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Single-Valued Neutrosophic SWARA-TOPSIS-Based Group Decision-Making for Prioritizing Renewable Energy Systems

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ABSTRACT

In this paper, new outcomes on the evaluation of sustainability factors for Renewable Energy Sources (RESs) under Single Valued Neutrosophic Sets (SVNSs). Multiple Criteria Decision-Making (MCDM) model and the SVN-Stepwise Weight Assessment Ratio Analysis (SWARA) with SVN-Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) termed as 'SVN-SWARA-TOPSIS' are applied to solve the RESs selection problem. Five sustainability indicators RSTEE (resource, social, technology, environmental and economic) and twelve criteria are considered for RESs selection. In the proposed SVN-SWARA-TOPSIS method, three decision experts are selected for assessing the sustainability factors to the evaluation of RESs. In the developed framework, weight of the assessment of sustainability criteria are estimated by SVN-SWARA approach and preference order of RES options is determined by SVN-TOPSIS method on SVNSs setting. Finally, comparative and sensitivity assessments are discussed to analyse the validity of obtained result.

1. Introduction

As an important aspect for social life, energy has crucial place in economic development of nations [1]. Most of the production and consumption activities comprise energy as a basic input. In developing countries, the demand for energy will rise immensely as per capita incomes and populations grow [2]. Energy-based devices that depend on non-renewable fossil fuels cause substantial environmental issues. In order to deal the concerns, it is significant to better finding of renewable energy resources/sources (RERs/RESs), which are affordable, clean and sustainable [3]. Derived from natural sources, the RESs contribute to disaster risk reduction and climate change mitigation [4]. Though, traditional energy resources are no longer sustainable because of accelerating the climate change. To solve the global treat, energy production and consumption should fulfill the global 2030 agenda of sustainable development goals (SDGs) with appropriate manipulation of diverse RERs [5].

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RERSs are naturally replenished energy sources which can assist more than comprehensive demand of energy if they are proficiently exploited. Each RES has its own advantages and disadvantages. To meet the concept of SDGs, there is an immediate need to move towards the RERs in preference to depend on fossil-based energy [6,7]. With the use of decision support framework, Mishra et al. [8] evaluated and prioritized the renewable energy resources (RERs) considering the multiple sustainability indicators. Sitorus and Brito-Parada [9] presented a new decision system to choose appropriate RER for a particular region, which determines objective weight of criteria and subjective preference of criteria during RER selection problem. To evaluate the RERs for sustainable development, Alkan et al. [10] studied a combined methodology by employing CRITIC, SWARA and CODAS approaches with interval-valued picture fuzzy information. Their results demonstrated that the developed approach was valuable to evaluating and selecting RESs. Ghenai et al. [1] gave an approach with SWARA and ARAS models to select and evaluate different RESs. The findings established that land-based wind energy was the optimal one among other RESs. For satisfying the SDGs, Seikh & Chatterjee [4] assessed the RER alternatives by extending the confidence level-based ARAS model from interval-valued Fermatean fuzzy perspective and incorporated with SWARA weighting model. The estimated outcomes concluded that developed approach is more capable for the assessment of RER alternatives. Jameel et al. [11] studied a collective entropy-SWARA-CoCoSo model with circular intuitionistic fuzzy information for evaluating RER options in the context of industry 4.0.

To tackle uncertain setting, Zadeh [12] introduced an idea of fuzzy set (FS) that has been widely employed to describe the uncertainty of realistic problems. with membership function (MF), therefore, it has been broadly implemented in various disciplines. As a generalization of FS, the concept of intuitionistic FS (IFS) has been initiated by Atanassov [13], which is depicted by MF, non-membership function (NMF) and indeterminacy function (IF). Since its origin, many theories and applications have been presented using IFS theory [14,15]. Though, there may be a situation wherein some experts evaluate profits of stock, first expert shows possibility of profit will be 0.7, second expert defines possibility of loss will be 0.4, the third panel is not sure whether the stock that will be profitable is 0.3. At this time, it can be effortlessly found that $0.6 + 0.3 + 0.4 > 1$, and therefore, the IFSs do not treat such circumstances. The SVNS doctrine comprises all significant features of decision-making with imperfect, indeterminate and inconsistent data, including “truth membership (TM)”, “indeterminacy membership (IM)” and “falsity membership (FM)” [16]. The SVNS theory has been employed to portray the uncertain decision information arises in real-life problems [17,18]. Meng et al. [19] considered a collective tool by integrating the geographic information system and the SVNS theory. Moreover, they applied their model to evaluate and select proper site for the waste-to-energy plant establishment. To merge the SVN numbers (SVNNs) into a single SVNN, Farid & Riaz [20] developed some dynamic aggregation operators and their characteristics. Additionally, they presented novel multi-criteria paradigm for IoT solution selection under the context of SVNSs. With the use of SVN information, Fetanat and Tayebi [21] proposed a decision support tool to evaluate and prioritize the hydrogen technologies by means of multiple criteria. They evaluated the criteria weights via CRITIC model and further ranked the hydrogen technologies using CRADIS tool. Mishra et al. [22] proposed novel SVN-score function and SVNDM-based method for evaluating the energy storage methods. Önden et al. [23] assessed the performance of artificial intelligence and virtual reality-based strategies through a novel SVN-Dombi Bonferroni-integrated approach. Wang [24] proposed a MCDM method using new score function and standard deviation. In addition, their method is used to solve software engineer recruitment and investment selection problems, wherein the information about criteria and alternatives is given in terms of SVNSs.

In 2010, Kersuliene et al. [25] introduced an idea of "Step-wise Weight Assessment Ratio Analysis (SWARA)" model, which estimates weight of criteria by considering decision-experts' (DEs') opinions. It has less computational complexity and pairwise comparisons [26,27]. Büyükselçuk and Badem [28] presented a hybrid neutrosophic SWARA-VIKOR method for assessing the suitable players for Turkish football team. For instance, Agarwal et al. [29] discussed a SWARA-WASPAS method to assess problems of "humanitarian supply chain management (HSCM)" and find the solutions for evading HSCM issues. Naz et al. [30] presented a framework with SWARA and MABAC approaches on 2-tuple linguistic q-rung orthopair FSs and implemented for dealing with decision-making concerns. Bouraima et al. [31] applied SWARA-CoCoSo method on interval rough sets called as IR-SWARA-CoCoSo tool for evaluating assessing the option railway systems with sustainability perspective. Debnath et al. [32] discussed SWARA-WASPAS tool for assessing suppliers in healthcare testing service. To support the SDGSs, Derse [33] evaluated and prioritized green reverse logistics barriers using integrated DEMATEL-FUCOM-SWARA model. Alrasheedi et al. [34] presented multiple criteria group decision making (MCGDM) tool on IFSs and applied to select appropriate RES over diverse pillars of sustainability perspectives.

The TOPSIS has been recognized as a broadly acknowledged MCGDM approach due to its simultaneous issues associated to the ideal and anti-ideal ratings, and simply computational procedure. In fuzzy TOPSIS (F-TOPSIS), linguistic assessment ratings are easily changed to triangular fuzzy numbers (TFNs) which are implemented to deal the MCGDM problems [35]. Recently, conventional TOPSIS approach has been generalized on diverse uncertain settings. Mishra et al. [36] developed IF-weighted information measure-based TOPSIS model for dealing investment policy selection problem. Khan et al. [37] developed a hybrid tool with TOPSIS and maximization deviation approach on Pythagorean hesitant fuzzy setting. Rani, et al. [38] developed a similarity measure-based PF-TOPSIS model for handling sustainable recycling partner assessment problem on PFSs setting. Kumari et al. [14] gave Shapley function-based TOPSIS approach to tackle MCGDM problem on IFSs and implemented to deal with cloud service selection problem. Saeidi et al. [39] studied sustainable HRM in manufacturing firms with hybrid Pythagorean fuzzy SWARA-TOPSIS method. Chakraborty [40] provided wide-ranging simulation-based comparative and mathematical assessment of TOPSIS and improved TOPSIS approaches to elucidate the misperception regarding their selection for dealing different MCGDM problems. Pandey et al. [41] reviewed diverse forms of MCGDM problems that are analyzed with F-TOPSIS approach and its diverse disciplines.

This study purposes to assess and rank the RERs by means of several sustainability indicators. In this regard, we develop an MCGDM ranking approach using the combination of SWARA, TOPSIS and SVNSs. This study first identifies the sustainability indicators and RER alternatives through comprehensive literature review and DEs' discussions. Next, a panel of DEs is created to provide the significance degree of each RER option over diverse criteria/indicators. Furthermore, the developed framework is implemented to obtain the preference orders of RER alternatives. This method first computes the DEs' significance values using SVN information. Then weight of criteria is estimated through SWARA model, while the RER options are prioritized based on defined criteria using SVN-SWARA-TOPSIS model.

The organization of manuscript is given as follows: Section 2 discusses elementary notions associated to SVNSs. Section 3 develops a combined single-valued neutrosophic SWARA-TOPSIS approach based on similarity measure under SVNSs setting. Section 4 applies developed approach to a case study of RERs assessment with various sustainability indicators, which proves its sensibleness and practicality. Section 5 gives comparative and sensitive discussions in the developed framework. Section 6 concludes the work.

2. Preliminaries

The current section confers the basis concepts of the paper.

Definition 1 [16]. A SVNS *E* on a fixed universe of discourse $Y=\{\iota_1,\iota_2,...,\iota_q\}$ is given by

$$E=\{(\iota_i,(\varsigma_E(\iota_i),\gamma_E(\iota_i),\delta_E(\iota_i)))|\iota_i\in Y\},\tag{1}$$

where $\varsigma_E:Y\to[0,1]$, $\gamma_E:Y\to[0,1]$ and $\delta_E:Y\to[0,1]$ signify TM, IM and FM degrees of an element ι_i in *E*, respectively with $0\le\varsigma_E+\gamma_E+\delta_E\le1.$ The family of all SVNSs is symbolized as $SVNSs(Y)$. A "*single-valued neutrosophic number/value (SVNN/SVNV)*" is described as $\wp=(\varsigma,\gamma,\delta)$, where $\varsigma,\gamma,\delta\in[0,1]$ and $0\le\varsigma+\gamma+\delta\le1.$

Definition 2 [43]. For a SVNN $\wp=(\varsigma,\gamma,\delta)$, the score value can be determined by Eq. (2).

$$\mathrm{S}(\wp)=\frac{2+\varsigma-\gamma-\delta}{3};\ \mathrm{S}(\wp)\in[0,1].\tag{2}$$

Definition 3 [44]. Let $\wp_i=(\varsigma_i,\gamma_i,\delta_i)$ be the SVNNs and $\omega=\{\omega_1,\omega_2,...,\omega_q\}$ be the weights' set of $\wp_i=(\varsigma_i,\gamma_i,\delta_i)$, $i=1,2,...,q,$ where ω_i is lying between 0 to 1 and $\omega_1+\omega_2+...+\omega_q=1.$ Then, SVN-weighted averaging (SVNWA) and SVN-weighted geometric (SVNWG) operators of α_j are as follows:

$$SVNWA(\wp_1,\wp_2,...,\wp_q)=\overset{q}{\underset{i=1}{\oplus}}(\omega_i\wp_i)=\left(1-\prod_{i=1}^{q}(1-\varsigma_i)^{\omega_i},\prod_{i=1}^{q}(\gamma_i)^{\omega_i},\prod_{i=1}^{q}(\delta_i)^{\omega_i}\right),\tag{3}$$

$$SVNWG(\wp_1,\wp_2,...,\wp_q)=\overset{n}{\underset{j=1}{\otimes}}(\omega_i\wp_i)=\left(\prod_{j=1}^{n}(\varsigma_i)^{w_j},1-\prod_{j=1}^{n}(1-\gamma_i)^{w_j},1-\prod_{j=1}^{n}(1-\delta_i)^{w_j}\right).\tag{4}$$

Definition 5 [44,45]. Let $E,F\in SVNSs(Y)$. Then, SVN-distance measure on *E* and *F* is given as

$$D(E,F)=\frac{1}{3n}\sum_{i=1}^{n}\left(|\varsigma_E(\iota_i)-\varsigma_F(\iota_i)|+|\gamma_E(\iota_i)-\gamma_F(\iota_i)|+|\delta_E(\iota_i)-\delta_F(\iota_i)|\right).\tag{5}$$

3. Proposed SVN-SWARA-TOPSIS Method

The aim of the study is to apply the developed SVN-SWARA-TOPSIS approach to choose an appropriate RESs. In the following, weight of RESs evaluation criteria is determined using the SVN-SWARA approach. For determining the weights of criteria and DEs, the SVN-SWARA-TOPSIS model is used on SVNSs information to choose RES options. An MCGDM ranking model is unified on the evaluations in reducing the bias and partiality. Brief description of the developed ranking model is presented as follows:

Step 1: *Initiate the set of options and criteria*

In the MCGDM model, the key aim is to select the best option from set of m options $S=\{S_1,S_2,...,S_m\}$ under the criteria set $T=\{T_1,T_2,...,T_n\}$. Assume a group of ℓ DEs $E=\{E_1,E_2,...,E_\ell\}$ is made to estimate the best option(s).

Step 2: *Evaluating the weight of DEs.*

Suppose that a significance rating of each DE is defined in form of linguistic values and is further stated in the SVNNs. To determine the rating of k^{th} DE, let $E_k=(\varsigma_k,\gamma_k,\delta_k)$ be an SVNN, then weight of k^{th} expert is calculated with the given expression as

$$\lambda_k = \left(\frac{\left(\varsigma_k + \gamma_k \left(\varsigma_k / (\varsigma_k + \delta_k)\right)\right)}{\sum_{k=1}^{\ell} \left(\varsigma_k + \gamma_k \left(\varsigma_k / (\varsigma_k + \delta_k)\right)\right)} \right), k = 1(1)\ell. \tag{6}$$

Clearly, $\sum_{k=1}^{\ell} \lambda_k = 1,\ \lambda_k \geq 0.$

Step 3: *Make the aggregated SVN-decision matrix (ASVN-DM).*

To find the ASVN-DM, every linguistic decision-matrix (LDM) $\square^{(k)} = \left(\xi_{ij}^{(k)}\right)_{m\times n}, k = 1,2,3$ is required to combine into an ASVN-DM. In the following, an SVNWA operator is implemented and then an ASVN-DM $\square = \left(\hat{\xi}_{ij}\right)_{m\times n}$ is created, where

$$\hat{\xi}_{ij} = SVNWA\left(h_{ij}^{(1)}, h_{ij}^{(2)}, \ldots, h_{ij}^{(\ell)}\right) = \left(1 - \prod_{k=1}^{\ell} (1-\varsigma_k)^{\lambda_k}, \prod_{k=1}^{\ell} (\gamma_k)^{\lambda_k}, \prod_{k=1}^{\ell} (\delta_k)^{\lambda_k} \right). \tag{7a}$$

Or

$$\hat{\xi}_{ij} = SVNWG\left(h_{ij}^{(1)}, h_{ij}^{(2)}, \ldots, h_{ij}^{(\ell)}\right) = \left(\prod_{k=1}^{\ell} (\varsigma_k)^{\lambda_k}, 1 - \prod_{k=1}^{\ell} (1-\gamma_k)^{\lambda_k}, 1 - \prod_{k=1}^{\ell} (1-\delta_k)^{\lambda_k} \right). \tag{7b}$$

Step 4: *Calculation of weight of diverse criteria*

The SWARA model utilizes the aim of estimation of subjective weight of attributes. By comparing diverse methods such as AHP (analytic hierarchy process) [46] and BWM (best worst method) [47], the computation procedure of SWARA method has more straightforwardness. As compared with the AHP tool, it does not require large number of pairwise comparisons and has higher consistency. Whereas compared with BWM, it does not require to deal complex linear objective functions, has less calculation complexity, and is simple to understand. Newly, SWARA tool was integrated with COPRAS developed Mishra et al. [48] to evaluate and prioritize bioenergy production process on IFSs setting. The SWARA begins to prioritize attributes with SVN-score ratings and then relative coefficient is determined to handle MCGDM problem. In the same way, algorithm of SWARA tool is presented in the following steps:

Step 4a: Each DE offers the linguistic performance rating of criteria. Using SVNWA operator, aggregate the linguistic decision matrix and corresponding SVNN as assessment ratings of criteria is given by DEs and is created an A-SVNN.

Step 4b: Find the SVN-score value of each A-SVNN of each criterion using Eq. (2).

Step 4c: According to the SVN-score ratings, we estimate the prioritization of defined criteria.

Step 4d: Computation of relative importance score (s_j) rating. The relative importance is determined from attribute that are place in the second spot, and succeeding relative importance is estimated with the discrimination between j^{th} and $(j\text{-}1)^{th}$ importance ratings of attributes.

Step 4e: Computation of relative coefficient of each attribute. Relative coefficient (k_j) of considered attribute is estimated as

$$k_j = \begin{cases} 1, & j = 1 \\ s_j + 1, & j > 1, \end{cases} \tag{8}$$

Step 4f: Estimation of weight. The weight p_j of considered attribute is computed as

$$p_j = \begin{cases} 1, & j = 1 \\ \dfrac{k_{j-1}}{k_j}, & j > 1 \end{cases} \tag{9}$$

Step 4g: Calculation of normalized weight. Normalized weight of attribute is obtained as follows:

$$w_j = \frac{p_j}{\sum_{j=1}^{n} p_j}. \tag{10}$$

Step 5: *Determination of ideal rating (IR) and anti-ideal rating (AIR)*

The IR and AIR for all attributes are important ratings for DEs in the developed MCGDM ranking model. Now, IR and AIR are defined in form of SVNSs as SVN-IR and SV-AIR. SVN-IR and SVN-AIR are signified as $\hat{\xi}_j^+$ and $\hat{\xi}_j^-$, respectively, and are calculated on the basis of given expressions:

$$\hat{\xi}_j^+ = \left(\varsigma_j^+, \gamma_j^+, \delta_j^+\right) = \begin{cases} \left(\max_i \hat{\varsigma}_{ij}, \min_i \hat{\gamma}_{ij}, \min_i \hat{\delta}_{ij}\right), & j \in T_b \\ \left(\min_i \hat{\varsigma}_{ij}, \max_i \hat{\gamma}_{ij}, \max_i \hat{\delta}_{ij}\right), & j \in T_n \end{cases}, \tag{11}$$

$$\hat{\xi}_j^- = \left(\varsigma_j^-, \gamma_j^-, \delta_j^-\right) = \begin{cases} \left(\min_i \hat{\varsigma}_{ij}, \max_i \hat{\gamma}_{ij}, \max_i \hat{\delta}_{ij}\right), & j \in T_b \\ \left(\max_i \hat{\varsigma}_{ij}, \min_i \hat{\gamma}_{ij}, \min_i \hat{\delta}_{ij}\right), & j \in T_n \end{cases}, \tag{12}$$

Step 6: *Determining the of discrimination rating from SVN-IR and SVN-AIR*

Apply Eq. (5), we find the weighted distance rating $D\left(S_i, \hat{\xi}_j^+\right)$ from the options S_i (i = 1, 2, ..., m) to SVN-IR $\hat{\xi}_j^+$ and presented as

$$D\left(S_i, \hat{\xi}_j^+\right) = \frac{1}{3n} \sum_{i=1}^{n} \left(\left|\hat{\varsigma}_{ij} - \varsigma_j^+\right| + \left|\hat{\gamma}_{ij} - \gamma_j^+\right| + \left|\hat{\delta}_{ij} - \delta_j^+\right|\right). \tag{13}$$

and distance rating $D\left(S_i, \hat{\xi}_j^-\right)$ from the options S_i (i = 1, 2, ..., m) to SVN-AIR $\hat{\xi}_j^-$ and expressed as

$$D\left(S_i, \hat{\xi}_j^-\right) = \frac{1}{3n} \sum_{i=1}^{n} \left(\left|\hat{\varsigma}_{ij} - \varsigma_j^-\right| + \left|\hat{\gamma}_{ij} - \gamma_j^-\right| + \left|\hat{\delta}_{ij} - \delta_j^-\right|\right). \tag{14}$$

Step 7: *Estimation of relative closeness rating (RCR)*

The RCR of each option over SVN-IR and SVN-AIR can be obtained utilizing the given expression as

$$RC(s_i) = \frac{D\left(S_i, \hat{\xi}_j^-\right)}{D\left(S_i, \hat{\xi}_j^+\right) + D\left(S_i, \hat{\xi}_j^-\right)}, \quad i = 1, 2, \ldots, m. \tag{15}$$

Step 8: Choose the highest rating of RCR, symbolized as RC (S_o), over the different RCR (S_i), i = 1, 2, ..., m). Hence, S_o is an appropriate option.

Step 9: *End.*

4. Case Study: Evaluation of sustainable indicators energy system selection

In the current section, we apply developed MCGDM ranking approach on a case study of RER alternatives assessment. For this purpose, we consider four RERs, which are onshore wind energy (S_1), polysilicon solar PV (S_2), phosphoric acid fuel cell (PAFC) (S_3) and solid oxide fuel cell (SOFC) (S_4) to be evaluated based on sustainability indicators. On the basis of comprehensive review of literature and discussion with experts, different sustainability aspects and 14 criteria are considered for sustainability perspectives and given in Table 1.

Table 1

Different RSTEE aspects of RESs assessment [1,49]

RSTEE aspects	Criteria	Type (B-Benefit, C- Cost)
Resource Indicator (R)	Material Intensity (T_1)	B

	Energy Intensity (construction) (T_2)	C
	Energy Intensity (fuel) (T_3)	B
Social Indicator (S)	Current Installed Capacity (T_4)	B
	Growth rate (T_5)	B
Technology Indicator (R)	Capacity factor (T_6)	B
	System efficiency (T_7)	B
	Lifetime (T_8)	B
Economic (Ec)	Capital Intensity (construction) (T_9)	C
	Capital Intensity (fuel) (T_{10})	C
	Delivery cost (T_{11})	C
Environmental (En)	CO_2 Intensity (construction) (T_{12})	C

Table 2 and 3 (adopted from [17, 18, 22]) depict assessment rating of DEs and attributes in form of LVs and further changes into SVNNs. Based on Eq. (6) and Table 2, weight of different DEs is determined and given in Table 4. Table 5 defines LDM of each DE for prioritizing the RESs over considered each attribute.

Table 2
LVs for rating the DEs performance for prioritizing the RESs [17,18]

LVs	SVNNs
Extremely qualified (EQ)	(0.9, 0.1, 0.1)
Very very qualified (VVQ)	(0.8, 0.25, 0.2)
Very qualified (VQ)	(0.7, 0.35, 0.3)
Qualified (Q)	(0.6, 0.45, 0.4)
Less qualified (LS)	(0.45, 0.75, 0.55)
Very less qualified (VLQ)	(0.25, 0.9, 0.75)

Table 3
Conversion of LVs to SVNNs for prioritizing the RESs [17,18,22]

LVs	SVNNs
Extremely high (EH)	(1, 0, 0)
Very very high (VVH)	(0.9, 0.1, 0.1)
Very high (VH)	(0.8, 0.15, 0.2)
High (H)	(0.7, 0.25, 0.3)
Moderately high (MH)	(0.6, 0.35, 0.4)
Fair (F)	(0.5, 0.5, 0.5)
Moderately low (ML)	(0.4, 0.65, 0.6)
Low (L)	(0.3, 0.75, 0.7)
Very low (VL)	(0.2, 0.85, 0.8)
Very very low (VVL)	(0.1, 0.9, 0.9)
Extremely low (EL)	(0, 1, 1)

Table 4
DEs' weight for prioritizing the RESs

DEs	LVs	SVNNs	Weight
E_1	EQ	(0.7, 0.35, 0.3)	0.3357
E_2	VVQ	(0.8, 0.25, 0.2)	0.3552
E_3	Q	(0.6, 0.45, 0.4)	0.3091

Table 5
LDM with different experts for prioritizing the RESs

	S_1	S_2	S_3	S_4
T_1	(H,VH,H)	(L,L,VL)	(F,L,F)	(F,H,MH)

T_2	(ML,F,ML)	(H,F,MH)	(H,F,F)	(F,F,MH)
T_3	(H,H,MH)	(MH,H,MH)	(F,ML,F)	(F,F,F)
T_4	(MH, H, F)	(F, ML,L)	(F,MH,F)	(F,MH,ML)
T_5	(MH,MH,F)	(H,MH,F)	(F,H,F)	(H,H,F)
T_6	(H,H,VH)	(MH,H,VH)	(H,F,H)	(F, MH,H)
T_7	(H, VH,F)	(H,F,ML)	(F,MH,H)	(F,ML,H)
T_8	(VH,H,MH)	(MH,F,F)	(F,F,ML)	(ML,F,MH)
T_9	(VL,ML,F)	(ML,MH,F)	(F,ML,L)	(F,ML,ML)
T_{10}	(ML,L,VL)	(MH,F,L)	(ML,F,F)	(F,L,MH)
T_{11}	(VL,F,ML)	(F,L,ML)	(L,ML,VL)	(F,ML,MH)
T_{12}	(ML,F,L)	(MH,ML,L)	(ML,VL,L)	(F,ML,VL)

Table 6
ASVN-DM for prioritizing the RESs

	S_1	S_2	S_3	S_4
T_1	(0.740, 0.209, 0.260)	(0.271, 0.780, 0.729)	(0.437, 0.577, 0.563)	(0.611, 0.350, 0.389)
T_2	(0.438, 0.592, 0.562)	(0.607, 0.355, 0.393)	(0.579, 0.396, 0.421)	(0.533, 0.448, 0.467)
T_3	(0.672, 0.277, 0.328)	(0.639, 0.311, 0.361)	(0.467, 0.549, 0.533)	(0.500, 0.500, 0.500)
T_4	(0.613, 0.347, 0.387)	(0.408, 0.622, 0.592)	(0.538, 0.441, 0.462)	(0.511, 0.478, 0.489)
T_5	(0.634, 0.315, 0.366)	(0.611, 0.349, 0.389)	(0.583, 0.391, 0.417)	(0.649, 0.310, 0.351)
T_6	(0.735, 0.213, 0.265)	(0.709, 0.239, 0.291)	(0.640, 0.320, 0.360)	(0.606, 0.356, 0.394)
T_7	(0.696, 0.258, 0.304)	(0.554, 0.430, 0.446)	(0.606, 0.356, 0.394)	(0.544, 0.443, 0.394)
T_8	(0.714, 0.234, 0.286)	(0.536, 0.444, 0.464)	(0.471, 0.542, 0.529)	(0.504, 0.489, 0.496)
T_9	(0.375, 0.656, 0.625)	(0.509, 0.481, 0.491)	(0.408, 0.622, 0.592)	(0.436, 0.595, 0.564)
T_{10}	(0.307, 0.743, 0.693)	(0.485, 0.503, 0.515)	(0.468, 0.546, 0.532)	(0.474, 0.517, 0.526)
T_{11}	(0.381, 0.648, 0.619)	(0.404, 0.626, 0.596)	(0.309, 0.741, 0.691)	(0.502, 0.492, 0.498)
T_{12}	(0.410, 0.619, 0.590)	(0.451, 0.552, 0.549)	(0.303, 0.747, 0.697)	(0.383, 0.647, 0.617)

Using Eq. (7), the individual opinion, i.e. an LDM of each DE are collected and combined to create an ASVN-DM, given in Table 6.

Table 7
Weight of criteria given by DEs in terms of LVs for prioritizing the RESs

Attributes	**E_1**	**E_2**	**E_3**	**ASVNNs**	**Score rating**
T_1	H	F	MH	(0.607, 0.355, 0.393)	0.626
T_2	ML	MH	MH	(0.509, 0.449, 0.475)	0.534
T_3	MH	F	ML	(0.509, 0.481, 0.491)	0.514
T_4	ML	ML	MH	(0.471, 0.537, 0.529)	0.467
T_5	H	MH	ML	(0.588, 0.379, 0.412)	0.605
T_6	H	MH	F	(0.611, 0.349, 0.389)	0.631
T_7	MH	H	VH	(0.709, 0.239, 0.291)	0.735
T_8	H	MH	H	(0.668, 0.282, 0.332)	0.693
T_9	MH	ML	F	(0.505, 0.487, 0.495)	0.509
T_{10}	ML	F	F	(0.468, 0.546, 0.532)	0.461
T_{11}	MH	ML	ML	(0.476, 0.528, 0.524)	0.474
T_{12}	MH	ML	L	(0.451, 0.552, 0.549)	0.454

Table 8
Subjectvie weight of attribute using SVN-SWARA for prioritizing the RESs

Criteria	**Crisp rating**	**s_j**	**k_j**	**p_j**	**w_j**
T_7	0.735	-	1.000	1.000	0.0986
T_8	0.693	0.042	1.042	0.960	0.0946
T_6	0.631	0.062	1.062	0.904	0.0891
T_1	0.626	0.005	1.005	0.899	0.0886

T_5	0.605	0.021	1.021	0.880	0.0868
T_2	0.534	0.071	1.071	0.822	0.0810
T_3	0.514	0.020	1.020	0.806	0.0795
T_9	0.509	0.005	1.005	0.802	0.0791
T_{11}	0.474	0.035	1.035	0.775	0.0764
T_4	0.467	0.007	1.007	0.770	0.0759
T_{10}	0.461	0.006	1.006	0.765	0.0755
T_{12}	0.454	0.007	1.007	0.760	0.0749

To estimate weight of attribute with SWARA, we first collect linguistic assessment ratings of criteria by the invited DEs and further convert these ratings in SVNNs via Table 3. With the help of SNWA operator, the individual assessment ratings of criteria are combined and acquire their aggregated ratings (see Table 7). Next, find the score value of aggregated assessment ratings of criteria and accordingly arrange the criteria positions. The required computational results of SWARA model are presented in Table 8. Thus, weight of attribute is obtained as $w_j =$ (0.0886, 0.0810, 0.0795, 0.0759, 0.0868, 0.0891, 0.0986, 0.0946, 0.0791, 0.0755, 0.0764, 0.0749).

By using formulae (11) and (12), SVN-IR and SVN-AIR of RERs are computed as

$\hat{\xi}_j^+$ = {(0.740, 0.209, 0.260), (0.438, 0.592, 0.562), (0.672, 0.277, 0.328), (0.613, 0.347, 0.387), (0.649, 0.310, 0.351), (0.735, 0.213, 0.265), (0.696, 0.258, 0.304), (0.714, 0.234, 0.286), (0.375, 0.656, 0.625), (0.307, 0.743, 0.693), (0.309, 0.741, 0.691), (0.303, 0.747, 0.697)}

$\hat{\xi}_j^-$ = {(0.271, 0.780, 0.729), (0.607, 0.355, 0.393), (0.467, 0.549, 0.533), (0.408, 0.622, 0.592), (0.583, 0.391, 0.417), (0.606, 0.356, 0.394), (0.544, 0.443, 0.446), (0.471, 0.542, 0.529), (0.509, 0.481, 0.491), (0.485, 0.503, 0.515), (0.502, 0.492, 0.498), (0.451, 0.552, 0.549)}.

Based on Eq. (13), the RCR $RC(S_i)$ of S_i (i = 1, 2, ..., 4) of each option is calculated and mentioned in Table 9. The preference of RESs is $S_1 \succ S_3 \succ S_4 \succ S_2$ and thus, wind energy system (S_1) is the optimum RES alternative.

Table 9
Preference order of RESs based on developed SVN-SWARA-TOPSIS method

RESs	$D\left(S_i, \hat{\xi}_j^+\right)$	$D\left(S_i, \hat{\xi}_j^-\right)$	$RC(S_i)$	Ranking
S_1	0.016	0.194	0.926	1
S_2	0.165	0.044	0.211	4
S_3	0.131	0.079	0.376	2
S_4	0.133	0.076	0.364	3

5. Comparative and sensitivity analysis

Next, comparative discussion is made between the outcomes achieved from the developed SVN-SWARA-TOPSIS method with different existing approaches.

5.1 Comparison with RESs-based method

First, we compare ranking outcomes with hybrid SWARA-ARAS [1] method. Based on Ghenai et al.'s [1] method, the utility degree (Q_i) of each alternative is determined as Q_1 = 1.0, Q_2 = 0.72, Q_3 = 0.73 and Q_4 = 0.88. Overall preference of RESs option is $S_1 \succ S_4 \succ S_3 \succ S_2$. Therefore, the most suitable RESS alternative is land-based wind energy system (S_1). Clearly, outcomes slightly change with developed SVN-SWARA-TOPSIS method. Hence, the developed SVN-SWARA-TOPSIS model is stronger than crisp-SWARA-ARAS approach [1] and has broader range of practicality. Also, Figure 1 shows that the depiction of utility degree of RESs with different MCGDM approaches.

5.2 Comparison with MCDM-based method

To confirm the rationality of ranking outcomes in the case study and to reveal reliability and of developed ranking approach, we compared it with existing SVN-MCDM methods SVN-VIKOR [17] and SVN-COPRAS [18] method using assessment data given by DEs and depicted in Figure 1.

5.2.1 SVN-VIKOR Method

Using SVN-VIKOR [17] model on the abovementioned case study, SVN-IR and SVN-AIR are same as the developed SVN-SWARA-TOPSIS method. Using hamming distance, the group utility (GU) (u_i) of each option is determined as u_1 = 0.095, u_2 = 0.749, u_3 = 0.619 and u_4 = 0.651. Next, the individual regret (IR) (v_i) of each alternative is computed as v_1 = 0.0522, v_2 = 0.0939, v_3 = 0.0946, v_4 = 0.0891. Combination of GU and IR of SVN-VIKOR, the compromise rating (CR) (e_i) of option is estimated as e_1 = 0.0, e_2 = 0.991, e_3 = 0.901 and e_4 = 0.86. Minimum value of CR determines an appropriate option. Thus, prioritization of RESs is $S_1 \succ S_4 \succ S_3 \succ S_2$ and hence, land-based wind energy system (S_1) is the optimum RES alternative.

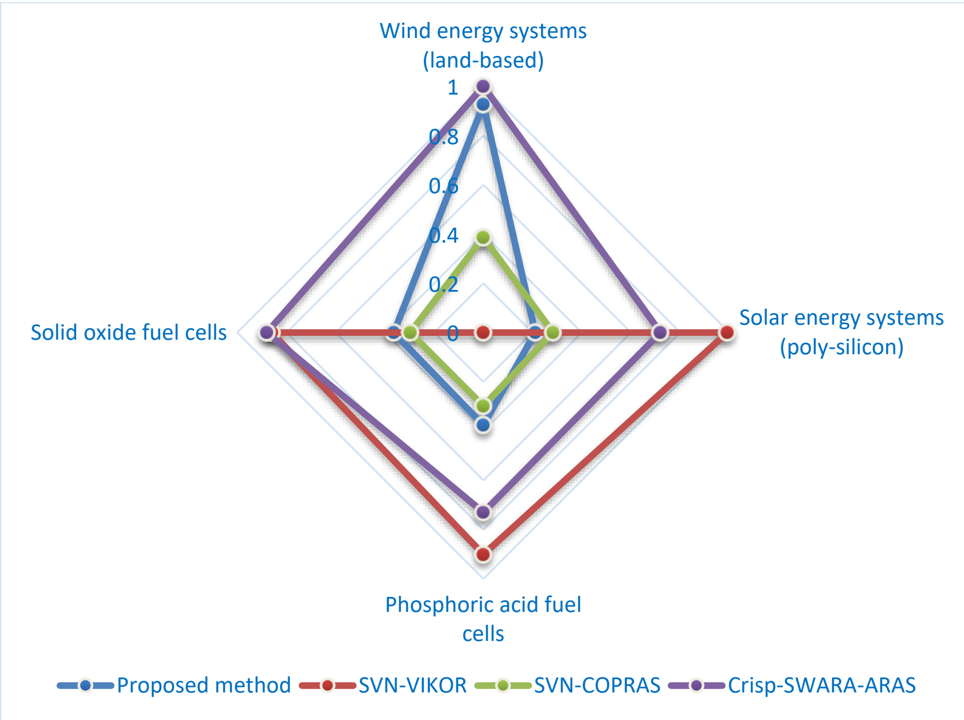

Fig. 1. Variation of assessment degree of RESs over different MCDM approaches

5.2.2 SVN-COPRAS model

Using the SVN-COPRAS [18] model on aforesaid case study, we obtain maximization and minimization indices are computed, which are denoted by H_i and L_i, respectively. The computed values are H_1 = (0.514, 0.436, 0.486), H_2 = (0.389, 0.589, 0.611), H_3 = (0.380, 0.606, 0.620), H_4 = (0.400, 0.579, 0.592), L_1 = (0.171, 0.846, 0.829), L_2 = (0.234, 0.760, 0.766), L_3 = (0.193, 0.816, 0.807) and L_4 = (0.217, 0.784, 0.783). Further, their corresponding SVN-score ratings are estimated as $S(H_1)$ = 0.531, $S(H_2)$ = 0.397, $S(H_3)$ = 0.385, $S(H_4)$ = 0.41, $S(L_1)$ = 0.165, $S(L_2)$ = 0.236, $S(L_3)$ = 0.19 and $S(L_4)$ = 0.217. The relative degree of each RES is obtained by means of minimization and maximization indices and presented as 0.3864, 0.2832, 0.298 and 0.2973. Lastly, the utility degrees of options are obtained as 100.0%, 73.3%, 77.11% and 76.94%. Thus, the ranking order of the RESs is $S_1 \succ S_3 \succ S_4 \succ S_2$ and thus, land-based wind energy system (S_1) is the optimum RES alternative.

To compare with crisp-SWARA-ARAS, SVN-VIKOR and SVN-COPRAS models, the SVN-SWARA-TOPSIS framework has following outcomes as

- An SVNS enhances the linguistic knowledge when a DE vacillates over diverse rating to assess RER selection problem. The implementation of SVNN provides more elastic procedure to define evaluation process of DEs. So, an elegant approach is presented to combine opinion of DEs and involvement for finding the suitable RERs.
- The developed MCGDM ranking model uses the SVNSs to prioritize the RERs, whereas unlike Ghenai et al. [1], crisp sets have been applied, a special case of SVNSs setting.
- An SVN-SWARA is applied to find subjective weight of attribute for prioritizing RERs in each MCGDM models such as Ghenai et al.'s [1] method, SVN-VIKOR [17] and SVN-COPRAS [18] method, which make the developed SVN-SWARA-TOPSIS model more practical and effective.

5.3 Sensitivity assessment

Next, a sensitivity assessment has discussed to study the developed SVN-SWARA-TOPSIS model. Here, we define 10 sets of weights of considered attributes and discussed Table 10. From Table 10 and Figure 2, for each set, we assign maximum weight value of attribute, while remaining attributes have lesser weight values. Based on the above-mentioned process, different groups of weights of attributes are created to the assessment of sensitivity of the developed ranking model for prioritizing RERs over different considered attributes.

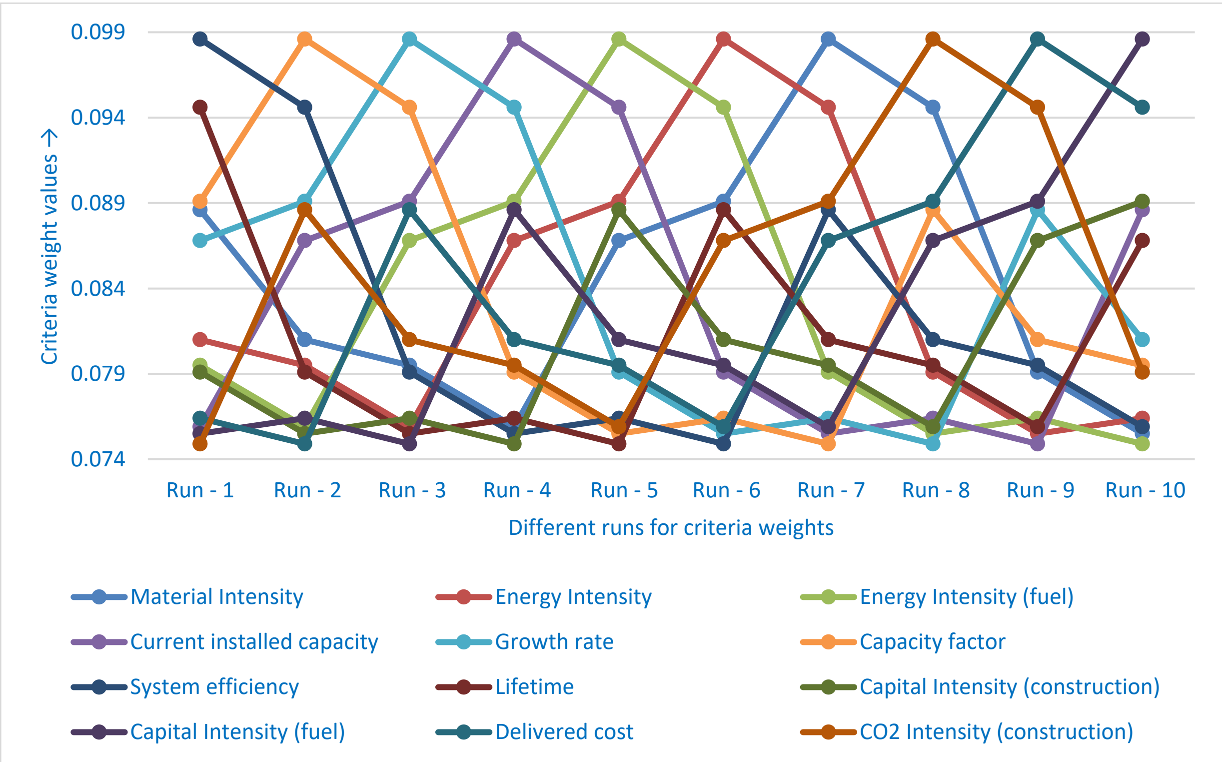

Fig. 2. Variation of weights of diverse attributes over different runs

Table 10

Sensitivity runs of criteria weight sets for RESs alternative selection

	Run-1	Run -2	Run -3	Run -4	Run -5	Run -6	Run -7	Run -8	Run -9	Run -10

T_1	0.0886	0.0810	0.0795	0.0759	0.0868	0.0891	0.0986	0.0946	0.0791	0.0755
T_2	0.0810	0.0795	0.0759	0.0868	0.0891	0.0986	0.0946	0.0791	0.0755	0.0764
T_3	0.0795	0.0759	0.0868	0.0891	0.0986	0.0946	0.0791	0.0755	0.0764	0.0749
T_4	0.0759	0.0868	0.0891	0.0986	0.0946	0.0791	0.0755	0.0764	0.0749	0.0886
T_5	0.0868	0.0891	0.0986	0.0946	0.0791	0.0755	0.0764	0.0749	0.0886	0.0810
T_6	0.0891	0.0986	0.0946	0.0791	0.0755	0.0764	0.0749	0.0886	0.0810	0.0795
T_7	0.0986	0.0946	0.0791	0.0755	0.0764	0.0749	0.0886	0.0810	0.0795	0.0759
T_8	0.0946	0.0791	0.0755	0.0764	0.0749	0.0886	0.0810	0.0795	0.0759	0.0868
T_9	0.0791	0.0755	0.0764	0.0749	0.0886	0.0810	0.0795	0.0759	0.0868	0.0891
T_{10}	0.0755	0.0764	0.0749	0.0886	0.0810	0.0795	0.0759	0.0868	0.0891	0.0986
T_{11}	0.0764	0.0749	0.0886	0.0810	0.0795	0.0759	0.0868	0.0891	0.0986	0.0946
T_{12}	0.0749	0.0886	0.0810	0.0795	0.0759	0.0868	0.0891	0.0986	0.0946	0.0791

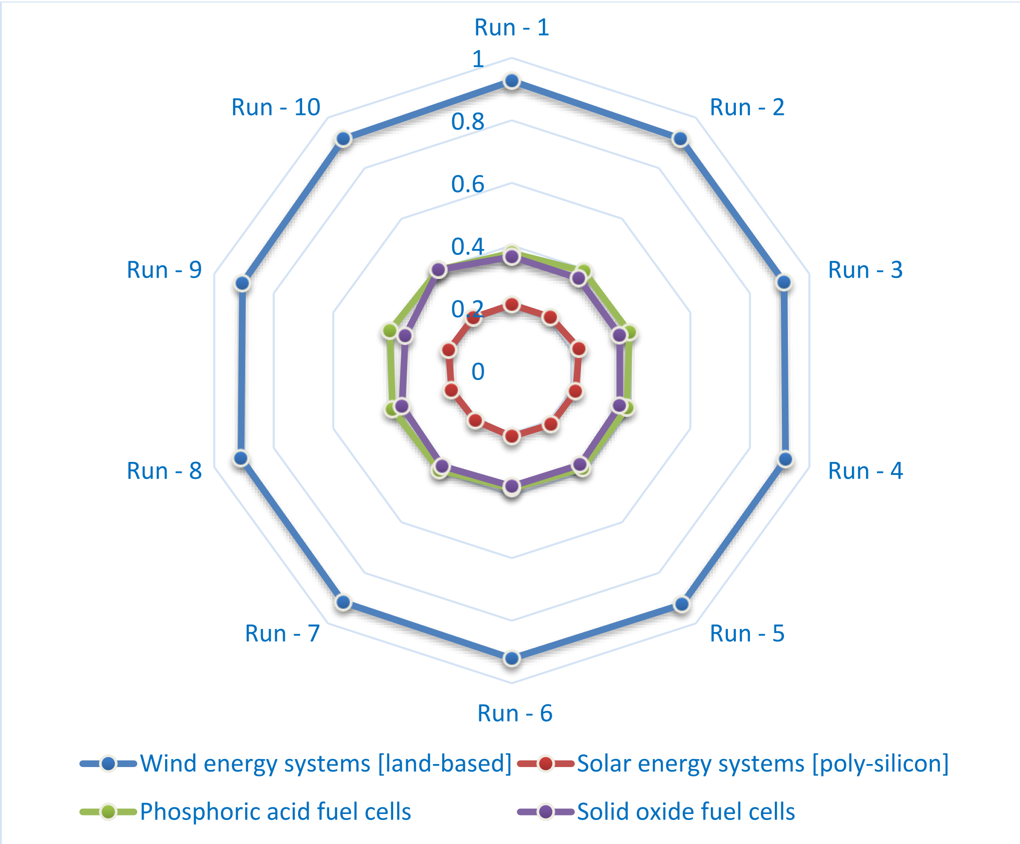

Fig. 3. The variation in the closeness coefficient of RESs over different runs

Table 11
The closeness coefficient degree for RESs alternatives over different runs of criteria weights

RESs	Run-1	Run -2	Run -3	Run -4	Run -5	Run -6	Run -7	Run -8	Run -9	Run -10
S_1	0.926	0.917	0.915	0.920	0.925	0.921	0.916	0.910	0.905	0.916
S_2	0.211	0.211	0.226	0.215	0.213	0.211	0.198	0.203	0.212	0.209
S_3	0.376	0.392	0.395	0.387	0.386	0.377	0.394	0.401	0.410	0.398
S_4	0.364	0.364	0.363	0.363	0.372	0.370	0.378	0.369	0.358	0.398

Sensitivity assessment outcomes presented in Table 11 and Figure 3 express that RCR could fluctuate with various weights of attributes and preference order of RERs. For instance, when DEs offers weight values to diverse attributes in form of sets-1 to 10, prioritization of RERs is land-based wind energy systems (S_1) ≻ PAFC (S_3) ≻ SOFC (S_4) ≻ polysilicon solar energy system (S_2).

This observation achieves that RERs selection is reliant on and sensitive to weights of defined attributes. Henceforth, developed framework is steady and efficient.

5. Conclusion

This study aimed to evaluate and prioritize some RESs including onshore wind energy (S_1), polysilicon solar PV (S_2), PAFC (S_3) and SOFC (S_4) on the basis of five sustainability aspects named RSTEE (Resource, Social, Technology, Economic and Environmental) and fourteen attributes, which are defined in Table 1. To this aim, we have proposed a combined ranking algorithm integrating the SWARA, the TOPSIS and SVNSs setting. In the following, to determine the weight of attribute, we have developed SVN-SWARA which estimates the subjective weight on SVNSs setting and defines the ambiguity related to different DEs' opinions and assessments. The outcomes of the developed ranking model show that the developed SVN-SWARA-TOPSIS can effectively deal with RESs assessment problem on SVNSs setting. Comparing with existing models and sensitivity assessment are expressed the validity of developed SVN-SWARA-TOPSIS method. This study has some limitations, which are (i) the presented SVN-SWARA-TOPSIS approach does not reflect the interrelationships between criteria, (ii) the presented SVN-SWARA-TOPSIS approach does not consider objective weight of criteria in the assessment of RESs assessment problem on SVNSs setting, and (iii) Moreover, the considered RES alternatives, RSTEE aspects and decision experts are very limited in this study. Further, the developed ranking model can be used to handle other MCGDM problems namely selecting a green or sustainable supplier, solid waste disposal method selection. Other MCDM techniques such as WISP, AROMAN, OCRA with SPC, RANCOM and MEREC approaches can also be utilized to prioritize the options.

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