Green energy sources selection for sustainable energy planning using multi-criteria decision-making approach

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Abstract. The objective of this research is to select the optimum green energy sources (GES) for sustainable energy planning from a given set of alternatives. This study proposes a hybrid model based on SWOT (Strength, Weakness, Opportunities, and Threats) and an integrated Entropy-Technique for Order of preference by Similarity to Ideal solution (TOPSIS) method for optimal GES. SWOT analysis is used to characterize the corresponding criterion of GES alternative. The information collected from the various energy sources related to different criteria for assessing the best alternative is always imprecise in nature. Thus, to reduce the impreciseness in data, entropy method is used, which extracts the precise weight from the available information. Again, TOPSIS method is applied to appraise the relative closeness to the ideal solution. The result shows that solar-photovoltaic is the most suitable sustainable GES, having highest score value evaluated by the integrated methodology. Thereafter, energy satisfaction index shows the effectiveness and robustness of the proposed integrated methodology.

Keywords. Green Energy Sources; SWOT analysis; Entropy Method; TOPSIS; Energy Satisfaction Index; Sustainable planning.

1. Introduction
Harnessing green sources of energy for sustainable revolutionizing of future are becoming more crucial in context with environmental and social issues. Therefore, there is a need to exploit the green energy sources (GES) as a part of clean energy generation for sustainable future. Further, sustainable development identifies resource efficiency for adopting green innovations. The optimal GES selection for sustainable development becomes a strenuous procedure because the energy managers have to make a choice between abundant alternatives. Maintaining harmony between GES in an energy market is also a big challenge. Optimal utilization of green energy alternative helps in multiple ways like reducing greenhouse gas emission, air pollutants and harnessing abundant resources. The research community is involved in utilizing an evaluation model for the selection of optimal GES. Multi-criteria decision-making (MCDM) methods can be used for optimal GES selection to attain sustainable development [1]. At the selection level, identification of optimum GES with conflicting criteria is quite difficult to define. An assessment may cover various areas whose boundaries may not be easily identifiable with their demands [2]. Therefore, the need for integration of green technology with multi-
criteria approaches is obvious for optimal GES selection. Different energy carriers are facing the problem of technological advancements for their sustainability to achieve optimum primary energy source from the best energy mix [3] by various techniques. Some of them are delineated in Table 1.

| Author(s)          | Year | Technique | Summary of the paper | Criteria                                      | Area            |
|--------------------|------|-----------|-----------------------|-----------------------------------------------|-----------------|
| Doukas and Psarras [4] | 2009 | TOPSIS    | Assessed renewable energy development | Impact on environment, investment cost, energy sufficiency. | Renewable energy |
| Heo et al. [5]      | 2010 | FAHP      | Assessment of renewable energy factors. | Technological, market, economic and environment. | Renewable energy |
| San Cristóbal [6]   | 2011 | VIKOR     | Assessed renewable energy projects. | Power, implementation period, O & M cost, CO₂ avoided. | Renewable energy |
| Pons and Aguado [7] | 2012 | AHP       | Sustainability assessment in school buildings. | Cost, time, transport, maintenance and safety. | Sustainable energy |
| Perera et al. [8]   | 2013 | FTOPSIS   | Assessment of standalone hybrid energy systems | LEC, unmet fraction, fuel, ICG capacity and battery banks. | Sustainable energy |
| Cannemi et al. [9]  | 2014 | ANP       | Selection of biomass power plants. | Global effect, local effects, social development, logistics. | Renewable energy |
| Chang [10]          | 2015 | McGP      | Selection the best location for facilities of renewable energy | Power generated, investment cost, jobs created, social acceptance | Renewable energy |
| Sola and Vitetta [11] | 2016 | Game theory | Demand-side energy management | Global effect, cost, logistics. | Micro grid |
| Lui et al. [12]     | 2017 | AHP       | To minimize the air pollution. | Local effects, social development, Cost, time. | Renewable energy |

In view of the current situation, GES selection can have a daunting pressure in the human life cycle for attaining sustainability. Many authors have used MCDM techniques to conform to an optimum decision. As per the author’s best knowledge, there is a lack of literature available on the use of combined Entropy and TOPSIS for the selection of optimum GES [13]. The objective of the present study is to select the optimum GES for sustainable energy planning. Entropy method is used to extract the precise weight from the available information whereas; TOPSIS is used to rank those sourcing alternatives according to their merit. Furthermore, sensitivity analysis is carried out for energy satisfaction index (ESI) to evaluate the robustness of the proposed methodology.

2. Materials and Methods

In this research, the major energy sources selected are large hydro (LH), small hydro (SH), wind (W), solar-photovoltaic (SP), concentrating solar (CS), geothermal (Geoth) and biomass (Biom). The various attributes considered are annual generation (AG), capacity factor (CF), mitigation potential...
(MP), CO₂ emission (CE) and generating cost (GC). SWOT (Strength, Weakness, Opportunities, Threats) analysis has been deployed for selecting the attributes as depicted in ‘Figure 1.’ Such complex problems regarding energy source selection with multiple alternatives and conflicting attributes are well suited to the application of MCDM [14]. In this work, a simple and well-known MCDM technique TOPSIS is employed, which determines optimal alternative from a finite set on the basis of maximizing the distance from the negative ideal point and minimizing the distance from the positive ideal point [15]. For any kind of MCDM problem, determination of attribute weights plays a crucial role on the final selection. Entropy is a decision support tool [16] which evaluates the weights for an MCDM problem where performance and decision maker’s (DMs) experiments fail to provide proper weightage to the attributes [17]. The entropy method is a mature easy-to-use method and widely used because of its agility (human intervention is not required) and practicality. However, the entropy method does not take the coupling effect among indicators into consideration. The degree of discreteness of an indicator can be determined by calculating the entropy of the indicator. Discreteness is important because the greater the degree of discreteness is, the greater the influence of the indicator on the comprehensive evaluation.

![Figure 1. SWOT analysis.](image)

3. Observation and findings
In this paper, an integrated entropy-TOPSIS methodology [13] is applied to evaluate and select the optimum GES for sustainable energy planning by considering multiple criterions. Research also investigate that; the proposed methodology can be implemented in real life problems. To meet the advanced contribution towards real life application, data has been collected from the published literature [18]. This section describes the outcome of the proposed integrated methodology.

Step 1: Development of hierarchy model; After identifying all the alternatives and their respective attributes, a decision model is created, which represents the bottoms up approach as delineated in ‘Figure 2.’ The problem is constructed into a rational system like attributes and alternatives as per their interdependencies.
Step 2: Construction of a decision matrix; The modified decision matrix is constructed considering seven alternatives and five attributes as depicted in table 1. The mentioned decision matrix data are then normalized. Normalization is required to neutralize the irregularities of different measurement units associated with various variables in a decision matrix into a compatible unit. After normalization \( m_{ij} \) of data, entropy value \( b_j \) and degree of divergence \( l_j \) is calculated using the equation (1) and (2) respectively. Each divergence value is divided by its row sum i.e. using equation (3) to evaluate the corresponding entropy weight of the attribute as shown in table 2.

\[
b_j = -c \sum_{i=1}^{n} m_{ij} \ln m_{ij}
\]

\[
l_j = 1 - b_j
\]

\[
w_j = \frac{l_j}{\sum_{j=1}^{f} l_j}
\]

Step 3: Normalization by TOPSIS; The results in the decision matrix (table 2) are then normalized using TOPSIS method to obtain normalized decision matrix.

Step 4: Weighted normalized matrix; After normalizing the decision matrix, the weighted normalized matrix is computed by multiplying the entropy weights (table 3) of each attribute to each element of the normalized decision matrix as shown in table 4.
Step 5: Performance measurement; For every attribute, best performance and worst performance is computed by taking the maximum and minimum value.

Step 6: Distance measurement: As TOPSIS is a distance based approach, therefore for all attributes distance from the positive ideal solution (PIS) and negative ideal solution (NIS) is computed using equation (4) and (5) respectively and tabulated in table 5.

\[ G_i^+ = \frac{\sum_{j=1}^{f} (h_{ij} + A^+)^2}{\sum_{j=1}^{f} (h_{ij} + A^+)^2} \quad (1 \leq i \leq f, 1 \leq j \leq e) \]  

\[ G_i^- = \frac{\sum_{j=1}^{f} (h_{ij} - A^-)^2}{\sum_{j=1}^{f} (h_{ij} - A^-)^2} \quad (1 \leq i \leq f, 1 \leq j \leq e) \]  

| Alternatives | LH   | SH   | W    | SP   | CS   | Geoth | Biom  |
|--------------|------|------|------|------|------|-------|-------|
| PIS value    | 0.1460 | 0.4693 | 0.4221 | 0.4986 | 0.5012 | 0.4927 | 0.4709 |
| NIS value    | 0.4644 | 0.0635 | 0.2127 | 0.0738 | 0.0337 | 0.0509 | 0.0596 |

Step 7: Determination of closeness measurement; For every alternative, relative closeness is computed by dividing NIS value by the sum of the distance to the PIS and NIS value. \( C_i \) is determined using equation (6). \( C_i \) exhibits the similarity to the positive ideal solution. According to the magnitude of \( C_i \), alternatives are arranged. The biggest \( C_i \) value is selected as the optimum alternative and the results of relative closeness have been depicted in table 6.

\[ C_i = \frac{G_i^-}{(G_i^+ + G_i^-)} \quad (1 \leq i \leq m) \]  

| Alternatives | LH   | SH   | W    | SP   | CS   | Geoth | Biom  |
|--------------|------|------|------|------|------|-------|-------|
| \( C_i \) value | 0.7608 | 0.1192 | 0.3351 | 0.1289 | 0.0630 | 0.0937 | 0.1124 |
| Rank         | 1    | 4    | 2    | 3    | 7    | 6     | 5     |

Finally, the magnitude of all the alternatives is tabulated in Table 6 and ranked according to the closeness to the ideal solution, wherein the alternative with the highest value is said to be optimum (large hydro). The methodology undertaken in this study is user-friendly and timesaving, as the process requires only Microsoft Office to analyse the results. Therefore, it can serve as an effective decision-making tool for the energy managers, policy makers and, end users.

4. Energy satisfaction index

Energy satisfaction index (ESI) is a truthful way of showing the uncertainties by varying the attitude of the decision maker ‘\( k \)’ and presenting the subsequent effects on the alternatives. If the weight assigned for the subjective factor is \( 0 < k < 1 \) then its corresponding objective factor is assigned a weight of \( (1 - k) \). Thus, ESI value for an alternative ‘\( i \)’ is computed by combining all the criterion factors with their significance weightings found from integrated entropy-TOPSIS methodology as per the equation (7) and (8) [19].

\[ ESI_i = [OFM_i + k(SFM_i - OFM_i)] \]  

\[ OFM_i = 1/[OFD_i \sum_{j=1}^{n} OFD_j^{-1}] \]  

where, \( OFM \) is the objective factor measure, \( OFD \) is the objective factor dimension, \( SFM \) is the subjective factor measure and \( ESI \) is the energy satisfaction index. ‘\( k \)’ is the attitude of the decision maker objective factor weight and ‘\( n \)’ is the number of energy alternatives (\( n = 7 \) in the present case).
The SFM values, i.e. global priorities for each energy alternatives are found from the integrated entropy-TOPSIS method as depicted in table 6. The choice of \( k \) is a tedious task. The value of ‘\( k \)’ depends on attitude of the decision maker and preference regarding the significance of objective and subjective factor measures.

![Figure 3. ESI with respect to GC.](image)

Thus, an ESI plot is strongly recommended to explore the effect of ‘\( k \)’ in the GES selection problem. From the ESI analysis of selection priority of GES framework, large hydro evolved as the optimum energy source. As soon as one of the optimum source of energy is exhausted, then the other sources can be utilized depending upon the availability and corresponding local factors. Therefore, to validate the ranking order suggested by an integrated entropy-TOPSIS methodology a MATLAB code is generated for equations (7) and (8). Thus, the priority results for GES in (table 6) is used to select the optimum alternative with respect to GC while remaining criterion remains constant. The graphical representation of ‘Figure 3’ is based on the relative performances of alternatives with respect to generating cost (GC) criteria. As GC plays a vital role from the economical aspect, ESI helps to justify the priorities of alternatives and allowing \( k = 0.2026 \) for the energy sources alternatives ranked as LH > W > SP > SH > Biom > Geoth > CS which is similar to ranking found in table 6. This study followed the analogy “higher the better” for the calculation of ESI.

5. Conclusion

Facing energy challenges in an energy dilemma, it is essential to select the best energy source for its sustainable development. In view of the demanding aspect the GES selection the capacity of the recommended entropy-TOPSIS methodology has been validated using various GES alternatives. Firstly, the recommended procedure is an MCDM that permits numerous stakeholders to diagnose distinctive sort of precedent and generate intuition on each of them. Secondly, the proposed integrated methodology facilitates the scrutiny using entropy-TOPSIS to straighten out the dilemma of failure of
intelligence that transpires while integrating estimated advices. Thirdly, this technique empowers significantly in the selection of optimum GES for cleaner production. Finally, computing the ESI, the posture of the DM has a high competence to incorporate both of the qualitative and quantitative data for ranking the convenient energy sources. The proposed GES selection framework improves the reliability of the decision acknowledging relevant construct for promising sustainable development to some extent [20]. The current research shows the large hydro to be the optimum GES. Therefore, this research can positively chair the researchers and energy managers in solving the sustainable energy planning dilemma adequately. This research work only deals with the tangible behaviour of the GES. The tangible output is extracted from the vagueness of information associated with the green energy parameters. The proposed methodology also takes care of the unpredictability of the instantaneous output of the GES. Again, there is a scope of future research in the areas of the intangible behaviour of the green energy parameters and their unpredictability towards the output of the GES.

References
[1] Mardani A, Ahmad J, Zavadskas E.K, Cavallaro F and Khalifah Z 2015 Sustainable and renewable energy: An overview of the application of multiple criteria decision making techniques and approaches Sustainability 7 (10) 13947-13984.
[2] Kumar M and Samuel C 2017 Selection of Best Renewable Energy Source by Using VIKOR Method. Tech. Econ. Smart Grids Sust. Energ. 2(1),8.
[3] Ludwig B. On the Optimum Sustainable Energy Mix. No. 1999-01-2708. SAE Technical Paper, 1999.
[4] Doukas H and Psarras J 2009 A linguistic decision support model towards the promotion of renewable energy. Energ. Sour. Part B 4(2),166-178.
[5] Heo E, Jinsoo K and Kyung-Jin B 2010 Analysis of the assessment factors for renewable energy dissemination program evaluation using fuzzy AHP. Renew. Sust. Energ. Rev. 14(8),2214-2220.
[6] San Cristóbal J R 2011 Multi-criteria decision-making in the selection of a renewable energy project in Spain: The VIKOR method. Renew. Energ. 36(2),498-502.
[7] Pons O and Antonio A 2012 Integrated value model for sustainable assessment applied to technologies used to build schools in Catalonia, Spain. Build. Environ. 53, 49-58.
[8] Perera A T D, Attalage R A, Perera K K C K and Dassanayake V P C 2013. A hybrid tool to combine multi-objective optimization and multi-criterion decision making in designing standalone hybrid energy systems. Appl. Energ. 107,412-425.
[9] Cannemi M, García-Melón M, Aragonés-Beltrán P and Gómez-Navarro T 2014. Modeling decision making as a support tool for policy making on renewable energy development. Energ. Policy 67,127-137.
[10] Chang C T 2015. Multi-choice goal programming model for the optimal location of renewable energy facilities. Renew. Sust. Energ. Rev.41,379-389.
[11] Sola M and Vitetta G M 2016. A Bayesian Demand-Side management strategy for smart Micro-Grid. Tech. Econ. Smart Grids Sust. Energ. 1(1), pp.1-15.
[12] Liu Y, He L and Shen J 2017. Optimization-based provincial hybrid renewable and non-renewable energy planning–A case study of Shanxi, China. Energy, 128,839-856.
[13] Bhowmik C, Bhowmik S, Ray A and Pandey K M 2017. Optimal green energy planning for sustainable development: A review. Renew. Sust. Energ. Rev.71,796-813.
[14] Büyüközkan G and Güleryüz S 2017 Evaluation of Renewable Energy Resources in Turkey using an integrated MCDM approach with linguistic interval fuzzy preference relations. Energy, 123,149-163.
[15] Datta A, Saha D, Ray A and Das P 2014 Anti-islanding selection for grid-connected solar photovoltaic system applications: A MCDM based distance approach. Sol. Energ.110, 519-532.
[16] Lotfi F H and Fallahnejad R 2010 Imprecise Shannon’s entropy and multi attribute decision
making. Entropy,12(1),53-62.

[17] Zhang L, Xu Y, Yeh C H, Liu Y and Zhou D 2016. City sustainability evaluation using multi-criteria decision making with objective weights of interdependent criteria. J. Cleaner Prod. 31,491-499.

[18] Lenzen M 2010 Current state of development of electricity-generating technologies: A literature review. Energies,3(3),462-591.

[19] Bhattacharya A, Sarkar B and Mukherjee S K 2005 Integrating AHP with QFD for robot selection under requirement perspective. Int. J. Prod. Res.43(17),3671-3685.

[20] Yazdani M, Chatterjee P, Zavadskas E K and Zolfani S H 2017 Integrated QFD-MCDM framework for green supplier selection. J. Cleaner Prod.142,3728-3740.