & 0.97681 & 1.00000 & 0.49898 \\ 1.00000 & - & 0.49103 & 1.00000 & 0.46635 \\ 1.00000 & 1.00000 & - & 1.00000 & 0.58546 \\ 0.92623 & 0.47125 & 0.92944 & - & 0.35680 \\ 1.00000 & 1.00000 & 1.00000 & 1.00000 & - \end{bmatrix}$$

3.2 Discussion

Based on the results, the best performance of the alternative belongs to A_4 which is Riyadh as this alternative is ranked at the first place using the proposed method. The score values represent the degree of confidence of decision makers' evaluations. Regarding to this matter, the decision makers arrange the alternative rank based on highest score to lowest score for final ranking. The most important sub criterion is the population density, C_{51} under social criteria C_5, as it has the highest weight obtained during the assessment. This indicates that social criteria play significant role in determining the suitability of a site for solar PV development. In ELECTRE, the score of an alternative reflects the number of other alternatives it outranks based on the strength of preference relationships. Riyadh, with a score of 2, means that it is preferred over two other alternatives according to the concordance-discordance value. Higher scores indicate stronger dominance and better overall performance. This scoring system helps the decision maker to clearly see which alternatives are most preferred and which are least, based on the evaluation process. Table 2 display the ranking order of alternative using proposed method.

Table 2
Ranking order of alternative using proposed method

Alternative	Score	Ranking
Abha, A_1	1	3
Jeddah, A_2	2	2
Dammam, A_3	0	4
Riyadh, A_4	2	1
Al Ahsa, A_5	0	5

Table 3 indicates the comparison of results between the ELECTRE method and TOPSIS method. There are 2 alternatives that have different ranking between the proposed method and TOPSIS. This happens because there is different approach of each method. The TOPSIS method disregards the sub-criteria involvement in the algorithm and instead uses the distance from the ideal and anti-ideal solution as the basis for ranking. Riyadh and Jeddah is ranked as first and second place by both ELECTRE and TOPSIS method. However, Abha is ranked third by ELECTRE but fourth by TOPSIS, while Dammam is ranked fourth in ELECTRE and third in TOPSIS. Al Ahsa remains in the last position for both methods. The proposed method provides a more structured and data-driven evaluation by including both sub-criteria weights and concordance-discordance analysis, offering a more comprehensive assessment framework for decision-making.

Table 3
Comparison result between proposed method and TOPSIS

Alternative	ELECTRE	Rank	TOPSIS	Rank
Abha, A_1	1	3	0.3730	4
Jeddah, A_2	2	2	0.6580	2
Dammam, A_3	0	4	0.3800	3
Riyadh, A_4	2	1	0.7270	1
Al Ahsa, A_5	0	5	0.3618	5

To evaluate the consistency between the two ranking methods, a correlation test was conducted using the Spearman rank correlation technique. This method was employed to quantify the strength and direction of the relationship between the rankings produced by ELECTRE and TOPSIS. Table 4 below display the calculation of Spearman Rank Correlation.

Table 4
Calculation of Spearman Rank Correlation

Alternative	Ranking		d_i,	d_i^2
	ELECTRE	TOPSIS	$(R_i^{(1)} - R_i^{(2)})$	
Abha, A_1	3	4	-1	1
Jeddah, A_2	2	2	0	0
Dammam, A_3	4	3	1	1
Riyadh, A_4	1	1	0	0
Al Ahsa, A_5	5	5	0	0

Equation below shows the formula to calculate Spearman Rank Corelation;

$$\rho = 1 - \frac{6\sum d_i^2}{n(n^2-1)} \tag{15}$$

$$\rho = 1 - \frac{6(2)}{5(5^2-1)} = 0.9 \tag{16}$$

The value of the Spearman Rank Corelation are in the range of between -1 and 1. Value of -1 indicates it has negative correlation between method. Value of 0 refers to non-existing correlation and value of 1 indicate a strong positive correlation. Since obtained value of ρ is 0.9, approaching to 1, it can be concluded as strong positive correlation.

4. Conclusions

In this paper, I have presented a developed method to evaluating the site for solar PV farm using ELECTRE based on Shannon Entropy method with concerning the objective weight. Since the assessment involves numerous sub-criteria with varying levels of importance, the Shannon Entropy method has been applied to overcome subjectivity in weight. Furthermore, two types of criteria weights are involved in this paper, which are subjective and objective weights. The subjective weight is determined using the CRITIC method, while the objective weight is obtained using the Shannon Entropy method. By applying the ELECTRE method using the integrated weights, the performance ranking for each alternative site can be determined. I also presented a research paper on determining the best location for a solar PV farm among five potential sites in Saudi Arabia that used as references. To verify the proposed method, the actual result from TOPSIS method were used for comparison to observed the differences of ranking between the methods. For further research, I suggest to explore the application of fuzzy linguistic sets in evaluating the criteria weights and site performance for better application of decision-making.

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References

[1] Hassan, Imad, Ibrahim Alhamrouni, and Nurul Hanis Azhan. "A CRITIC–TOPSIS multi-criteria decision-making approach for optimum site selection for solar PV farm." *Energies* 16, no. 10 (2023): 4245. https://doi.org/10.3390/en16104245

[2] Zubair, Muhammad, Ahmed Bilal Awan, R. P. Praveen, and Muhammad Abdulbaseer. "Solar energy export prospects of the Kingdom of Saudi Arabia." *Journal of Renewable and Sustainable Energy* 11, no. 4 (2019). https://doi.org/10.1063/1.5098016

[3] Orfanogiannaki, Katerina, and Dimitris Karlis. "Multivariate Poisson hidden Markov models with a case study of modelling seismicity." *Australian & New Zealand Journal of Statistics* 60, no. 3 (2018): 301-322.https://doi.org/10.1111/anzs.12242

[4] Sorooshian, Shahryar, and Javad Dodangeh. "A moderated practice for strategy implementation analysis." *American Journal of Applied Sciences* 10, no. 9 (2013): 1039. https://doi.org/10.3844/ajassp.2013.1039.1042

[5] Yi, Y. U. N. "Entropy method for determination of weight of evaluating indicators in fuzzy synthetic evaluation for water quality assessment." *Journal of Environmental sciences* 18, no. 5 (2006): 1020-1023.https://doi.org/10.1016/S1001-0742(06)60032-6

[6] Govindan, Kannan, and Martin Brandt Jepsen. "ELECTRE: A comprehensive literature review on methodologies and applications." *European Journal of Operational Research* 250, no. 1 (2016): 1-29. https://doi.org/10.1016/j.ejor.2015.07.019

[7] Hassan, Aakash, Yasir M. Al-Abdeli, Martin Masek, and Octavian Bass. "Optimal sizing and energy scheduling of grid-supplemented solar PV systems with battery storage: Sensitivity of reliability and financial constraints." *Energy* 238 (2022): 121780. https://doi.org/10.1016/j.energy.2021.121780

[8] Saracoglu, Burak Omer, Olayinka S. Ohunakin, Damola S. Adelekan, Jatinder Gill, Opemipo E. Atiba, Imhade P. Okokpujie, and Aderemi A. Atayero. "A framework for selecting the location of very large photovoltaic solar power plants on a global/supergrid." *Energy Reports* 4 (2018): 586-602. https://doi.org/10.1016/j.egyr.2018.09.002

[9] Zell, Erica, Sami Gasim, Stephen Wilcox, Suzan Katamoura, Thomas Stoffel, Husain Shibli, Jill Engel-Cox, and Madi Al Subie. "Assessment of solar radiation resources in Saudi Arabia." *Solar Energy* 119 (2015): 422-438. https://doi.org/10.1016/j.solener.2015.06.031

[10] Hwang, Ching-Lai, and Kwangsun Yoon. "Methods for multiple attribute decision making." In *Multiple attribute decision making: methods and applications a state-of-the-art survey*, pp. 58-191. Berlin, Heidelberg: Springer Berlin Heidelberg, 1981. https://doi.org/10.1007/978-3-642-48318-9

[11] Pang, Jihong, Genbao Zhang, and Guohua Chen. "ELECTRE I Decision Model of Reliability Design Scheme for Computer Numerical Control Machine." *J. Softw.* 6, no. 5 (2011): 894-900. https://doi.org/10.4304/jsw.6.5.894-900

[12] Effatpanah, Saeed Khojaste, Mohammad Hossein Ahmadi, Pasura Aungkulanon, Akbar Maleki, Milad Sadeghzadeh, Mohsen Sharifpur, and Lingen Chen. "Comparative analysis of five widely-used multi-criteria decision-making methods to evaluate clean energy technologies: A case study." *Sustainability* 14, no. 3 (2022): 1403.https://doi.org/10.3390/su14031403

[13] Saidin, Mohamad Shahiir, Lai Soon Lee, Siti Mahani Marjugi, Muhammad Zaini Ahmad, and Hsin-Vonn Seow. "Fuzzy method based on the removal effects of criteria (MEREC) for determining objective weights in multi-criteria decision-making problems." *Mathematics* 11, no. 6 (2023): 1544. https://doi.org/10.3390/math11061544

[14] Parida, Bhubaneswari, Selvarasan Iniyan, and Ranko Goic. "A review of solar photovoltaic technologies." *Renewable and sustainable energy reviews* 15, no. 3 (2011): 1625-1636. https://doi.org/10.1016/j.rser.2010.11.032

[15] Wang, Ying-Ming, and Taha MS Elhag. "Fuzzy TOPSIS method based on alpha level sets with an application to bridge risk assessment." *Expert systems with applications* 31, no. 2 (2006): 309-319. https://doi.org/10.1016/j.eswa.2005.09.040