Application of the PSI Method in Selecting Sustainable Energy Development Technologies

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ABSTRACT

The development of renewable energy is not only an urgent solution for addressing climate change but also a driving force for sustainable economic growth. The transition to clean, inexhaustible energy sources not only helps to reduce greenhouse gas emissions and protect the environment but also ensures national energy security, creates employment opportunities, and enhances the quality of life for individuals. Presently, various technologies exist for sustainable energy development, each characterized by multiple criteria, complicating the evaluation of their performance. This study presents a straightforward method for identifying the best option among eight sustainable energy development alternatives: hydropower, geothermal, biomass, wind, solar, concentrated solar power, coal technology, and oil-fired power plants, each of which is characterized by 17 distinct criteria. The simple method utilized is the Preference Selection Index (PSI) method, which eliminates the need for criteria weighting. This absence of criteria weight calculation in the PSI method distinguishes it from other ranking techniques that typically require such calculations. Therefore, the PSI method significantly simplifies the comparison of the available options compared to other ranking methods, as it bypasses the need for criteria weight calculations. The optimal option identified through the PSI method was also compared with the optimal option identified using 6 other methods: Multi Atributive Ideal Real Com parative Analysis (MAIRCA), Evaluation Based on Distance from Average Solution (EDAS), COmplex PRroportional ASsessment (COPRAPS), Multiobjective Optimization On the basis of Ratio Analysis (MOORA), Proximity Indexed Value (PIV), and Technique for Order Preference by Similarity to Ideal Solution (TOPSIS). Notably, all employed methods consistently identified geothermal energy as the optimal choice.

Keywords-sustainable energy development; energy policy; PSI method; MCDM

I. INTRODUCTION

Energy is a fundamental factor that drives social development. From industrial production to daily life, energy plays a crucial role in every aspect of life [1, 2]. However, the exploitation and use of traditional energy not only causes environmental pollution but also depletes natural resources. Therefore, the development of sustainable energy has become a top priority for ensuring sustainable socioeconomic development [3]. Currently, there are many options for generating sustainable energy, such as hydropower, geothermal, biomass, wind, and solar energy. Each option has its own advantages and disadvantages and requires a comprehensive assessment. This assessment needs to be based on various criteria, such as investment costs, operating costs, production efficiency, environmental impact, reliability, capacity, technology maturity, resource availability, load-following capability, land use area, emissions (CO_2, NO_x, SO_2, CH_4), and water consumption [4, 5]. This leads to the selection of the optimal solution among the energy development solutions, which is a complex process that requires a combination of technical, economic, and social factors. The diversity of criteria in each option makes the comparison of options a Multi Criteria Decision Making (MCDM) action [6, 7]. Some studies have applied MCDM methods to select the optimal option for developing energy sources, which can be summarized as follows:

To select the optimal option for the location of green energy projects, the Weighted Aggregates Sum Product ASsessment (WASPAS) method has been used to rank options and the Method based on the Removal Effects of Criteria (MEREC) has been used to weight criteria [8]. To select the optimal option for renewable energy projects in North Khorasan province (Iran), the options were ranked using the Vlsekriterijumska optimizacijaI KOmpromisno Resenje (VIKOR) method, and the entropy method was used to weight the criteria [9]. The VIKOR method has been used to select the optimal option for the location of solar power plants in Iran, and the weights of the criteria were calculated by integrating the Best Worst Method (BWM) and Grey Relational Analysis (GRA) methods [10]. In [11], the Analytic Hierarchy Process (AHP) method was used to select the best option among the four energy generation options, including wind, solar, photovoltaic, and biomass energy. In another study, the AHP method was used to select the optimal option from 64 locations for hydropower plant construction in the Ping River Basin (Thailand) [12]. In another study, the COmbined COmpromise

SOlution (COCOSO) method has been used to select the optimal option among solutions to overcome the challenges of developing an energy strategy in Libya [13]. In all the three studies, the weights of the criteria were determined using the AHP method. The selection of the best option for sustainable renewable energy development solutions for Malaysia was performed using two methods: the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Simple Additive Weighting (SAW), with the weights of the criteria assigned by the subjective opinion of the assessor [14]. To select the optimal option among five different electricity development options in Iran, the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) method has been used to compare the options, and the subjective opinion of the assessor has also been used to determine the weights of the criteria [15].

The above studies show that MCDM methods have been widely used in selecting the optimal option for energy development in various aspects. However, the MCDM methods used in these studies were required to calculate the weights for the criteria or the weights of the criteria were assigned based on the subjective opinion of the assessor. The choice of the method for calculating weights for the criteria is also a very complex decision because there are a large number of different weight calculation methods, and the chosen weight calculation method has a significant influence on the final decision on the option considered to be the best [16]. If subjective weighting methods, such as PIvot Pairwise RElative Criteria Importance Assessment (PIPRECIA) [17] or Rank Order Centroid (ROC) [18], are used, the weights of the criteria depend on the subjective opinions of the evaluator. Conversely, if objective weighting methods such as Entropy, Symmetry Point of Criterion (SPC) [19], or MEREC [20] are used, the weights of the criteria are calculated based only on numerical data, which may not accurately reflect the importance of the criteria [21]. This suggests that if a method is used to rank energy development options without calculating the weights for the criteria, the final decision on the best energy development option will not depend on the weighting method or on the subjective opinion of the ranker.

The Preference Selection Index (PSI) is a method for selecting the optimal option from available methods, while users do not need to calculate weights for the criteria, eliminating the complexity in the calculation process and subjectivity in calculating weights for the criteria. This method has proven successful in many different fields [22, 23]. Several studies have applied the PSI method in various fields, such as selecting 3D printers [24], scholarship recipients [25], materials [26], electric bicycles [27], transportation companies [28], and personnel for a company [29]. However, to date, no published document has reported the application of the PSI method for ranking energy development options. The simplicity and proven success of the PSI method in various fields, coupled with the gap in its non-application in energy development option ranking, justifies its use in this research.

Section II presents the steps involved in applying the PSI method. The application of the PSI method to rank energy development options is presented in Section III. In this section, the ranking results of the energy development options obtained using the PSI method are compared with those obtained using other methods. The conclusions of the study and directions for future research in Section IV constitute the final content of this paper.

II. PSI METHOD

The PSI method was applied in 6 steps to select the best option from many options [22].

Step 1: Construct a decision matrix consisting of m options and n criteria. Let y_{ij} be the value of criterion j at option i with $j = 1, ..., n$, and $i = 1, ..., m$.

Step 2: Normalize the data. According to [23], the PSI method is suitable for combining with four data normalization methods (N1, N2, N3, and N4). B and C are two letters corresponding to the type of criteria: the larger the better and the smaller the better. For energy development options, some criteria are of type B, such as reliability, capacity, and technology maturity, whereas others are of type C, including capital cost, fixed operation and maintenance costs, and variable operation and maintenance costs.

In (1)-(6), $\max(y_{ij})$ and $\min(y_{ij})$ represent the maximum and minimum values of criterion j across all alternatives, respectively. Let n_{ij} denote the normalized value of criterion j for alternative i.

Linear normalization (N1):

$$n_{ij} = \frac{y_{ij}}{\max(y_{ij})}, if\ j \in B \quad (1)$$

$$n_{ij} = \frac{\min(y_{ij})}{y_{ij}}, if\ j \in C \quad (2)$$

Max linear normalization (N2):

$$n_{ij} = \frac{y_{ij}}{\max(y_{ij})}, if\ j \in B \quad (3)$$

$$n_{ij} = 1 - \frac{y_{ij}}{max(y_{ij})}, if\ j \in C \quad (4)$$

Jüttler-Körth normalization (N3):

$$n_{ij} = 1 - \left|\frac{\max(y_{ij}) - y_{ij}}{\max(y_{ij})}\right|, if\ j \in B \quad (5)$$

$$n_{ij} = 1 - \left|\frac{\min(y_{ij}) - y_{ij}}{\max(y_{ij})}\right|, if\ j \in C \quad (6)$$

Z-score normalization (N4):

$$n_{ij} = \frac{y_{ij} - \frac{\sum_{i=1}^{m} y_{ij}}{m}}{\sqrt{\frac{\sum_{i=1}^{m}\left(y_{ij} - \frac{\sum_{i=1}^{m} y_{ij}}{m}\right)^2}{m}}}, if\ j \in B \quad (7)$$

$$n_{ij} = -\frac{y_{ij} - \frac{\sum_{i=1}^{m} y_{ij}}{m}}{\sqrt{\frac{\sum_{i=1}^{m}\left(y_{ij} - \frac{\sum_{i=1}^{m} y_{ij}}{m}\right)^2}{m}}}, if\ j \in C \quad (8)$$

Step 3: Let n_j be the average normalized value of criterion j, which is determined using (9):

$$n_j = \frac{1}{m}\sum_{i=1}^{m} n_{ij} \quad (9)$$

Step 4: Let $\varnothing_j$ denote the deviation in the priority of criterion j, which is calculated using (10):

$$\emptyset_j = 1 - \sum_{i=1}^{n}\left[n_{ij} - n\right]^2 \quad (10)$$

Step 5: Let β_j be the common priority value for criterion j, which is calculated using (11):

$$\beta_j = \frac{\emptyset_j}{\sum_{j=1}^{m}\emptyset_j} \quad (11)$$

Step 6: Let PSI_i be the priority index of option i, which is calculated using (12). The option with the highest PSI_i is the best option.

$$PSI_i = \sum_{j=1}^{n} n_{ij} \cdot \beta_j \quad (12)$$

III. SELECTING SUSTAINABLE ENERGY DEVELOPMENT TECHNOLOGIES

Table I summarizes the information of eight electricity generation technology options, including hydropower, geothermal energy, biomass energy, wind energy, solar energy, concentrated solar power, coal technology, and oil-fired power plants, denoted from A1 to A8, respectively. The data for these options were obtained from [30]. Seventeen criteria, including capital costs, fixed operation and maintenance costs, variable operation and maintenance costs, reliability, capacity, technology maturity, resource availability, load-following capability, land area, CO_2 emissions, NO_x emissions, SO_2 emissions, CH_4 emissions, water consumption, job creation, safety risks, and social acceptance were used to characterize each option, denoted as C1 to C17, respectively. Among them, C1, C2, C3, C9, C10, C11, C12, C13, C14, and C16 are type C criteria, and the remaining seven are type B criteria. Each criterion is briefly described as follows:

- Capital cost (C1): Total initial investment required to construct a power plant.
- Fixed operation and maintenance cost (C2): Periodic costs that do not vary with the amount of electricity generated, such as employee salaries and insurance.
- Variable operation and maintenance costs (C3): Costs that vary with the amount of electricity generated, such as fuel and consumable materials.
- Reliability (C4): The ability of a power plant to operate continuously and stably.
- Capacity (C5): Maximum amount of electricity that a plant can generate.
- Technological maturity (C6): Level of development and reliability of electricity generation technology.
- Resource availability (C7): The amount of natural resources (coal, gas, water, wind, etc.) available for electricity generation.
- Load-following capability (C8): The ability to adjust electricity generation to meet the demand.
- Land area (C9): The land area required to construct and operate a plant.
- CO_2 emissions (C10), NO_x emissions (C11), SO_2 emissions (C12), and CH_4 emissions (C13) are the amounts of pollutants emitted to the environment.
- Water consumption (C14): The amount of water used during the electricity generation process.
- Job creation (C15): Number of jobs created by the project.
- Safety risks (C16): Risks that may occur during construction and operation.
- Social acceptance (C17): Level of acceptance of the project by the local community.

The PSI method was used to select the best among the eight options listed in Table I. It should be noted that C13 and C14 are two type C criteria, but the value of C13 in options A1 and A5 and the value of C14 in option A4 are zero, therefore (2) cannot be used. Thus, in this case, the N1 normalization type cannot be used, but the data can only be normalized according to the N2, N3, and N4 types. Ranking of options was performed using the PSI method with three normalization types, N2, N3, and N4. First, apply to normalization type N2.

The normalized values were calculated by applying (3) and (4), and the normalized values are shown in Table II.

Applying formulas (9), (10), and (11) in sequence, the values of parameters n_j, $\varnothing_j$, and β_j were calculated and are summarized in Table III.

TABLE I. SOME SUSTAINABLE DEVELOPMENT TECHNOLOGIES

Opt.	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
	C	**C**	**C**	**B**	**B**	**B**	**B**	**B**	**C**	**C**	**C**	**C**	**C**	**C**	**B**	**C**	**B**
A1	2000	40	2	4	50	5	25	2	750	12	0.03	0.015	0	68	0.27	0.945	68
A2	880	12	0	2	27	4	23000	-1	35	49.174	0.178	0.257	0	1	0.87	0.000245	94
A3	8000	77	0	2	52	3	15400	1	40	16	0.065	0.04	0	3.02	0.23	0.000245	94
A4	1250	34	0	4	45	5	1800	-1	100	25	0.06	0.05	0	0	0.17	0.00189	69
A5	5200	13.5	17	5	85	4	87.6	1	18	18.913	0.28	0.02	0	150	0.25	0.00174	56
A6	2800	50	10	4	82.5	4	3.61	0	5000	70	0.9	0.5	40	135	0.21	0.0149	56
A7	800	16	3.5	4	70	3	162.82	0	2.5	800	2	3.5	5.5	78	0.11	1.08	32
A8	600	10	10	4	55	5	65.09	2	2.5	700	1	4.5	8	78	0.11	1.69	30

TABLE II. NORMALIZED VALUES ACCORDING TO N2

Opt	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
A1	0.7500	0.4805	0.8824	0.8000	0.5882	1.0000	0.0011	1.0000	0.8500	0.9850	0.9850	0.9967	1.0000	0.5467	0.3103	0.4408	0.7234
A2	0.8900	0.8442	1.0000	0.4000	0.3176	0.8000	1.0000	-0.5000	0.9930	0.9385	0.9110	0.9429	1.0000	0.9933	1.0000	0.9999	1.0000
A3	0.0000	0.0000	1.0000	0.4000	0.6118	0.6000	0.6696	0.5000	0.9920	0.9800	0.9675	0.9911	1.0000	0.9799	0.2644	0.9999	1.0000
A4	0.8438	0.5584	1.0000	0.8000	0.5294	1.0000	0.0783	-0.5000	0.9800	0.9688	0.9700	0.9889	1.0000	1.0000	0.1954	0.9989	0.7340
A5	0.3500	0.8247	0.0000	1.0000	1.0000	0.8000	0.0038	0.5000	0.9964	0.9764	0.8600	0.9956	1.0000	0.0000	0.2874	0.9990	0.5957
A6	0.6500	0.3506	0.4118	0.8000	0.9706	0.8000	0.0002	0.0000	0.0000	0.9125	0.5500	0.8889	0.0000	0.1000	0.2414	0.9912	0.5957
A7	0.9000	0.7922	0.7941	0.8000	0.8235	0.6000	0.0071	0.0000	0.9995	0.0000	0.0000	0.2222	0.8625	0.4800	0.1264	0.3609	0.3404
A8	0.9250	0.8701	0.4118	0.8000	0.6471	1.0000	0.0028	1.0000	0.9995	0.1250	0.5000	0.0000	0.8000	0.4800	0.1264	0.0000	0.3191

TABLE III. SOME PARAMETERS IN PSI

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17
n_j	0.6636	0.5901	0.6875	0.725	0.686	0.825	0.2203	0.25	0.8513	0.7358	0.7179	0.7533	0.8328	0.5725	0.319	0.7238	0.6636
$\varnothing_j$	0.7543	0.6574	0.967	0.315	0.3753	0.195	1.0661	2.5	0.8461	1.2207	0.8457	1.1338	0.8353	1.0946	0.5633	1.1109	0.4672
β_j	0.1197	0.1669	0.0161	0.3338	0.3044	0.3922	-0.032	-0.731	0.075	-0.108	0.0752	-0.065	0.0803	-0.046	0.2128	-0.054	0.2596

Applying (12), the PSI index for each option was calculated and is summarized in Table IV. The ranking of the options is summarized in the last column of this table.

TABLE IV. PSI INDEX AND RANKING OF OPTIONS

Opt.	PSI	Rank
A1	0.4582	7
A2	1.4827	1
A3	0.5280	6
A4	1.4676	2
A5	0.9745	4
A6	1.1011	3
A7	0.9356	5
A8	0.4538	8

Thus, the ranking of the options using the PSI method when normalizing the data using the N2 method was completed. Similarly, when normalization was performed using the N3 and N4 methods, the results are summarized in Table V.

TABLE V. RANKING OF METHODS USING THE PSI METHOD WITH DIFFERENT DATA NORMALIZATION METHODS

Opt.	Normalization style		
	N2	N3	N4
A1	7	7	2
A2	1	1	1
A3	6	6	5
A4	2	2	3
A5	4	4	4
A6	3	3	8
A7	5	5	7
A8	8	8	6

It is easy to see that when using the PSI method to rank the options, the ranking of the options is consistent when using the two normalization types N2 and N3. In addition, when using three different normalization types, N2, N3, and N4, the PSI method consistently confirms that A2 is the best option. This shows that the application of the PSI method was completed to find the best option. However, to further consolidate this finding, the results of the PSI method were compared with those of other methods.

In [30], the weights of 17 criteria from C1 to C17 were calculated using the CRITIC (CRiteria Importance Through Inter-criteria Correlation) method with corresponding values of 0.062, 0.058, 0.053, 0.065, 0.069, 0.061, 0.075, 0.072, 0.059, 0.056, 0.054, 0.043, 0.053, 0.052, 0.066, 0.055, 0.047. In [30], the ranking of options was also performed using three methods: MAIRCA, EDAS, and COPRAS. In this study, three more methods were also used to rank the options, including MOORA, PIV, and TOPSIS. These three methods have been used extensively in recently published studies [31, 32]. The ranking results of the options using the PSI method (with three different normalization types N2, N3, N4), denoted as PSI & N2, PSI & N3, PSI & N4, and using the six methods MAIRCA, EDAS, COPRAS, MOORA, PIV, and TOPSIS, with the weights of the criteria calculated by the CRITIC method, are illustrated in Figure 1.

According to the results in Figure 1, it shows that:

The ranking of the options is not completely the same when ranked by different methods, which is normal and has been stated in recently published documents [33].

When using the PSI method, A2 was found to be the best option among the eight available alternatives. Notably, A2 was also the best option when other methods were used, including MAIRCA, EDAS, COPRAS, MOORA, PIV, and TOPSIS. This result shows that using the PSI method to identify the best solution is correct in this case. In addition, the ranking of the options ranked by the PSI method also has a high level of stability, which is typical when using two data normalization methods N2 and N3, and the ranking of the options is completely consistent. These results indicate that using the PSI method to select the best option for electricity development was considered successful in this study. The PSI method is used to select the best energy development option without assigning weights to criteria while still ensuring consistency with other methods (MAIRCA, EDAS, COPRAS, MOORA, PIV, and TOPSIS), which requires the calculation of criterion weights, highlighting the PSI method's advantage in this case.

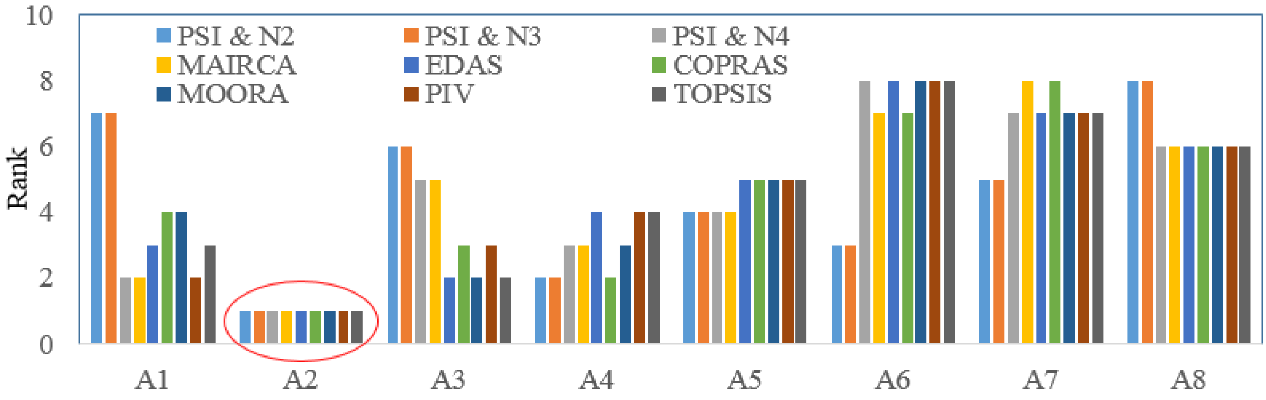

Fig. 1. Ranking of options using different methods.

IV. CONCLUSIONS

The application of the Preference Selection Index (PSI) method for selecting sustainable energy development options showed that among the eight options, including hydropower, geothermal energy, biomass energy, wind energy, solar energy, concentrated solar power, coal technology, and oil-fired power plants, geothermal energy is considered to have the highest performance. The sustainable energy development option considered to be the best when using the PSI method (with three data normalization methods, N2, N3, and N4) is consistent with the results from the MAIRCA, EDAS, COPRAPS, MOORA, PIV, and TOPSIS methods. Accordingly, the best sustainable energy development option was found with the following criteria indices: capital cost (C1) of 880, fixed operation and maintenance costs (C2) of 12, variable operation and maintenance costs (C3) of 0, reliability (C4) of 2, capacity (C5) of 27, technological maturity (C6) of 4, resource availability (C7) of 23000, load-following capability (C8) of -1, land area (C9) of 35, CO_2 emissions (C10) of 49.174, NOx emissions (C11) of 0.178, SO_2 emissions (C12) of 0.257, CH_4 emissions (C13) of 0, water consumption (C14) of 1, job creation (C15) of 0.87, safety risk (C16) of 0.000245, and social acceptance (C17) of 94.

The PSI method successfully identified the best option as the other methods but eliminated the need to calculate weights for the criteria. This implies that the PSI method should be used if one does not want to spend a lot of time and effort in choosing the method for calculating weights for the criteria and to eliminate the influence of the subjective opinion of the assessor on the final result. The application of the PSI method to evaluate the performance and lifespan of equipment when using energy from various sustainable energy development options is a task that needs to be implemented in the near future to further improve the comparison of sustainable energy development options.

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