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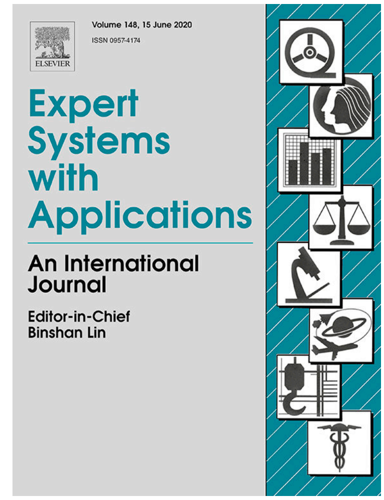

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An integrated decision support framework using single-valued neutrosophic-MASWIP-COPRAS for sustainability assessment of bioenergy production technologies

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Abstract

As a clean and renewable energy, bioenergy is one of the most prospective alternatives to fossil fuels. Therefore, it has been received much attention and occupied a considerable status in the world's energy consumption. Moreover, the sustainable bioenergy production can effectively decrease the risk of energy poverty and contribute to the economic and ecological benefits, particularly in developing countries. However, the selection of bioenergy production technologies (BPTs) has significant challenges and uncertainties due to various factors. Thus, the aim of this study is to evaluate the BPTs and choose the most suitable and sustainable alternative among them. For this purpose, an integrated decision-making framework is proposed under single-valued neutrosophic environment. In the present approach, the method based on the removal effects of criteria (MEREC) and stepwise weight assessment ratio analysis (SWARA) weighting integrated procedure (MASWIP) is introduced to compute the relative significances of the considered sustainability indicators. Then, the MASWIP-based complex proportional assessment (COPRAS) is introduced to prioritize the BPTs from single-valued neutrosophic perspective. Further, the present framework is implemented on a case study of BPTs evaluation problem with uncertain, inconsistent and indeterminate information, which approves the effectiveness and practicality of introduced method. To assess its robustness and stability, sensitivity and comparative studies are performed. The advantages of the developed method are emphasized in terms of stability and reliability by comparisons with five existing approaches, and the effectiveness of the present approach is verified. The findings of the study prove that the application of single-valued neutrosophic MASWIP-based COPRAS method in BPT selection is robust.

Keywords: Single-valued neutrosophic sets; Sustainability; Bioenergy production technology; COPRAS; MEREC; SWARA.

1. Introduction

Bioenergy is a renewable form of energy produced from organic matter (called "biomass"). It can be converted into liquid transportation fuel through a chemical conversion method at a biorefinery and called as "biofuel" (Narwane et al., 2021). In addition, it can be converted into heat and electricity called "biogas or biopower or biomethane" through a direct combustion process. Bioenergy, in terms of biomass, biofuel or biogas, can be utilized for heat and electricity generation, thermal energy, fuels for transports etc (Jonkman et al., 2019; Abdel-Basset et al., 2021). In comparison with the fossil fuels, bioenergy has noticeable advantages on account of its renewability and huge capacity, and therefore plays a decisive role in global energy consumption from sustainable perspective (De Corato et al., 2018). Nowadays, as the promising renewable substitution of fossil fuels, bioenergy has been developing in order to fulfil the demand of global energy and reduce the environmental footprints (Rabbani et al. 2018).

Heating is one of the oldest and most extensive applications of biomass for bioenergy production (Rabbani et al., 2018). Over the past few decades, several biofuels can be supplied from biomass for the transport industry, consisting of biodiesel, ethanol and advanced hydro carbon biofuels (Yue et al., 2014). There are diverse conversion technologies which depend on the types of biomass and the required form of bioenergy (Khishtandar et al., 2020). On account of the variety of biomass, bioenergy and conversion techniques, there is a need for a better understanding of how diverse "bioenergy production technologies (BPTs)" can promote sustainable development in the countries. In developed countries, there is an increasing trend towards utilizing modern technologies and well-organized bioenergy conversion by means of variety of biofuels (Khishtandar et al., 2017; Rabbani et al., 2018; Mishra et al., 2020).

Sustainability relies on an adjustment between social, environmental and economic aspects (Destek and Sinha, 2020) and can be described as a procedure in which resource utilization, investment directions, and technical facets that enriches the prospective to fulfil human requirements and objectives. Given the diversity of adaptation procedures for bioenergy, a better assessment is needed to improve the BPTs in encouraging sustainable perspectives in the nations (Rabbani et al., 2018; Mishra et al., 2020). Moreover, sustainability is multidimensional and inaccurate in nature, so it is challenging to define and escalate the possible significance of sustainable perspectives (Abdel-Basset et al., 2021). Thus, assembling the accurate data on the BPTs with sustainable perspectives is a challenging task for policymakers and environmentalists.

Uncertainty is an important factor in the assessment of BPTs (Awudu and Zhang, 2012). In the literature, some tools and models have been suggested to handle the decision-making problems of BPTs assessment (Khishtandar et al., 2017; Mishra et al., 2020). However, these models are often difficult to be applied in realistic BPTs evaluation problem involving uncertain, incomplete, indeterminate and inconsistent data. To deal with such situations, Smarandache (1999) established the "neutrosophic set (NS)" theory to tackle the uncertain, incomplete, indeterminate and inconsistent information, which cannot be handled by "fuzzy sets (FSs)" (Zadeh, 1965) and "intuitionistic fuzzy sets (IFSs)" (Atanassov, 1986). Smarandache explains it as "a philosophical disciplines that analysis the origin, nature and scope of neutralities, as well as their interactions with various ideational spectra" (Smarandache, 1999). Further, several extensions of NSs are developed, for instance, "single-valued neutrosophic sets (SVNSs)", "trapezoidal neutrosophic sets (TNSs)", "bipolar neutrosophic sets (BNSs)", "type-2 neutrosophic sets (T2NSs)" and others (Wang et al., 2010; Uluçay et al., 2018; Sarma et al., 2019; Simic et al., 2022). These NSs are employed on the basis of types of uncertainty of real-life problems.

Among these extensions, the concept of SVNSs (Wang et al., 2010) has received a huge interest by several authors due to its flexibility and applicability in dealing with the practical situations. Nancy and Garg (2019) established a SVNS-based method to evaluate the multiple criteria group decision-making problems with inconsistent and indeterminate information. By means of “single-valued neutrosophic (SVN)” information, Garg and Nancy (2020) studied a decision-making methodology based on a distance measure and “technique for order preference by similarity to ideal solution (TOPSIS)” for solving single-valued neutrosophic decision-making problems. Chutia et al. (2021) invented a ranking procedure for ordering the “single-valued neutrosophic numbers (SVNNs)”. Jin et al. (2022) explored some new measures of distance for SVNSs and presented its application in multiple criteria group decision-making situations. In the recent past, lots of theories and applications have been presented from single-valued neutrosophic perspective (Karaaslan and Hunu, 2020; Zhang et al., 2021; Rani et al., 2021a; Mishra et al., 2021a; Hezam et al., 2022).

In the literature, very few studies (Khishtandar et al., 2017; Mishra et al., 2020; Abdel-Basset et al., 2021) have been presented to assess the BPTs by means of novel decision support systems. Based on the existing studies, some key motivations are identified behind the present work, which as

- Khishtandar et al. (2017) presented a decision-analysis framework using the “outranking method” with “hesitant fuzzy linguistic term sets (HFLTSs)” to evaluate ten BPTs with respect to fifteen sub-criteria. They have presented their framework under “hesitant fuzzy linguistic term set (HFLTS)” context that cannot tackle the vague, indeterminate and inconsistent information effectively. In addition, their study has considered the criteria weights by making assumptions (like, holistic approach which offers same weight for each criterion) that did not comprise all the benchmarks of the BPTs evaluation problem.
- Mishra et al. (2020) investigated a hybrid method for evaluating the sustainable BPTs that was categorized into two phases. Firstly, the SWARA model has presented to determine the subjective weights of criteria and secondly, the BPTs have ranked by means of IFS-based “complex proportional assessment (COPRAS)”. They have evaluated six BPTs based on four sustainable aspects and eleven sub-criteria. Some flaws of this study are: (i) it considered the IFS theory that did not express the multiple uncertainties efficiently; and (ii) only 11 sub-criteria have taken that did not comprise all the benchmarks of the BPTs problem.
- Abdel-Basset et al. (2021) discussed a combined framework to rank the aspects and criteria with the use of sustainability of BPTs. The “Decision making trial and evaluation laboratory (DEMATEL)” tool was used to recognize the weights of aspects and their indicators. Then, the EDAS was applied to prioritize the seven BPTs. Their study has some shortcomings: (i) The priority order of BPTs has been provided by considering interdependent relationships among the BPTs; but other aspects are not combined in the decision-analysis problem. (ii) They considered only subjective weighting assessment of indicators using DEMATEL method that did not comprise all benchmarks of the BPTs assessment problem.
- In the literature (Khishtandar et al. 2017; Abdel-Basset et al., 2021), the weight values of “decision experts (DEs)” are not considered during the process of BPTs assessment, while the computation of DEs’ weights plays a vital role in group decision-making problem.
- In existing studies (Khishtandar et al. 2017; Mishra et al., 2020; Abdel-Basset et al., 2021), there is no study regarding the integrated weighted procedure based on objective and subjective criteria weights under

SVN environment. However, a hybrid weighting model can conquer the inadequacies which occur either in an objective weight-determining process or in a subjective weight-determining process.

- Multi-criteria BPTs decision-making problem has evaluated by several models but they have some drawbacks in treating the SVN-information based BPTs problem with fully unknown DEs and criteria weights.

Based on the motivations, this study develops an innovative MCDM approach, which involves three decision-making procedures, the "method based on the removal effects of criteria (MEREC)" (Keshavarz-Ghorabaee et al., 2021) and "stepwise weight assessment ratio analysis (SWARA)" (Kersuliene et al., 2010) weighting integrated procedure (MASWIP) and "complex proportional assessment (COPRAS)" (Zavadskas et al., 1994) with SVNNs for assessing six BPTs with sustainable perspectives.

In the following, we present the key contributions of this study:

- To evaluate the BPTs concerning sustainability indicators, a hybrid SVN-information based decision-making method is proposed that combines the MASWIP and COPRAS models.
- The weight values of the DEs are computed by score function-based procedure.
- The MASWIP is introduced with the integration of objective weighting model by MEREC and subjective weighting model by SWARA model for computing the criteria weights under SVN environment.
- Sensitivity analysis and comparison with extant methods are discussed to validate the stability and robustness of the obtained results.

The other parts of this study are organized as: In Section 2, we explain the comprehensive literature review related to this paper. In Section 3, we discuss an integrated SVN-MASWIP-COPRAS method within SVNS environment. In Section 4, we demonstrate a case study of BPTs evaluation problem with sustainable viewpoints. In addition, this section presents sensitivity and comparative analyses. Lastly, Section 5 confers the conclusions drawn from this study and future scope for further researches.

2. Literature Review

In the present section, we briefly review the literature associated with the SVNSs, MEREC model, SWARA model, COPRAS method and MCDM tools for BPTs assessment.

2.1. SVNSs

The theory of FSs (Zadeh, 1965) provides an influential outline to deal with the vague or indistinct problems. Due to its flexibility and ability, several authors have presented a lot of applications of FSs (Bozanic et al., 2021; Mustafa et al., 2022; Narang et al., 2022). Further, Atanassov (1986) expanded the FS to IFS, which achieves more accurate results of uncertain real-life problems. The notion of IFS consists of membership and non-membership grades, and permits the researchers to consider the hesitancy effect of decision experts (Kushwaha et al., 2020). However, in some situations, if a professional is called for his/her decision regarding a certain statement, then he or she may articulate that 0.5 being the "possibility that the statement is true", 0.6 being the "possibility that the statement is false" and 0.2 being the "possibility that he or she is on the fence". Such types of situations are beyond the scope of FS and IFS. To handle this situation, Smarandache (1999) put forward the theory of NSs. The interesting characteristic of NS is that it is modelled by the "truth-membership grade (TG)", "indeterminacy-membership grade (IG)" and "falsity-membership grade (FG)", which are lie in $]0^{-},1^{+}[$. It can express the uncertain, inaccurate, indeterminate and inconsistent information in the objective world, which cannot be expressed by the FS, IFS, "Pythagorean fuzzy sets (PFSs)", and "interval-valued intuitionistic fuzzy sets (IVIFSs)". Since its appearance, numerous authors have paid their interest on NS theory (Rani and Mishra, 2020a, b; Karamustafa and Cebi, 2021; Mishra et al., 2021b, c; Qi et al., 2022; Karadayi-Usta, 2022). As a generalized version of NS, Wang et al. (2010) proposed the notion of SVNSs, which can be applied in realistic scientific and engineering applications. In the literature, the SVNSs have been applied in several disciplines. For example, Han et al. (2020) suggested a SVN-information based model for transforming the original problem into crisp multi-objective problem. Further, their application has been discussed in MCDM problem. Kumar et al. (2020) introduced a contactless defect diagnosis for the diagnosis of bearing defect in the centrifugal pump. For this purpose, they proposed an innovative variational mode decomposition method based on symmetric SVN cross entropy measure. You et al. (2021) developed a new consensus reaching model based on SVN-information and its applicability in multi-criteria group decision making problems. Mishra et al. (2022) put forward a hybrid methodology by combining MEREC and "multi-objective optimization by ratio analysis plus the full multiplicative form (MULTIMOORA)" approaches for solving the low-carbon tourism strategies assessment problem under SVNS settings. Huang et al. (2022) proposed the relative distance-based and similarity-based measures to compare the single-valued neutrosophic values. Based on the presented relative measures, some ranking methods have been introduced to rank the alternatives. Hezam et al. (2022) gave a hybridized decision support system by incorporating the MEREC and ranking sum models with SVN information-based "double normalization-based multiple aggregation (DNMA)" approach with its application in the assessment of alternative fuel vehicles. However, there is no study which combines the MEREC and the SWARA models with SVN-information based COPRAS method for assessing the BPTs with multiple sustainability indicators. However, there is no study which incorporates the SVN-information with hybrid weighting model based on MEREC and SWARA, and the ranking approach based on COPRAS method for multi-criteria BPTs assessment.

2.2. MEREC and SWARA Models for Criteria Weights

During the MCDM process, the computation of criteria weights is a crucial component for the DEs. In the literature, the criteria weight-determining models are divided into objective and subjective weights. For objective weights of criteria, a new weight-determining model, namely MEREC, has been developed by Keshavarz-Ghorabaee et al. (2021). This method uses each criterion's removal effect on the performance of options for evaluating the criteria weights. Recently, few studies have combined the MEREC model with some ranking approaches (Hezam et al., 2022; Mishra et al., 2022; Radmehr et al., 2022). Due to its effectiveness, this study firstly combines the MEREC model with COPRAS and SWARA methods under SVNS context.

For subjective weights of criteria, Kersuliene et al. (2010) launched the SWARA method, whose key characteristic is the possibility to assess DEs' opinion related to the significance ratio of the criteria in the process of their weights evaluation. The SWARA method assists the DEs for better decisions in an ample range of situations and provides better criteria rankings for important goals. In addition, the DEs' opinions are included in the process of decision making. In comparison with the frequently used "analytic hierarchy process (AHP)", the SWARA model does not require a large number of pairwise comparisons, has lower computational complexity and high consistency. The use of AHP will develop the models by means of the criteria and priorities; on the other hand, the SWARA acquire the models in accordance with the situation, priorities, and weights. As compared to "best worst method (BWM)", the SWARA method does not require to compute linear objective functions, has lesser computational intricacy and easy to understand (Karabasevic et al., 2015). Due to diverse advantages of SWARA method, Agarwal et al. (2020) studied a hybridized model by combining the fuzzy SWARA and "weighted aggregated sum product assessment (WASPAS)" method for assessing the solutions to overcome humanitarian supply chain management barriers. Rani et al. (2021b) incorporated the SWARA model with "combined compromise solution (CoCoSo)" technique for assessing the RESs assessment problem under SVNS context. Ayyildiz (2022) presented a hybrid Fermatean fuzzy SWARA method to prioritize the indicators of sustainable development goal-7. Apart from these studies, several authors have utilized the SWARA model for diverse purposes (Ghenai et al., 2020; Yücenur and Şenol, 2021; Saraç et al., 2022).

2.3. COPRAS Method

MCDM is a process planned to examine several options/alternatives concerning numerous criteria and conflicting goals (Biswas, 2020). The methods developed for MCDM process assist the DEs in making an optimal decision by considering different perspectives (Pamučar and Janković, 2020). Among the numerous MCDM methods, the COPRAS (Zavadskas et al., 1994) method has gained popularity due to its easy mathematical steps and high superiority in dealing with the complex criteria and problems involving a large number of options. This method can be used to minimize or maximize criteria in an assessment where more than one criterion should be considered. The COPRAS method has been extended and applied in different areas. Yücenur et al. (2020) presented an integrated method based on COPRAS and SWARA methods to rank the most suitable city for the establishment of biogas facility. Balali et al. (2021) combined the COPRAS approach with "analytic hierarchy process (ANP)" to prioritize efficient risks on human resources threats in natural gas supply projects. An integrated Pythagorean fuzzy-information based COPRAS approach with entropy and SWARA model has been investigated and applied for fuel cell and hydrogen components selection (Alipour et al., 2021). Further, Chaurasiya and Jain (2022) investigated a new Pythagorean fuzzy COPRAS based decision support system for assessing the multiple criteria healthcare waste treatments. Kusakci et al. (2022) studied the AHP and interval type-2 fuzzy set based COPRAS model for the sustainability evaluation of Turkish metropolitans under uncertain environment. Further, Rani et al. (2022) suggested a hybrid COPRAS method with the integration of CRITIC and score function under interval-valued Fermatean fuzzy environment. In the literature, no one has developed a hybrid SVN-MASWIP-COPRAS model for the assessment of BPTs with multiple sustainability indicators.

2.4. Decision-Making Methods for BPTs Selection

In the recent past, some methods have been developed to prioritize and select the most suitable BPT from sustainable viewpoints. For instance, Khishtandar et al. (2017) introduced a decision support system based on hesitant fuzzy linguistic data for the evaluation of BPTs. That study considered a set of 15 sustainable indicators to assess the considered BPTs. Further, a hybridized MCDM methodology was proposed by Mishra et al. (2020), which incorporates the SWARA model and the COPRAS method from intuitionistic fuzzy perspective. They utilized their model for assessing the BPTs by considering the multiple aspects of sustainability under IFS context. Recently, Abdel-Basset et al. (2021) presented an innovative methodology by combining the DEMATEL and the EDAS approaches for the assessment of sustainable BPTs under trapezoidal neutrosophic environment. In that study, the DEMATEL approach employed to derive the criteria weights, while the EDAS approach used to find the ranking of candidate BPTs with trapezoidal neutrosophic data.

As per existing studies on BPTs assessment (Khishtandar et al., 2017; Mishra et al., 2020; Abdel-Basset et al. 2021), we have identified some limitations, which are (i) the insufficiencies of consideration of sustainable dimensions, factors and their implication values-based concerns, and the lack of case studies in India. (ii) The previously introduced works are presented within the contexts of "hesitant fuzzy linguistic term sets (HFLTSs)", IFSs and trapezoidal neutrosophic sets, respectively, which are unable to capture the indeterminate and inconsistent information of realistic BPTs assessment problem from sustainability perspectives. To overcome the limitations of existing studies, this work considers the "social, economic, environmental and technological (SEET)" aspects of sustainability that manage all the benchmarks of the BPTs assessment problem with uncertain, incomplete, indeterminate and inconsistent information.

3. Proposed Research Methods

The present section proposes a SVN-information based framework containing two approaches MASWIP and COPRAS, which are the combination of three interesting MCDM approaches, and further utilized to assess and select the most appropriate BPTs.

3.1. Preliminaries

In this part of the study, we present some basic concepts of SVNSs.

Definition 1 (Wang et al., 2010). Let V be a universal set. A "single-valued neutrosophic set (SVNS)" M in V is characterized by a TG $\mathrm{T}_M(v)$, IG $\mathrm{I}_M(v)$ and FG $\mathrm{F}_M(v)$. A SVNS can be defined as

$$M=\left\{\left(v,\mathrm{T}_M(v),\mathrm{I}_M(v),\mathrm{F}_M(v)\right)\middle| v\in V\right\},$$

where $\mathrm{T}_M(v)\in[0,1]$, $\mathrm{I}_M(v)\in[0,1]$, $\mathrm{F}_M(v)\in[0,1]$ and $0\le\mathrm{T}_M(v)+\mathrm{I}_M(v)+\mathrm{F}_M(v)\le 3.$ Wang et al. (2010) defined the triplet $\left(\mathrm{T}_M(v),\mathrm{I}_M(v),\mathrm{F}_M(v)\right)$ as a "single valued neutrosophic number (SVNN)".

Definition 2 (Wang et al., 2010). Consider $\alpha_1=\left(\mathrm{T}_{\alpha_1},\mathrm{I}_{\alpha_1},\mathrm{F}_{\alpha_1}\right)$ and $\alpha_2=\left(\mathrm{T}_{\alpha_2},\mathrm{I}_{\alpha_2},\mathrm{F}_{\alpha_2}\right)$ be two SVNNs. Then the operations on SVNNs are presented as

- $\alpha_1^c=\left(\mathrm{F}_{\alpha_1},1-\mathrm{I}_{\alpha_1},\mathrm{T}_{\alpha_1}\right),$
- $\alpha_1\subseteq\alpha_2$ if $\mathrm{T}_{\alpha_1}\le\mathrm{T}_{\alpha_2}$, $\mathrm{I}_{\alpha_1}\ge\mathrm{I}_{\alpha_2}$ and $\mathrm{F}_{\alpha_1}\ge\mathrm{F}_{\alpha_2}$,

- $\alpha_1 = \alpha_2$ if and only if $\alpha_1 \subseteq \alpha_2$ and $\alpha_2 \subseteq \alpha_1$.

Definition 3 (Ye, 2014): Let $\alpha_1 = \left(T_{\alpha_1}, I_{\alpha_1}, F_{\alpha_1}\right)$ and $\alpha_2 = \left(T_{\alpha_2}, I_{\alpha_2}, F_{\alpha_2}\right)$ be two SVNNs and $\gamma > 0$. Then the laws for SVNNs are shown as

(a) $\alpha_1 + \alpha_2 = \left(T_{\alpha_1} + T_{\alpha_2} - T_{\alpha_1} T_{\alpha_2}, I_{\alpha_1} + I_{\alpha_2} - I_{\alpha_1} I_{\alpha_2}, F_{\alpha_1} + F_{\alpha_2} - F_{\alpha_1} F_{\alpha_2}\right)$;

(b) $\alpha_1 \alpha_2 = \left(T_{\alpha_1} T_{\alpha_2}, I_{\alpha_1} I_{\alpha_2}, F_{\alpha_1} F_{\alpha_2}\right)$;

(c) $\gamma \alpha_1 = \left(1-(1-T_{\alpha_1})^{\gamma}, 1-(1-I_{\alpha_1})^{\gamma}, 1-(1-F_{\alpha_1})^{\gamma}\right)$;

(d) $\alpha_1^{\gamma} = \left(T_{\alpha_1}^{\gamma}, I_{\alpha_1}^{\gamma}, F_{\alpha_1}^{\gamma}\right)$.

Peng et al. (2016) mentioned that the basic operational laws defined by Ye (2014) may be impractical in certain scenarios. To overcome this problem, Peng et al. (2016) re-defined the basic operations between SVNNs utilizing the benefits of Archimedean t-norm and t-conorm. A strict Archimedean t-norm (Klir and Yuan, 1995; Klement and Mesiar, 2005) can be expressed as $\Theta(x, y) = \Delta^{-1}(\Delta(x) + \Delta(y))$, ($\Delta$ being it's additive generator) and its dual form (strict Archimedean t-conorm) is described as $\nabla(x) = \Delta(1-x)$.

Definition 4 (Peng et al., 2016). Let $\alpha_1 = \left(T_{\alpha_1}, I_{\alpha_1}, F_{\alpha_1}\right)$ and $\alpha_2 = \left(T_{\alpha_2}, I_{\alpha_2}, F_{\alpha_2}\right)$ be two SVNNs and $\gamma > 0$, then the Archimedean operations between the SVNNs are defined as

(a) $\alpha_1 + \alpha_2 = \left(\nabla^{-1}(\nabla(T_{\alpha_1}) + \nabla(T_{\alpha_2})), \Delta^{-1}(\Delta(I_{\alpha_1}) + \Delta(I_{\alpha_2})), \Delta^{-1}(\Delta(F_{\alpha_1}) + \Delta(F_{\alpha_2}))\right)$;

(b) $\alpha_1 \alpha_2 = \left(\Delta^{-1}(\Delta(T_{\alpha_1}) + \Delta(T_{\alpha_2})), \nabla^{-1}(\nabla(I_{\alpha_1}) + \nabla(I_{\alpha_2})), \nabla^{-1}(\nabla(F_{\alpha_1}) + \nabla(F_{\alpha_2}))\right)$;

(c) $\gamma \alpha_1 = \left(\nabla^{-1}(\nabla(\gamma T_{\alpha_1})), \Delta^{-1}(\gamma \Delta(I_{\alpha_1})), \Delta^{-1}(\gamma \Delta(F_{\alpha_1}))\right)$;

(d) $\alpha_1^{\gamma} = \left(\Delta^{-1}(\Delta(\gamma T_{\alpha_1})), \nabla^{-1}(\gamma \nabla(I_{\alpha_1})), \nabla^{-1}(\gamma \nabla(F_{\alpha_1}))\right)$.

Definition 5 (Peng et al., 2016). Consider $\alpha_j = \left(T_j, I_j, F_j\right)$ be a set of SVNSs and $\varpi = \left(\varpi_1, \varpi_2, \ldots, \varpi_n\right)^T$ be the weight value of α_j, satisfying $\varpi_j \in [0,1]$ and $\sum_{j=1}^{n} \varpi_j = 1$. Then the "single-valued neutrosophic weighted average (SVNWA)" and "single-valued neutrosophic weighted geometric (SVNWG)" operators are given by

$$SVNWA\left(\alpha_1, \alpha_2, \ldots, \alpha_n\right) = \bigoplus_{j=1}^{n}\left(\varpi_j \alpha_j\right) = \left(\nabla^{-1}\left(\sum_{j=1}^{n} \varpi_j \nabla(T_j)\right), \Delta^{-1}\left(\sum_{j=1}^{n} \varpi_j \Delta(I_j)\right), \Delta^{-1}\left(\sum_{j=1}^{n} \varpi_j \Delta(F_j)\right)\right), \tag{1}$$

$$SVNWG\left(\alpha_1, \alpha_2, \ldots, \alpha_n\right) = \bigotimes_{j=1}^{n}\left(w_j \alpha_j\right) = \left(\Delta^{-1}\left(\sum_{j=1}^{n} \varpi_j \Delta(T_j)\right), \nabla^{-1}\left(\sum_{j=1}^{n} \varpi_j \nabla(I_j)\right), \nabla^{-1}\left(\sum_{j=1}^{n} \varpi_j \nabla(F_j)\right)\right). \tag{2}$$

where Δ is called the additive generator of the Archimedean t-norm and ∇ is defined as $\nabla(x) = \Delta(1-x)$.

Definition 6 (Smarandache, 2020): The score function for a SVNN $\alpha = \left(T_\alpha, I_\alpha, F_\alpha\right)$ is presented as

$$\mathbb{S}(\alpha) = \frac{2 + T_\alpha - I_\alpha - F_\alpha}{3}, \ \mathbb{S}(\alpha) \in [0,1]. \tag{3}$$

Moreover, the accuracy and certainty functions are given by

$$a(\alpha) = T_\alpha - F_\alpha \text{ and } c(\alpha) = T_\alpha. \tag{4}$$

3.2. An Integrated SVN-MASWIP-COPRAS Framework

In this section, we introduce a hybrid SVN-MASWIP-COPRAS methodology based on SVN-information, the MEREC and the SWARA based weighted integrated procedure and COPRAS method. In the proposed framework, innovative formulae are presented to derive the weights of DEs and criteria on SVNSs setting. The calculation process of developed SVN-MASWIP-COPRAS is specified as follows (see Fig. 1):

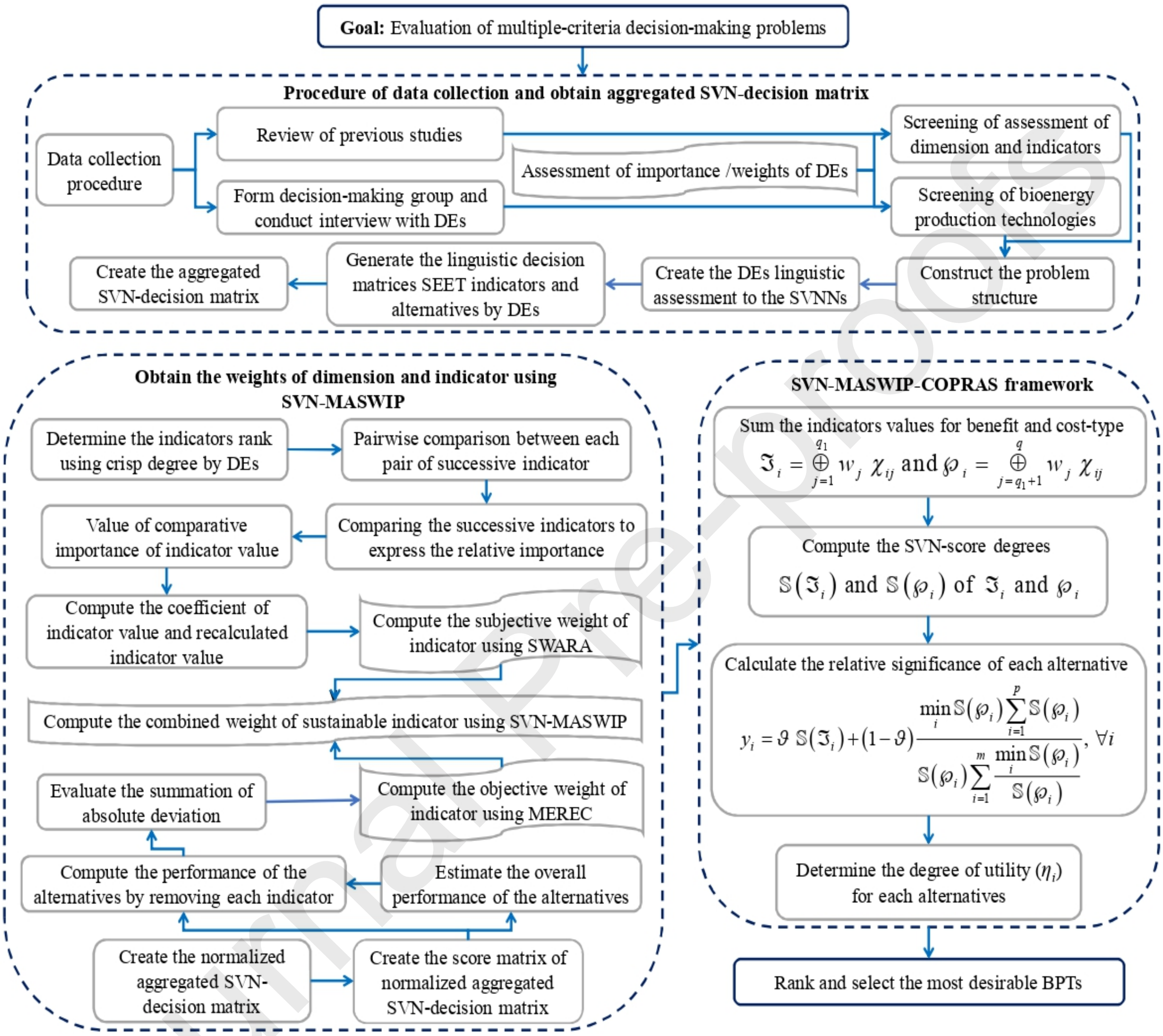


Fig. 1: Implementation structure of SVN-MASWIP-COPRAS framework

Step 1: Form the "linguistic decision matrix (LDM)".

Let us assume that a set of 'l' DEs $\{b_1, b_2, ..., b_l\}$ participates in the process of MCDM. Each DE evaluates the alternatives $d_i \in D = \{d_1, d_2, ..., d_p\}$ by means of a defined set of criteria $\{g_1, g_2, ..., g_q\}$ in terms of "linguistic values (LVs)". Therefore, we have a set of l "linguistic decision matrices (LDMs)" $\Omega^{(e)} = \left(\chi_{ij}^{(e)}\right)_{p\times q}$ $(1 \le e \le l)$, in which $\chi_{ij}^{(e)}$ denotes the SVNNs, that is considered from a predefined SVNN linguistic rating.

Step 2: Determine the DEs' weights.

In order to find the weights of DEs, we firstly express the preferences for DEs' weights with SVNNs $\xi_e = (\mathrm{T}_e, \mathrm{I}_e, \mathrm{F}_e)$ $(1 \le e \le l)$. Then the formula for numeric weights of DEs is presented by the following expression:

$$\varpi_e = \frac{2 + \mathrm{T}_e - \mathrm{I}_e - \mathrm{F}_e}{\sum_{e=1}^{l} [2 + \mathrm{T}_e - \mathrm{I}_e - \mathrm{F}_e]}, \text{ where } \varpi_e \ge 0 \text{ and } \sum_{e=1}^{l} \varpi_e = 1. \tag{5}$$

Step 3: Find the "aggregated SVN-decision-matrix (A-SVN-DM)".

The A-SVN-DM $\Omega = (\chi_{ij})_{p \times q}$ is computed by aggregating the elements $\chi_{ij}^{(e)} = (\mathrm{T}_{ij}^{(e)}, \mathrm{I}_{ij}^{(e)}, \mathrm{F}_{ij}^{(e)})$ using SVNWA operator, where

$$\chi_{ij} = (\mathrm{T}_{ij}, \mathrm{I}_{ij}, \mathrm{F}_{ij}) = SVNWA_{\varpi}(\chi_{ij}^{(1)}, \chi_{ij}^{(2)}, ..., \chi_{ij}^{(l)}) = \left(\nabla^{-1}\left(\sum_{e=1}^{l} \varpi_e \nabla(\mathrm{T}_e) \right), \Delta^{-1}\left(\sum_{e=1}^{l} \varpi_e \Delta(\mathrm{I}_e) \right), \Delta^{-1}\left(\sum_{e=1}^{l} \varpi_e \Delta(\mathrm{F}_e) \right) \right) \tag{6}$$

Step 4: Determine the criteria weights by MASWIP.

We consider that each criterion has different significance. In order to derive the criteria weights, we present the procedural steps for MASWIP, which as

Case I: Objective weights determination by MEREC

The MEREC model involves the following steps:

Step 4a: In this step, a linear normalization is used to create the normalized A-SVN-DM $\mathbb{N} = (\varsigma_{ij})_{p \times q}$, where

$$\varsigma_{ij} = (\overline{\mathrm{T}}_{ij}, \overline{\mathrm{I}}_{ij}, \mathrm{F}_{ij}) = \begin{cases} \chi_{ij} = (\mathrm{T}_{ij}, \mathrm{I}_{ij}, \mathrm{F}_{ij}), & j \in g_b, \\ (\chi_{ij})^c = (\mathrm{F}_{ij}, 1 - \mathrm{I}_{ij}, \mathrm{T}_{ij}), & j \in g_n. \end{cases} \tag{7}$$

In Eq. (7), g_b and g_n denote the sets of benefit and cost criteria.

Step 4b: Create the score matrix $M = (\lambda_{ij})_{p \times q}$ of each SVNN ς_{ij}, where

$$\lambda_{ij} = \left(\frac{2 + \mathrm{T}_{ij} - \mathrm{I}_{ij} - \mathrm{F}_{ij}}{3} \right). \tag{8}$$

Step 4c: Obtain the overall performance of the alternatives.

Here, a measure with equivalent criteria weights is used to find alternatives' overall performances. It is determined as

$$O_i = ln\left(1 + \left(\frac{1}{n} \sum_j \left| ln(\lambda_{ij}) \right| \right) \right). \tag{9}$$

Step 4d: Compute the assessment of alternatives by removing each criterion.

In the present step, we find the alternatives' performances based on removal of each criterion individually. Consequently, we obtain *n* sets of performances related to *n* criteria. Now, the required formula for the assessment of alternatives is given as

$$O'_{ij} = ln\left(1 + \left(\frac{1}{n} \sum_{k, k \ne j} \left| ln(O_{ik}) \right| \right) \right). \tag{10}$$

Step 4e: Estimate the removal effect of the j^{th} criterion on the basis of previous steps

$$E_j = \sum_i \left| \vartheta'_{ij} - \vartheta_i \right|. \tag{11}$$

Step 4f: The objective weights of criteria are derived as

$$w_j^M = \frac{E_j}{\sum_{j=1}^{q} E_j}, 1 \le j \le q. \tag{12}$$

Case II: Subjective weights evaluation by SWARA method

Step 4g: By utilizing Eq. (3), determine the score values of the considered criteria.

Step 4h: Based on the score values, prioritize the criteria from most important to least important. Subsequently, the comparative significance (s_j) of score value is obtained with the use of criteria on j^{th} and $(j\text{-}1)^{th}$ positions.

Step 4i: Find out the comparative coefficient using

$$k_j = \begin{cases} 1, & j = 1, \\ s_j + 1, & j > 1. \end{cases} \tag{13}$$

Step 4j: Based on Step 4i, the recalculated weight r_j , which as

$$r_j = \begin{cases} 1, & j = 1, \\ \dfrac{k_{j-1}}{k_j}, & j > 1. \end{cases} \tag{14}$$

Step 4k: The subjective weights of criteria are derived by

$$w_j^S = \frac{r_j}{\sum_{j=1}^{q} r_j}, 1 \le j \le q. \tag{15}$$

Case III: Estimate the integrated weight by integrating Eq. (12) and Eq. (15), which as

$$w_j = \gamma\, w_j^M + (1-\gamma)\, w_j^S, \tag{16}$$

In Eq. (16), γ signifies the decision precision coefficient and sorts out which weight is dominating. The experts lean towards the subjective weight if γ is high; and in case if γ is low, experts favour the objective weight. The parameter γ ∈[0, 1] can be termed as the risk attitude for a group decision-making problem. A high value of γ infers that the expert inclines toward risk. Else, he/she turns into a risk adverse person who regards the trustworthiness of the evaluation group.

Step 5: Sum the degrees of benefit and cost types of criteria

In this step, each alternative is assessed based on the sum of values for benefit and cost criteria. Let $\Delta = \{1, 2, ..., q_1\}$ be a set of benefit types of criteria. Now, the evaluation of benefit criteria degree $(\Im_i)$ for each alternative is expressed by

$$\Im_i = \bigoplus_{j=1}^{q_1} w_j\, \chi_{ij} = \left(\nabla^{-1}\left(\sum_{j=1}^{q_1} w_j \nabla(\mathrm{T}_{ij}) \right), \Delta^{-1}\left(\sum_{j=1}^{q_1} w_j \Delta(\mathrm{I}_{ij}) \right), \Delta^{-1}\left(\sum_{j=1}^{q_1} w_j \Delta(\mathrm{F}_{ij}) \right) \right), \ \ \forall i. \tag{17}$$

Let $\nabla = \{q_1 + 1, q_1 + 2, ..., q\}$ be a set of cost types of criteria. Then the evaluation of cost criteria degree $(\wp_i)$ for each alternative is estimated as

$$\wp_i = \mathop{\oplus}_{j=q_1+1}^{q} w_j\,\chi_{ij} = \left(\nabla^{-1}\left(\sum_{j=q_1+1}^{q} w_j \nabla(\mathrm{T}_{ij}) \right), \Delta^{-1}\left(\sum_{j=q_1+1}^{q} w_j \Delta(\mathrm{I}_{ij}) \right), \Delta^{-1}\left(\sum_{j=q_1+1}^{q} w_j \Delta(\mathrm{F}_{ij}) \right) \right), \ \forall i. \quad (18)$$

In formulae (17) and (18), q_1, q and w_j denote the total number of benefit criteria, total number of criteria and weight of the j^{th} criterion ($1 \le j \le q$).

Step 6: Compute the "relative degree (*RD*)".

With the use of Eq. (19), compute the *RD* of i^{th} alternative, which as

$$y_i = \vartheta\,\mathbb{S}(\Im_i) + (1-\vartheta)\frac{\min_i \mathbb{S}(\wp_i)\sum_{i=1}^{p}\mathbb{S}(\wp_i)}{\mathbb{S}(\wp_i)\sum_{i=1}^{m}\frac{\min_i \mathbb{S}(\wp_i)}{\mathbb{S}(\wp_i)}}, \ \forall i. \quad (19)$$

Here, $\mathbb{S}(\Im_i)$ and $\mathbb{S}(\wp_i)$ are the SVN-score degrees of $\Im_i$ and $\wp_i$, correspondingly. In Eq. (19), ϑ determines the coefficient of DEs' strategies and $\vartheta \in [0,1]$. The DE is pessimistic for $\vartheta < 0.5$, optimistic for $\vartheta > 0.5$ and unbiased for $\vartheta = 0.5$, and maximum value is associated as significance degree to the cost, benefit and both types of criteria.

Step 7: Determine the priority order and "degree of utility (*UD*)".

Based on step 6, we prioritize the alternatives, where the utmost value of RD has been given as high preference. Comparing the optimal candidate with other alternatives, we evaluate the UD of each alternative by using Eq. (20), which as

$$\eta_i = \frac{y_i}{y_{\max}} \times 100\%, \ 1 \le i \le p. \quad (20)$$

Step 9: End.

4. Case Study: Sustainable Assessment for BPTs Selection

In the present section, we implement the present SVN-MASWIP-COPRAS approach in the assessment of candidate BPTs, which confirms its practicality and efficacy. During these times, various conversion procedures have been discussed to change biomass into bioenergy. Yue et al. (2014) stated the main challenges and prospects in the optimization of biomass-to-bioenergy supply chains. They studied the key energy procedures from terrestrial and aquatic biomass to bioenergy/biofuel yields. Various processes are established and have been developed, for instance, biofuels from oil crops, and starch- and sugar-based feedstock and some other processes like algae to biofuels, are relatively novel, and are still in the primary stage. A study of BPT assessment in Iran (Khishtandar et al., 2017) has been discussed to estimate the BPTs and opt the suitable BPT option. Nonetheless, in this paper, to assemble the data, the comprehensive framework was discussed in diverse steps. A survey procedure with the use of interviews and literature is conducted to recognize the key dimensions and indicators for evaluation of BPTs. Based on the outcomes of the survey, four prime dimensions, comprising social (S), environmental (E), economic (E) and technological (T), called as SEET dimensions/aspects were considered with 14 related indicators. For this purpose, six BPTs, containing oil crops to biodiesel (d_1), wet biomass to biogas (d_2), forest residues to ethanol (d_3), forest residues to biodiesel (d_4), wet biomass to biodiesel (d_5) and agricultural and municipal wastes to biogas (d_6) were taken over 14 indicators belonging to SEET dimensions.

Based on literature review and discussion with experts, we have identified the SEET aspects and related 14 indicators in Table 1 and Fig. 2.

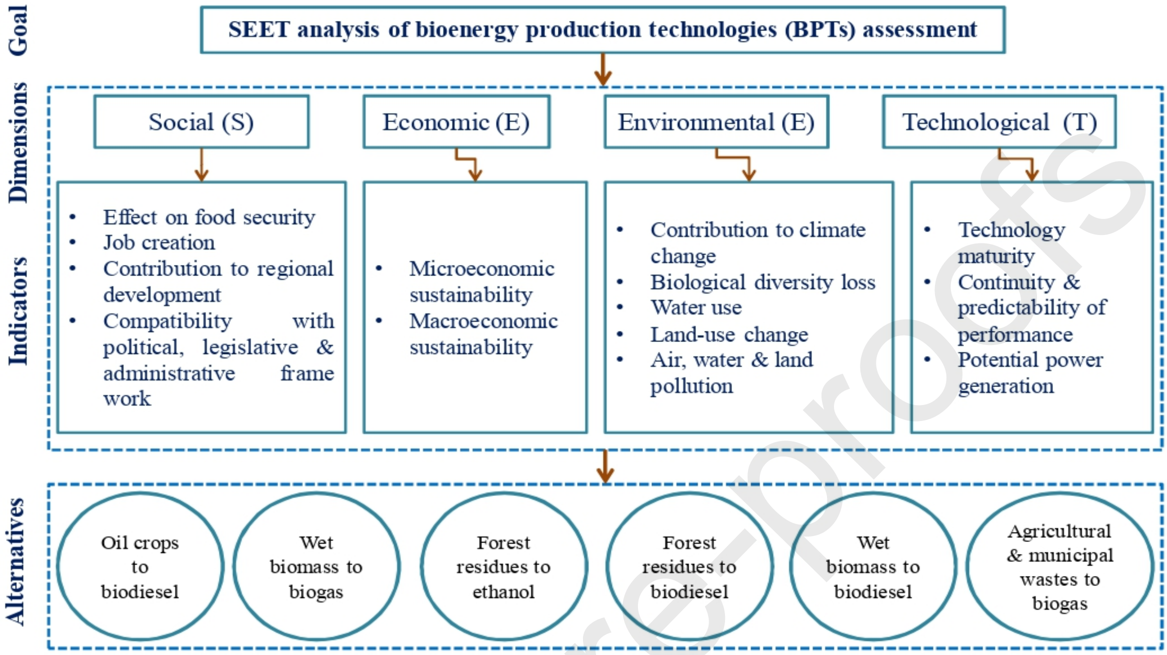


Fig. 2: The framework for BPTs assessment from SEET aspects

Table 1: The SEET dimension for sustainability assessment of BPTs selection

Dimension	Indicators	References
Social	Effects on food security (g_1)	Buchholz et al. (2009), Khishtandar et al. (2017), Mishra et al. (2020), Abdel-Basset et al. (2021)
	Job creation (g_2)	Doukas et al. (2007), Troldborg et al. (2014), Rovere et al. (2010), Buchholz et al. (2009), Abdel-Basset et al. (2021)
	Contribution to regional development (g_3)	Doukas et al. (2007), Khishtandar et al., (2017) Mishra et al. (2020)
	Compatibility with political, legislative and administrative framework (g_4)	Beccali et al. (2003), Buchholz et al. (2009), Kurka and Blackwood (2013), Abdel-Basset et al. (2021)
Economic	Microeconomic sustainability (g_5)	Doukas et al. (2007), Rovere et al. (2010), Buchholz et al. (2009), Kurka and Blackwood (2013), Khishtandar et al. (2017), Mishra et al. (2020), Abdel-Basset et al. (2021)
	Macroeconomic sustainability (g_6)	Vera and Langlois (2007), Rovere et al. (2010), Buchholz et al. (2009), Kurka and Blackwood (2013), Khishtandar et al. (2017), Mishra et al. (2020), Abdel-Basset et al. (2021)
Environmental	Contribution to climate change (g_7)	Vera and Langlois (2007), Doukas et al. (2007), Rovere et al. (2010), Buchholz et al. (2009), Khishtandar et al. (2017), Mishra et al. (2020), Abdel-Basset et al. (2021)
	Biological diversity loss (g_8)	Buchholz et al. (2009), Khishtandar et al. (2017), Mishra et al. (2020), Abdel-Basset et al. (2021)
	Water use (g_9)	Rovere et al. (2010), Khishtandar et al. (2017), Mishra et al. (2020), Abdel-Basset et al. (2021)
	Land- use change (g_{10})	Troldborg et al. (2014), Rovere et al. (2010), Khishtandar et al. (2017), Abdel-Basset et al. (2021)

	Air, water and land pollution (g_{11})	Beccali et al. (2003), Vera and Langlois (2007), Rovere et al. (2010), Buchholz et al. (2009), Khishtandar et al. (2017), Mishra et al. (2020), Abdel-Basset et al. (2021)]
Technological	Technology maturity (g_{12})	Beccali et al. (2003), Doukas et al. (2007), Kurka and Blackwood (2013), Troldborg et al. (2014), Mishra et al. (2020), Abdel-Basset et al. (2021)
	Continuity and predictability of performance (g_{13})	Beccali et al. (2003), Kurka and Blackwood (2013), Troldborg et al. (2014), Rovere et al. (2010), Khishtandar et al. (2017), Mishra et al. (2020), Abdel-Basset et al. (2021)
	Potential power generation (g_{14})	Troldborg et al. (2014), Khishtandar et al. (2017), Abdel-Basset et al. (2021)

Tables 2-3 present the LVs and their corresponding SVNNs for the DEs and criteria in BPTs assessment. On account of Table 4 and Eq. (5), we compute the weights of four DEs, who are responsible for the evaluation of BPTs. Table 5 denotes the LDM obtained from DEs' opinions in the assessment of each BPT alternative over a predefined set of 14 indicators. By aggregating the four DEs' opinions, we create the final A-SVN-DM in Table 6 with the use of Eq. (6) (Taking $\Delta(x) = -\ln x$, $\Delta^{-1}(x) = e^{-x}$, $\nabla(x) = -\ln(1-x)$ and $\nabla^{-1}(x) = 1 - e^{-x}$), and Table 5. Since g_7, g_8 and g_{11} are cost types of criteria, and others are of benefit types, therefore, we normalize the A-SVN-DM by using Eq. (7) and shown in Table 7.

Table 2: LVs for the weights of DEs

LVs	SVNNs
Extremely knowledgeable (EK)	(0.90, 0.10, 0.10)
Very knowledgeable (VK)	(0.75, 0.25, 0.20)
Much knowledgeable (MK)	(0.60, 0.35, 0.40)
Knowledgeable (K)	(0.50, 0.45, 0.50)
Less knowledgeable (LK)	(0.40, 0.75, 0.60)
Inexperienced (I)	(0.20, 0.90, 0.80)

Table 3: Linguistic scale table for rating the criteria in BPTs evaluation

LVs	SVNNs
Extremely significant (ES)	(1.0, 0.0, 0.0)
Very significant (VS)	(0.9, 0.1, 0.1)
Much significant (MS)	(0.8, 0.15, 0.2)
Significant (S)	(0.7, 0.25, 0.3)
Quite significant (QS)	(0.6, 0.35, 0.4)
Reasonable (R)	(0.5, 0.5, 0.5)
Quite insignificant (QI)	(0.4, 0.65, 0.6)
Insignificant (I)	(0.3, 0.75, 0.7)
Much insignificant (MI)	(0.2, 0.85, 0.8)
Very insignificant (VI)	(0.1, 0.9, 0.9)
Extremely insignificant (EI)	(0.0, 1.0, 1.0)

Table 4: Numeric weights of DEs

DEs	LVs	SVNNs	Weights
b_1	VQ	(0.60, 0.35, 0.40)	0.2741
b_2	VVQ	(0.75, 0.25, 0.20)	0.3407
b_3	Q	(0.50, 0.45, 0.50)	0.2296
b_4	LS	(0.40, 0.75, 0.60)	0.1556

Table 5: The LDM for assessing the BPTs by four DEs

	d_1	d_2	d_3	d_4	d_5	d_6
g_1	(QS,QI,R,S)	(S,S,MS,S)	(R,I,R,R)	(R,S,QS,S)	(QS,S,QS,R)	(S,S,S,MS)
g_2	(R,S,QS,S)	(S,MS,QS,MS)	(S,R,R,S)	(R,R,QS,S)	(S,R,S,QS)	(R,S,MS,QS)
g_3	(R,S,QS,R)	(S,MS,S,MS)	(R,QI,R,QS)	(S,S,R,QS)	(S,R,S,S)	(R,R,MS,S)
g_4	(S,R,QI,R)	(S,QI,S,I)	(R,QI,R,R)	(R,S,R,QS)	(QS,S,R,QI)	(R,S,QI,S)
g_5	(QS,QS,R,QI)	(S,QS,S,R)	(S,R,S,R)	(S,MS,QS,S)	(R,QS,QS,R)	(MS,S,QS,S)
g_6	(R,QS,S,MS)	(QS,S,QS,QS)	(S,R,R,QI)	(R,QS,R,QS)	(S,R,QS,S)	(R,QS,S,MS)
g_7	(QI,I,QS,R)	(I,S,R,QS)	(R,QI,R,I)	(R,QI,R,S)	(S,QI,I,QI)	(I,I,S,R)
g_8	(MI,R,I,MI)	(S,R,S,QI)	(I,R,I,R)	(QI,R,QS,R)	(I,VI,R,I)	(QS,I,R,QI)
g_9	(S,R,MS,QS)	(QI,QS,S,MS)	(R,QI,S,I)	(R,S,QI,QS)	(MS,S,R,MS)	(S,QI,QS,S)
g_{10}	(S,QI,I,MI)	(QS,R,S,I)	(R,S,QI,QS)	(R,QI,S,MS)	(R,S,QI,I)	(S,QS,R,MS)
g_{11}	(QS,R,QI,S)	(S,R,QS,QI)	(R,I,QS,QI)	(R,S,R,QI)	(S,QS,R,QI)	(S,S,R,QS)
g_{12}	(QI,R,I,QS)	(QS,R,QI,I)	(MS,R,QI,QI)	(R,S,MS,QI)	(MS,QI,R,I)	(QS,S,R,QI)
g_{13}	(QI,R,QS,S)	(R,MS,QS,R)	(S,QS,R,QI)	(R,QS,S,QI)	(QS,QI,R,QS)	(I,R,MS,QS)
g_{14}	(MI,QS,S,QI)	(QS,MI,I,MS)	(S,QI,I,QS)	(MS,I,R,I)	(R,MI,QS,S)	(S,QS,QI,I)

Table 6: The A-SVN-DM for BPTs evaluation

	d_1	d_2	d_3	d_4	d_5	d_6
g_1	(0.522, 0.445, 0.462)	(0.704, 0.222, 0.273)	(0.426, 0.574, 0.561)	(0.601, 0.327, 0.369)	(0.593, 0.330, 0.375)	(0.695, 0.231, 0.282)
g_2	(0.601, 0.327, 0.369)	(0.689, 0.210, 0.262)	(0.545, 0.371, 0.401)	(0.541, 0.414, 0.439)	(0.595, 0.334, 0.373)	(0.680, 0.283, 0.329)
g_3	(0.568, 0.364, 0.399)	(0.696, 0.221, 0.273)	(0.468, 0.517, 0.514)	(0.618, 0.309, 0.353)	(0.626, 0.317, 0.357)	(0.704, 0.222, 0.273)
g_4	(0.525, 0.439, 0.453)	(0.552, 0.411, 0.433)	(0.450, 0.547, 0.532)	(0.560, 0.374, 0.406)	(0.559, 0.373, 0.407)	(0.562, 0.376, 0.405)
g_5	(0.523, 0.418, 0.448)	(0.619, 0.312, 0.358)	(0.595, 0.353, 0.387)	(0.689, 0.227, 0.279)	(0.532, 0.408, 0.440)	(0.689, 0.235, 0.287)
g_6	(0.620, 0.313, 0.357)	(0.607, 0.312, 0.363)	(0.532, 0.431, 0.447)	(0.524, 0.374, 0.406)	(0.601, 0.342, 0.381)	(0.620, 0.313, 0.357)
g_7	(0.427, 0.568, 0.560)	(0.518, 0.417, 0.445)	(0.420, 0.582, 0.561)	(0.492, 0.491, 0.491)	(0.468, 0.517, 0.514)	(0.440, 0.547, 0.547)
g_8	(0.308, 0.689, 0.661)	(0.584, 0.367, 0.398)	(0.380, 0.613, 0.592)	(0.477, 0.495, 0.499)	(0.312, 0.713, 0.678)	(0.444, 0.542, 0.543)
g_9	(0.644, 0.297, 0.340)	(0.601, 0.336, 0.376)	(0.484, 0.497, 0.499)	(0.542, 0.415, 0.438)	(0.693, 0.235, 0.283)	(0.580, 0.374, 0.406)
g_{10}	(0.444, 0.539, 0.538)	(0.538, 0.412, 0.441)	(0.542, 0.397, 0.423)	(0.576, 0.387, 0.410)	(0.500, 0.447, 0.462)	(0.629, 0.304, 0.349)
g_{11}	(0.526, 0.432, 0.453)	(0.555, 0.397, 0.425)	(0.439, 0.551, 0.548)	(0.532, 0.411, 0.432)	(0.559, 0.381, 0.414)	(0.618, 0.309, 0.353)
g_{12}	(0.426, 0.558, 0.548)	(0.459, 0.513, 0.517)	(0.563, 0.398, 0.417)	(0.621, 0.312, 0.350)	(0.549, 0.419, 0.436)	(0.559, 0.373, 0.407)
g_{13}	(0.517, 0.444, 0.461)	(0.613, 0.306, 0.348)	(0.549, 0.390, 0.425)	(0.608, 0.325, 0.369)	(0.586, 0.372, 0.400)	(0.551, 0.401, 0.429)
g_{14}	(0.487, 0.455, 0.482)	(0.415, 0.564, 0.576)	(0.501, 0.469, 0.483)	(0.529, 0.440, 0.460)	(0.477, 0.496, 0.515)	(0.529, 0.414, 0.443)

Table 7: Normalized A-SVN-DM for BPTs evaluation

	d_1	d_2	d_3	d_4	d_5	d_6
g_1	(0.522, 0.445, 0.462)	(0.704, 0.222, 0.273)	(0.426, 0.574, 0.561)	(0.601, 0.327, 0.369)	(0.593, 0.330, 0.375)	(0.695, 0.231, 0.282)
g_2	(0.601, 0.327, 0.369)	(0.689, 0.210, 0.262)	(0.545, 0.371, 0.401)	(0.541, 0.414, 0.439)	(0.595, 0.334, 0.373)	(0.680, 0.283, 0.329)
g_3	(0.568, 0.364, 0.399)	(0.696, 0.221, 0.273)	(0.468, 0.517, 0.514)	(0.618, 0.309, 0.353)	(0.626, 0.317, 0.357)	(0.704, 0.222, 0.273)

g_4	(0.525, 0.439, 0.453)	(0.552, 0.411, 0.433)	(0.450, 0.547, 0.532)	(0.560, 0.374, 0.406)	(0.559, 0.373, 0.407)	(0.562, 0.376, 0.405)
g_5	(0.523, 0.418, 0.448)	(0.619, 0.312, 0.358)	(0.595, 0.353, 0.387)	(0.689, 0.227, 0.279)	(0.532, 0.408, 0.440)	(0.689, 0.235, 0.287)
g_6	(0.620, 0.313, 0.357)	(0.607, 0.312, 0.363)	(0.532, 0.431, 0.447)	(0.524, 0.374, 0.406)	(0.601, 0.342, 0.381)	(0.620, 0.313, 0.357)
g_7	(0.560, 0.432, 0.427)	(0.445, 0.583, 0.518)	(0.561, 0.418, 0.420)	(0.491, 0.509, 0.492)	(0.514, 0.483, 0.468)	(0.547, 0.453, 0.440)
g_8	(0.661, 0.311, 0.308)	(0.398, 0.633, 0.584)	(0.592, 0.387, 0.380)	(0.499, 0.505, 0.477)	(0.678, 0.287, 0.312)	(0.543, 0.458, 0.444)
g_9	(0.644, 0.297, 0.340)	(0.601, 0.336, 0.376)	(0.484, 0.497, 0.499)	(0.542, 0.415, 0.438)	(0.693, 0.235, 0.283)	(0.580, 0.374, 0.406)
g_{10}	(0.444, 0.539, 0.538)	(0.538, 0.412, 0.441)	(0.542, 0.397, 0.423)	(0.576, 0.387, 0.410)	(0.500, 0.447, 0.462)	(0.629, 0.304, 0.349)
g_{11}	(0.453, 0.568, 0.526)	(0.425, 0.603, 0.555)	(0.548, 0.449, 0.439)	(0.432, 0.589, 0.532)	(0.414, 0.619, 0.559)	(0.353, 0.691, 0.618)
g_{12}	(0.426, 0.558, 0.548)	(0.459, 0.513, 0.517)	(0.563, 0.398, 0.417)	(0.621, 0.312, 0.350)	(0.549, 0.419, 0.436)	(0.559, 0.373, 0.407)
g_{13}	(0.517, 0.444, 0.461)	(0.613, 0.306, 0.348)	(0.549, 0.390, 0.425)	(0.608, 0.325, 0.369)	(0.586, 0.372, 0.400)	(0.551, 0.401, 0.429)
g_{14}	(0.487, 0.455, 0.482)	(0.415, 0.564, 0.576)	(0.501, 0.469, 0.483)	(0.529, 0.440, 0.460)	(0.477, 0.496, 0.515)	(0.529, 0.414, 0.443)

To compute the indicators' weights, we firstly used the MEREC model for objective weights. For this purpose, we create the score matrix by means of Eq. (8) and Table 7. Using Eq. (9), we have derived the BPTs' overall performance values, which are O_1 = 0.463, O_2 = 0.453, O_3 = 0.479, O_4 = 0.435, O_5 = 0.432 and O_6 = 0.411. In accordance with Eqs (10)-(11), we have computed the BPTs' overall performance values by eliminating each indicator individually and removal effect of the sustainable indicators. Thus, final objective weights of criteria are derived by utilizing Eq. (12), and are given in Table 8 (see Fig. 3).

Table 8: Results of MEREC model

	(O'_{ij})						E_j	w_j^M
	d_1	d_2	d_3	d_4	d_5	d_6		
g_1	0.435	0.439	0.441	0.414	0.411	0.396	0.138	0.0633
g_2	0.443	0.439	0.456	0.408	0.411	0.393	0.124	0.0569
g_3	0.440	0.438	0.446	0.415	0.412	0.397	0.125	0.0572
g_4	0.436	0.427	0.444	0.411	0.408	0.386	0.163	0.0744
g_5	0.436	0.433	0.458	0.420	0.405	0.396	0.126	0.0575
g_6	0.444	0.432	0.453	0.410	0.410	0.391	0.134	0.0615
g_7	0.437	0.415	0.455	0.402	0.402	0.383	0.180	0.0823
g_8	0.446	0.409	0.457	0.403	0.415	0.382	0.161	0.0736
g_9	0.445	0.431	0.448	0.408	0.417	0.387	0.137	0.0628
g_{10}	0.427	0.426	0.455	0.411	0.403	0.391	0.162	0.0739
g_{11}	0.427	0.413	0.453	0.396	0.391	0.360	0.235	0.1074
g_{12}	0.426	0.418	0.455	0.415	0.406	0.386	0.168	0.0768
g_{13}	0.435	0.433	0.455	0.414	0.409	0.384	0.144	0.0657
g_{14}	0.433	0.413	0.450	0.406	0.399	0.383	0.190	0.0868

Table 9: Score degrees of indicators obtained by DEs in terms of LVs for BPTs assessment

Indicators	b_1	b_2	b_3	b_4	**Aggregated SVNNs**	**Score degree**
g_1	QS	R	S	S	(0.595, 0.347, 0.386)	0.621
g_2	R	QS	QS	QI	(0.568, 0.425, 0.453)	0.563
g_3	S	R	QI	R	(0.525, 0.439, 0.453)	0.544
g_4	QI	R	QS	QS	(0.495, 0.468, 0.482)	0.515

g_5	MS	QS	QS	MS	(0.684, 0.243, 0.297)	0.715
g_6	S	QS	MS	MS	(0.699, 0.230, 0.283)	0.729
g_7	QS	S	MS	QI	(0.643, 0.283, 0.329)	0.323
g_8	S	QS	S	R	(0.619, 0.312, 0.358)	0.350
g_9	QS	I	R	QS	(0.478, 0.492, 0.509)	0.492
g_{10}	QI	R	R	QI	(0.434, 0.560, 0.541)	0.444
g_{11}	QS	QS	R	I	(0.512, 0.428, 0.459)	0.458
g_{12}	S	QS	S	QI	(0.608, 0.325, 0.369)	0.638
g_{13}	R	QS	S	R	(0.562, 0.378, 0.412)	0.591
g_{14}	S	QI	R	QI	(0.508, 0.471, 0.476)	0.520

Table 10: Subjective weights of indicators obtained by SWARA procedure for BPTs assessment

Indicators	**Score degree**	(s_j)	(k_j)	(r_j)	(w_j^S)
g_6	0.729	-	1.000	1.000	0.0857
g_5	0.715	0.014	1.014	0.9862	0.0845
g_{12}	0.638	0.077	1.077	0.9157	0.0785
g_1	0.621	0.017	1.017	0.9004	0.0772
g_{13}	0.591	0.030	1.030	0.8742	0.0749
g_2	0.563	0.028	1.028	0.8504	0.0729
g_3	0.544	0.019	1.019	0.8345	0.0715
g_{14}	0.520	0.024	1.024	0.8149	0.0699
g_4	0.515	0.005	1.005	0.8108	0.0695
g_9	0.492	0.023	1.023	0.7926	0.0679
g_{11}	0.458	0.034	1.034	0.7665	0.0657
g_{10}	0.444	0.014	1.014	0.7559	0.0648
g_8	0.350	0.094	1.094	0.6909	0.0592
g_7	0.323	0.027	1.027	0.6727	0.0577

In the SWARA tool, the behaviour of the DEs is an essential part for assessing the subjective weights of indicators. Then, the DEs offer the ordering of all the indicators using their inherent knowledge and experience (see Table 9). From Table 10, Eq. (13) and Eq. (15), the most significant indicator is assigned as rank 1 and the less significant indicator is depicted as last place. Then the subjective weights are estimated and presented in Table 10 (see Fig. 3).

$w_j^S =$ (0.0772, 0.0729, 0.0715, 0.0695, 0.0845, 0.0857, 0.0577, 0.0592, 0.0679, 0.0648, 0.0657, 0.0785, 0.0749, 0.0699).

By using Eq. (16), Table 8 and Table 10, the integrated weight vector using SVN-MASWIP is computed and given in Fig. 3.

$w = \left(w_1, w_2, \ldots, w_q\right)^T =$ (0.0702, 0.0649, 0.0643, 0.0720, 0.0710, 0.0736, 0.0700, 0.0664, 0.0654, 0.0693, 0.0866, 0.0776, 0.0703, 0.0783).

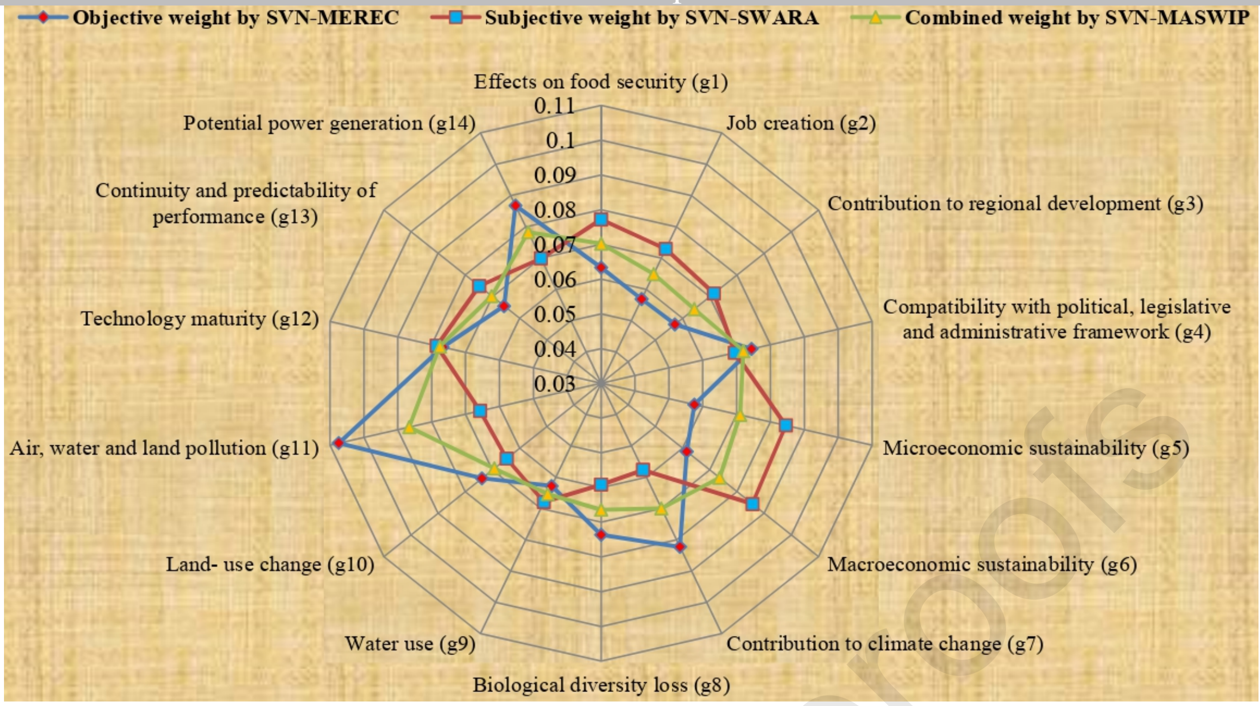


Fig. 3: Final weights of indicators using the MEREC, SWARA and MASWIP

Table 11: The computational outcome of SVN-MASWIP-COPRAS framework

Option	$\Im_i$	$\mathbb{S}(\Im_i)$	$\wp_i$	$\mathbb{S}(\wp_i)$	y_i	η_i	Ranking
d_1	(0.452, 0.503, 0.528)	0.474	(0.120, 0.872, 0.872)	0.125	0.3183	92.83%	5
d_2	(0.521, 0.428, 0.468)	0.542	(0.164, 0.812, 0.825)	0.175	0.3288	95.89%	4
d_3	(0.436, 0.532, 0.546)	0.453	(0.113, 0.885, 0.880)	0.116	0.3145	91.72%	6
d_4	(0.503, 0.442, 0.477)	0.528	(0.144, 0.841, 0.845)	0.153	0.3307	96.44%	3
d_5	(0.495, 0.459, 0.492)	0.515	(0.131, 0.859, 0.862)	0.137	0.3320	96.82%	2
d_6	(0.531, 0.408, 0.450)	0.558	(0.150, 0.831, 0.841)	0.159	0.3429	100.00%	1

Using (17)-(20) (Taking $\Delta(x) = -\ln x$, $\Delta^{-1}(x) = e^{-x}$, $\nabla(x) = -\ln(1-x)$ and $\nabla^{-1}(x) = 1-e^{-x}$), the values of $\Im_i$, $\mathbb{S}^*(\Im_i)$, $\wp_i$, $\mathbb{S}^*(\wp_i)$, y_i and η_i of BPTs are computed over the criteria $g_j\left(j=1(1)14\right)$, shown in Table 11. On basis of Table 11, the prioritization order of BPTs is $d_6 \succ d_5 \succ d_4 \succ d_2 \succ d_1 \succ d_3$ and hence, the agricultural and municipal wastes to biogas (d_6) is the optimum BPT alternative.

4.1. Sensitivity Analysis

This section discusses the sensitivity analysis with respect to diverse values of indicators' weights. The indicators' weights are obtained and presented in Table 12 over different values of parameter γ for BPTs assessment and shown in Fig. 4. With the use of MASWIP, an integrated process of indicator weights is discussed to show the sensitivity of the developed framework for diverse weight values of indicators and SEET aspects.

The results obtained from sensitivity analysis are presented in Table 13 and Fig. 5, which show that the overall *UD* could fluctuate with varied indicator weights, and hence the preferences of the BPTs. For instance, when $\gamma = 0.5$, then the prioritization order of BPTs candidates is $d_6 \succ d_5 \succ d_4 \succ d_2 \succ d_1 \succ d_3$. The results obtained from sensitivity analysis in Table 14 and Fig. 6 show that the overall UD could vary with various strategy coefficient ϑ for SVN-MASWIP-COPRAS approach, and thus, the ranking of BPTs candidates. For instance, when $\vartheta = 0.5$, then the preference order of BPTs is $d_6 \succ d_5 \succ d_4 \succ d_2 \succ d_1 \succ d_3$. Thus, we conclude that the BPTs evaluation is dependent on and sensitive to taken indicators' weight and strategy parameter coefficient. Consequently, the proposed method is stable and efficient with different weights of indicators.

Table 12: Variation indicator weights over diverse values of parameter γ for BPTs assessment

γ	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
g_1	0.0772	0.0758	0.0744	0.0730	0.0716	0.0702	0.0688	0.0674	0.0661	0.0647	0.0633
g_2	0.0729	0.0713	0.0697	0.0681	0.0665	0.0649	0.0633	0.0617	0.0601	0.0585	0.0569
g_3	0.0715	0.0701	0.0686	0.0672	0.0658	0.0643	0.0629	0.0615	0.0600	0.0586	0.0572
g_4	0.0695	0.0700	0.0705	0.0710	0.0715	0.0720	0.0725	0.0730	0.0735	0.0740	0.0744
g_5	0.0845	0.0818	0.0791	0.0764	0.0737	0.0710	0.0683	0.0656	0.0629	0.0602	0.0575
g_6	0.0857	0.0833	0.0809	0.0784	0.0760	0.0736	0.0712	0.0687	0.0663	0.0639	0.0615
g_7	0.0577	0.0602	0.0626	0.0651	0.0675	0.0700	0.0724	0.0749	0.0774	0.0798	0.0823
g_8	0.0592	0.0606	0.0621	0.0635	0.0650	0.0664	0.0679	0.0693	0.0707	0.0722	0.0736
g_9	0.0679	0.0674	0.0669	0.0664	0.0659	0.0654	0.0649	0.0644	0.0638	0.0633	0.0628
g_{10}	0.0648	0.0657	0.0666	0.0675	0.0684	0.0693	0.0703	0.0712	0.0721	0.0730	0.0739
g_{11}	0.0657	0.0699	0.0740	0.0782	0.0824	0.0866	0.0907	0.0949	0.0991	0.1032	0.1074
g_{12}	0.0785	0.0783	0.0782	0.0780	0.0778	0.0776	0.0775	0.0773	0.0771	0.0769	0.0768
g_{13}	0.0749	0.0740	0.0731	0.0721	0.0712	0.0703	0.0694	0.0684	0.0675	0.0666	0.0657
g_{14}	0.0699	0.0716	0.0733	0.0750	0.0767	0.0783	0.0800	0.0817	0.0834	0.0851	0.0868

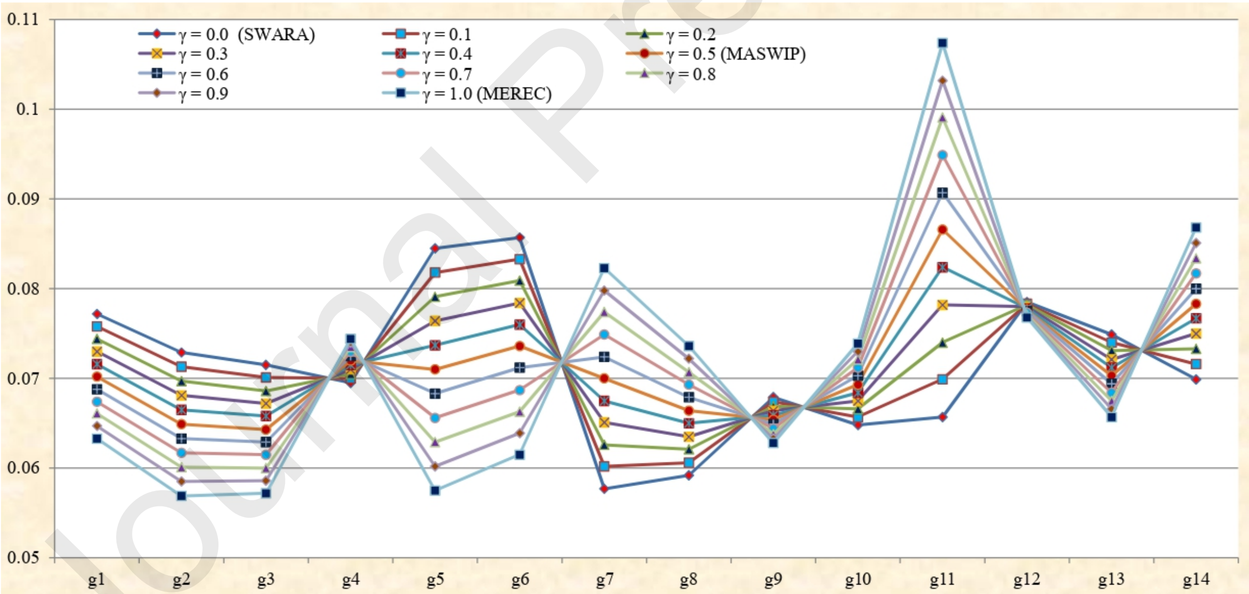


Fig. 4: Variation of weights of indicators with different values of parameter γ

Table 13: Ranking of overall *UD* for each BPT with various values of parameter γ

BPTs	γ = 0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
d_1	0.3146	0.3154	0.3162	0.3170	0.3177	0.3183	0.3190	0.3195	0.3201	0.3206	0.3211
d_2	0.3295	0.3294	0.3293	0.3292	0.3290	0.3288	0.3286	0.3283	0.3280	0.3276	0.3272
d_3	0.3075	0.3090	0.3104	0.3118	0.3132	0.3145	0.3158	0.3170	0.3182	0.3194	0.3206
d_4	0.3285	0.3290	0.3295	0.3299	0.3303	0.3307	0.3310	0.3313	0.3315	0.3318	0.3320
d_5	0.3293	0.3300	0.3305	0.3311	0.3316	0.3320	0.3325	0.3329	0.3333	0.3336	0.3340
d_6	0.3427	0.3428	0.3429	0.3429	0.3429	0.3429	0.3428	0.3427	0.3426	0.3425	0.3423

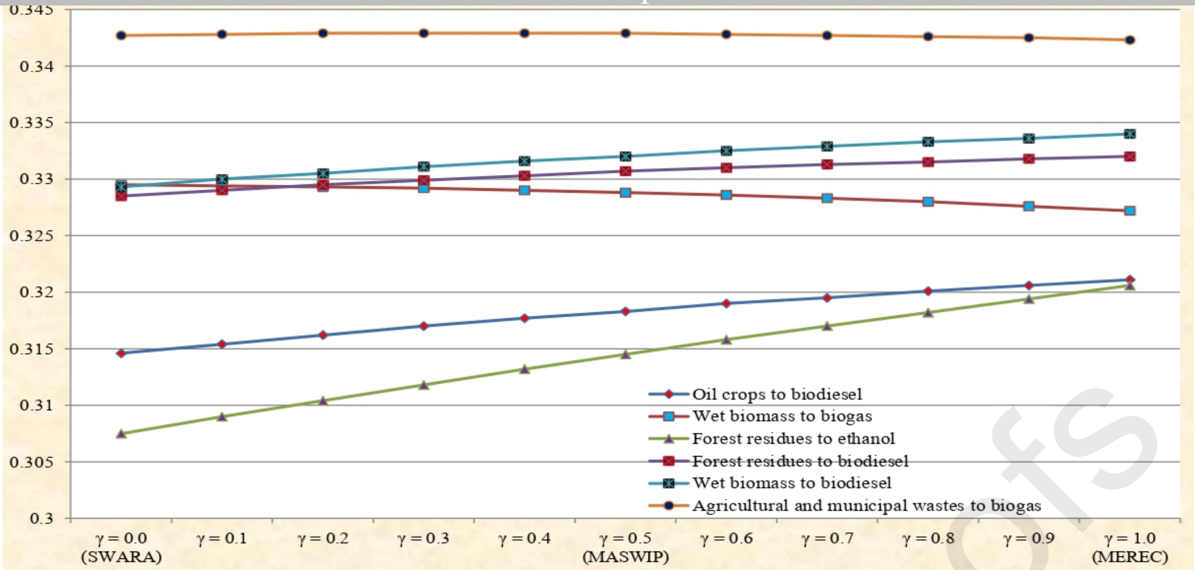


Fig. 5: Variation of utility degree of BPTs over different weight of indicators with diverse parameter values

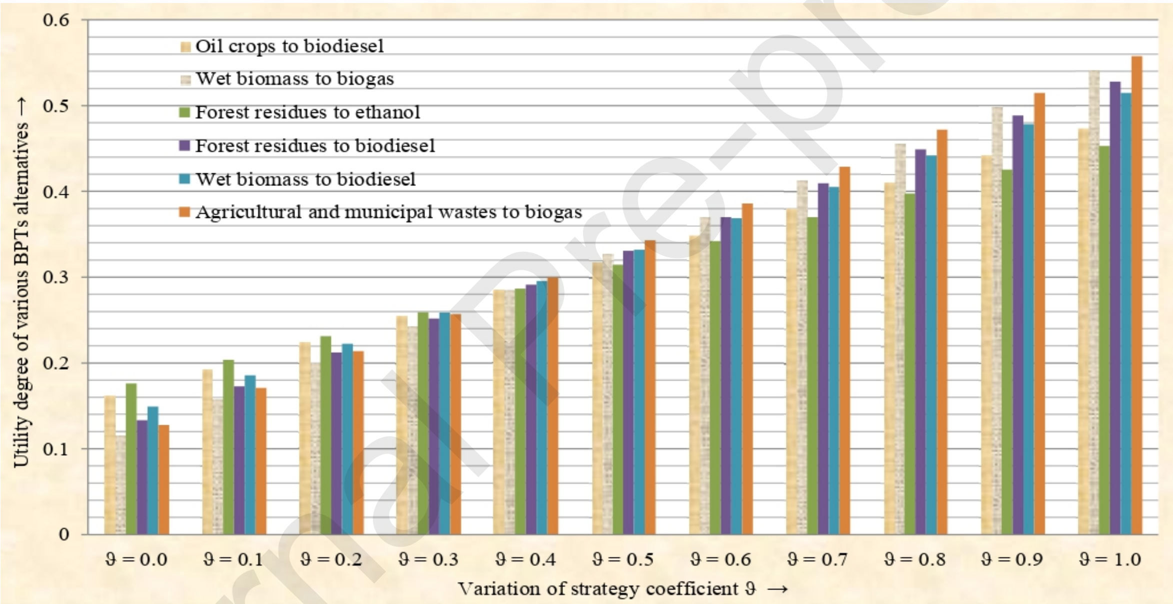


Fig. 6: Variation of utility degree of BPTs with different values of strategy parameter ϑ

Table 14: The *UDs* of BPTs over diverse values of strategy parameter ϑ

BPTs	$\vartheta = 0.0$	$\vartheta = 0.1$	$\vartheta = 0.2$	$\vartheta = 0.3$	$\vartheta = 0.4$	$\vartheta = 0.5$	$\vartheta = 0.6$	$\vartheta = 0.7$	$\vartheta = 0.8$	$\vartheta = 0.9$	$\vartheta = 1.0$
d_1	0.1627	0.1938	0.2250	0.2561	0.2872	0.3183	0.3494	0.3806	0.4117	0.4428	0.4739
d_2	0.1161	0.1586	0.2012	0.2437	0.2863	0.3288	0.3713	0.4139	0.4564	0.4990	0.5415
d_3	0.1760	0.2037	0.2314	0.2591	0.2868	0.3145	0.3422	0.3699	0.3976	0.4253	0.4530
d_4	0.1332	0.1727	0.2122	0.2517	0.2912	0.3307	0.3701	0.4096	0.4491	0.4886	0.5281
d_5	0.1491	0.1857	0.2223	0.2589	0.2955	0.3320	0.3686	0.4052	0.4418	0.4784	0.5149
d_6	0.1279	0.1709	0.2139	0.2569	0.2999	0.3429	0.3859	0.4289	0.4719	0.5148	0.5578

4.2. Comparative Study

To confirm the robustness of obtained results, we compare the proposed method with some of the existing approaches, such as the SVN-TOPSIS method (Nancy and Garg, 2019), SVN-WASPAS (Zavadskas et al., 2016), HFL-ELECTRE (Khishtandar et al., 2017), IF-SWARA-COPRAS (Mishra et al., 2020) and TN-DEMATEL-EDAS (Abdel-Basset et al. 2021).

4.2.1. SVN-TOPSIS Appraoch

This approach involves the following procedural steps:

Steps 1-4: Same as the proposed SVN-MASWIP-COPRAS

Step 5: Find the "single-valued neutrosophic ideal solution (SVN-IS)" and "single-valued neutrosophic anti-ideal solution (SVNA-IS)" by using

$$\hat{\xi}_j^{+} = \left(\mathrm{T}_j^{+}, \mathrm{I}_j^{+}, F_j^{+}\right) = \begin{cases} \left(\max_i \hat{\mathrm{T}}_{ij}, \min_i \hat{\mathrm{I}}_{ij}, \min_i \hat{\mathrm{F}}_{ij}\right), & j \in g_{\max} \\ \left(\min_i \hat{\mathrm{T}}_{ij}, \max_i \hat{\mathrm{I}}_{ij}, \max_i \hat{\mathrm{F}}_{ij}\right), & j \in g_{\min} \end{cases}, \tag{21}$$

$$\hat{\xi}_j^{-} = \left(\mathrm{T}_j^{-}, \mathrm{I}_j^{-}, F_j^{-}\right) = \begin{cases} \left(\min_i \hat{\mathrm{T}}_{ij}, \max_i \hat{\mathrm{I}}_{ij}, \max_i \hat{\mathrm{F}}_{ij}\right), & j \in g_{\max} \\ \left(\max_i \hat{\mathrm{T}}_{ij}, \min_i \hat{\mathrm{I}}_{ij}, \min_i \hat{\mathrm{F}}_{ij}\right), & j \in g_{\min} \end{cases}. \tag{22}$$

Step 6: Compute the discrimination degree of each alternative from SVN-IS and SVNA-IS by utilizing the following expressions:

$$J_w\left(\hat{\xi}_{ij}, \xi_j^{+}\right) = \frac{2}{3\left(2^{(1-\alpha/2)}-1\right)} \sum_{i=1}^{p} w_j \left[\begin{array}{l} \left(\dfrac{\left(\hat{\mathrm{T}}_{ij}\right)^2 + \left(\mathrm{T}_j^{+}\right)^2}{2}\right)^{\alpha/2} - \dfrac{\hat{\mathrm{T}}_{ij}^{\alpha} + \left(\mathrm{T}_j^{+}\right)^{\alpha}}{2} \\ + \left(\dfrac{\left(\hat{\mathrm{I}}_{ij}\right)^2 + \left(\mathrm{I}_j^{+}\right)^2}{2}\right)^{\alpha} - \dfrac{\hat{\mathrm{I}}_{ij}^{\alpha} + \left(\mathrm{I}_j^{+}\right)^{\alpha}}{2} \\ + \left(\dfrac{\left(\hat{\mathrm{F}}_{ij}\right)^2 + \left(\mathrm{F}_j^{+}\right)^2}{2}\right)^{\alpha/2} - \dfrac{\hat{\mathrm{F}}_{ij}^{\alpha} + \left(\mathrm{F}_j^{+}\right)^{\alpha}}{2} \end{array} \right], \tag{23}$$

$$J_w\left(\hat{\xi}_{ij}, \hat{\xi}_j^{-}\right) = \frac{2}{3\left(2^{(1-\alpha/2)}-1\right)} \sum_{i=1}^{p} w_j \left[\begin{array}{l} \left(\dfrac{\left(\hat{\mathrm{T}}_{ij}\right)^2 + \left(\mathrm{T}_j^{-}\right)^2}{2}\right)^{\alpha/2} - \dfrac{\hat{\mathrm{T}}_{ij}^{\alpha} + \left(\mathrm{T}_j^{-}\right)^{\alpha}}{2} \\ + \left(\dfrac{\left(\hat{\mathrm{I}}_{ij}\right)^2 + \left(\mathrm{I}_j^{-}\right)^2}{2}\right)^{\alpha/2} - \dfrac{\hat{\mathrm{I}}_{ij}^{\alpha} + \left(\mathrm{I}_j^{-}\right)^{\alpha}}{2} \\ + \left(\dfrac{\left(\hat{\mathrm{F}}_{ij}\right)^2 + \left(\mathrm{F}_j^{-}\right)^2}{2}\right)^{\alpha/2} - \dfrac{\hat{\mathrm{F}}_{ij}^{\alpha} + \left(\mathrm{F}_j^{-}\right)^{\alpha}}{2} \end{array} \right]. \tag{24}$$

Step 7: The "closeness index (CI)" is determined by Eq. (25), which as

$$C_i = \frac{J_w\left(\hat{\xi}_{ij}, \hat{\xi}_j^{-}\right)}{J_w\left(\hat{\xi}_{ij}, \hat{\xi}_j^{-}\right) + J_w\left(\hat{\xi}_{ij}, \hat{\xi}_j^{+}\right)}, \; C_i \in [0, 1]. \tag{25}$$

The higher degree of *CI* determines the most optimal candidate.

The SVN-TOPSIS method has implemented on the aforesaid BPTs assessment problem. Then, the SVN-IS and SVNA-IS are calculated by using Eqs (21)-(22), given as

ξ_j^{+} = {(0.704, 0.222, 0.273), (0.689, 0.210, 0.262), (0.704, 0.222, 0.273), (0.562, 0.376, 0.405), (0.689, 0.227, 0.279), (0.620, 0.313, 0.357), (0.420, 0.582, 0.561), (0.312, 0.713, 0.678), (0.693, 0.235, 0.283), (0.629, 0.304, 0.349), (0.439, 0.551, 0.548), (0.621, 0.312, 0.350), (0.613, 0.306, 0.348), (0.529, 0.414, 0.443)}.

$\xi_j^- = \{(0.426, 0.574, 0.561), (0.541, 0.414, 0.439), (0.468, 0.517, 0.514), (0.450, 0.547, 0.532), (0.523, 0.418, 0.448), (0.532, 0.431, 0.447), (0.518, 0.417, 0.445), (0.584, 0.367, 0.398), (0.484, 0.497, 0.499), (0.444, 0.539, 0.538), (0.618, 0.309, 0.353), (0.426, 0.558, 0.548), (0.517, 0.444, 0.461), (0.415, 0.564, 0.576)\}$.

The whole procedural steps of SVN-TOPSIS are presented in Table 15. On account of computational results in Table 15, the BPTs is prioritized as $d_6 \succ d_5 \succ d_4 \succ d_2 \succ d_1 \succ d_3$ and hence, agricultural and municipal wastes to biogas (d_6) is the most suitable BPT from considered sustainable indicators.

Table 15: Outcomes by using SVN-TOPSIS model

BPTs	$J_E\left(\xi_{ij}, \xi_j^+\right)$	$J_E\left(\xi_{ij}, \xi_j^-\right)$	C_i	Ranking
d_1	0.034	0.026	0.436	5
d_2	0.027	0.039	0.591	4
d_3	0.043	0.022	0.337	6
d_4	0.020	0.035	0.629	3
d_5	0.019	0.037	0.665	2
d_6	0.015	0.050	0.774	1

4.2.2. SVN-WASPAS Approach

It involves the following procedures:

Steps 1-4: Follow the present approach

Step 5: Derive the measures of "weighted sum model (WSM)" $P_i^{(1)}$ and "weighted product model (WPM)" $P_i^{(2)}$ with the use of Eq. (26)-Eq. (27).

$$P_i^{(1)} = \underset{j=1}{\overset{t}{\oplus}} w_j \varsigma_{ij} = \left(\nabla^{-1}\left(\sum_{j=1}^{t} w_j \nabla(\overline{t}_{ij}) \right), \Delta^{-1}\left(\sum_{j=1}^{t} w_j \Delta(\overline{i}_{ij}) \right), \Delta^{-1}\left(\sum_{j=1}^{t} w_j \Delta(\overline{f}_{ij}) \right) \right), \tag{26}$$

$$P_i^{(2)} = \underset{j=1}{\overset{t}{\otimes}} w_j \varsigma_{ij} = \left(\Delta^{-1}\left(\sum_{j=1}^{t} w_j \Delta(\overline{t}_{ij}) \right), \nabla^{-1}\left(\sum_{j=1}^{t} w_j \nabla(\overline{i}_{ij}) \right), \nabla^{-1}\left(\sum_{j=1}^{t} w_j \nabla(\overline{f}_{ij}) \right) \right). \tag{27}$$

Step 6: Determine the WASPAS measure or *UD* of each alternative using

$$P_i = \theta P_i^{(1)} + \left(1-\theta\right) P_i^{(2)}, \tag{28}$$

wherein $\theta \in [0,1]$ is a decision mechanism coefficient.

Step 7: Rank the alternatives as per the score values of P_i.

Table 16: Computed outcomes by SVN-WASPAS

BPTs	**WSM measure**		**WPM measure**		**WASPAS measure (P_i)**	**Ranking**
	$P_i^{(1)}$	$\mathbb{S}\left(P_i^{(1)}\right)$	$P_i^{(2)}$	$\mathbb{S}\left(P_i^{(2)}\right)$		
d_1	(0.541, 0.418, 0.435)	0.563	(0.531, 0.434, 0.446)	0.550	0.5566	5
d_2	(0.562, 0.382, 0.410)	0.590	(0.539, 0.428, 0.436)	0.558	0.5741	4
d_3	(0.528, 0.438, 0.449)	0.547	(0.523, 0.447, 0.454)	0.541	0.5440	6
d_4	(0.562, 0.385, 0.409)	0.590	(0.554, 0.404, 0.418)	0.577	0.5835	3
d_5	(0.567, 0.385, 0.410)	0.591	(0.556, 0.405, 0.422)	0.576	0.5835	2
d_6	(0.593, 0.355, 0.386)	0.617	(0.575, 0.388, 0.403)	0.595	0.6060	1

Using Eq.(26)-Eq.(28) (Taking $\Delta(x) = -\ln x$, $\Delta^{-1}(x) = e^{-x}$, $\nabla(x) = -\ln(1-x)$, and $\nabla^{-1}(x) = 1-e^{-x}$), the measures of WSM, WPM and WASPAS of each BPT candidate are computed and shown in Table 16. The

SVN-WASPAS method determines the ranking order of BPTs as $d_6 \succ d_5 \succ d_4 \succ d_2 \succ d_1 \succ d_3$ and the optimum BPT alternative for given case study is agricultural and municipal wastes to biogas (d_6). Table 17 and Fig. 7 present the comprehensive overview of the diverse methods for BPTs assessment.

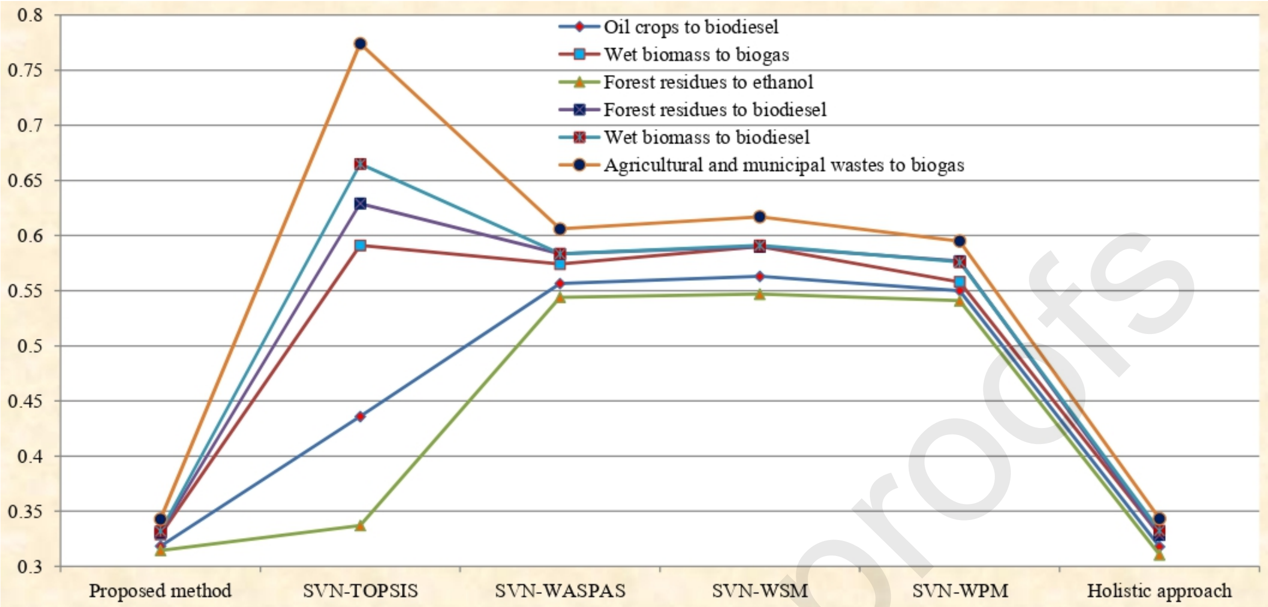


Fig. 7: The comparison of results of different BPTs on various approaches.

Table 17: A comprehensive overview of the results by different methods

Benchmarks	**Zavadskas et al. (2016)**	**Nancy and Garg (2019)**	**Khishtandar et al. (2017)**	**Mishra et al. (2020)**	**Abdel-Basset et al. (2021)**	**Proposed Framework**
Ranking tool	WASPAS	TOPSIS method	ELECTRE	COPRAS	EDAS	COPRAS
Alternatives/criteria assessment	SVNSs	SVNSs	HFLTSs	IFSs	TNSs	SVNSs
Aggregation procedures	Arithmetic, Geometric	Not taken	Arithmetic	Arithmetic,	Arithmetic, Geometric	Arithmetic, Geometric
Theme of prioritization	Compromise solution	Compromise solution	outranking method	Compromise solution	Scoring value	Compromise solution
Criteria weights	Assumed	divergence measure procedure	Computed with Holistic approach	SWARA method	DEMATEL method	New MASWIP
MCDM process	Single	Single	Group	Group		Group
Does the preference order consider nature of criteria	No	No	Yes	Yes	Yes	Yes
DEs' weights	Not taken	Not taken	Not taken	Derived	Not taken	Derived by score function-based formula
Optimal BPTs	d_6	d_6	d_6	d_6	d_6	d_6

On the basis of comparative results, the advantages of introduced SVN-MASWIP-COPRAS model are given as

- For evaluating the BPTs, Khishtandar et al. (2017), Mishra et al. (2020) and Abdel-Basset et al. (2021) considered only the subjective weights of criteria by holistic procedure, SWARA model and DEMATEL process. In (Zavadskas et al., 2016; Nancy and Garg, 2019), the authors have assumed the criteria weights. While, the MASWIP presented in this study is utilized to evaluate the objective, subjective and combined weights of criteria in the evaluation of BPTs, which makes the proposed MCDM model more practical, effective and convenient.

- The SVN-MASWIP-COPRAS method considered the both types of criteria, i.e., benefit and cost. Consideration of both types of criteria with intricate proportion consist more precise information in comparison with just handling the benefit or cost criteria. Therefore, the proposed method enhances the rationality of initial information as well as accuracy of the results.
- In the developed study and Mishra et al. (2020), the DEs' weights are evaluated using the score value-based procedure, which avoids the loss of information in taking decisions. Consequently, the present study can provide more exact decision for MCDM problems with multiple indicators, unlike arbitrarily preferred weights in Khishtandar et al. (2017) and Abdel-Basset et al. (2021).
- The proposed model is more practicable than the SVN-TOPSIS when the numbers of criteria or alternatives are huge. For the SVN-MASWIP-COPRAS method, there is no need to compute the SVN-IS and SVNA-IS. The outcomes in this study are computed by dealing with the real data, which illustrates that the present method can handle more intricate and practical decision-making problems.

4.3. Implication and Discussion

In this study, the overall SEET aspects' weights have been computed based on MASWIP and shown in Fig. 8. Also, the similar process is used to compute the indicators' weights and preferences as in Table 12 and shown in Fig. 4. Here, Fig. 9 presents the SEET aspects and their indicators with weight values. The outcomes of the SEET aspects and their indicators were found by different DEs. From Fig. 8, the key aspects are obtained as follows: environmental has highest weight 0.3577, followed by social with weight 0.2714, technological with weight 0.2262 and economic has the minimum weight of 0.1446. From Fig. 9, the integrated weights of different indicators on environmental aspect, the Air, water and land pollution indicator is the best with weight 0.2421, after that the Contribution to climate change indicator with weight 0.1957, and the water use indicator is the last one with weight 0.1828. On the similar way, for the indicators of the technical aspect, Potential power generation has the maximum weight of 0.3462, after that technical maturity with weight 0.3431, and Continuity and predictability of performance is lowest with weight 0.3108. For the indicators of the economic aspects, macroeconomic sustainability has the maximum weight of 0.509, after that microeconomic sustainability with weight 0.491. Finally, for the indicators of the social aspect, Compatibility with political, legislative and administrative procedure is the highest significant indicator with weight 0.2653, after that the Effects on food security with weight 0.2587, and Contribution to regional development is least significant with weight 0.2369. According to Table 14, the outcomes by SVN-MASWIP-COPRAS methodology specified that the agricultural and municipal wastes to biogas (d_6) is the best BPT followed by wet biomass to biodiesel (d_5), Forest residues to biodiesel (d_4) and Forest residues to ethanol (d_3).

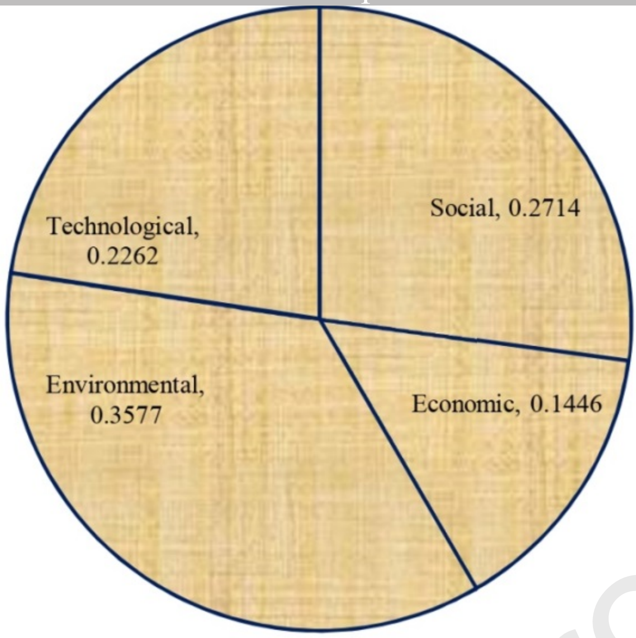
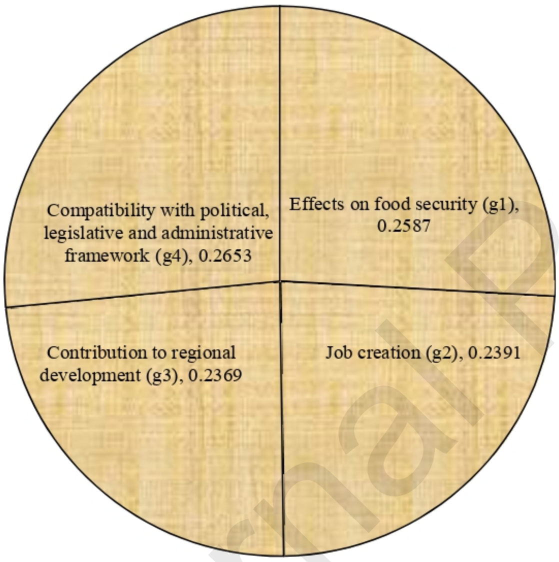
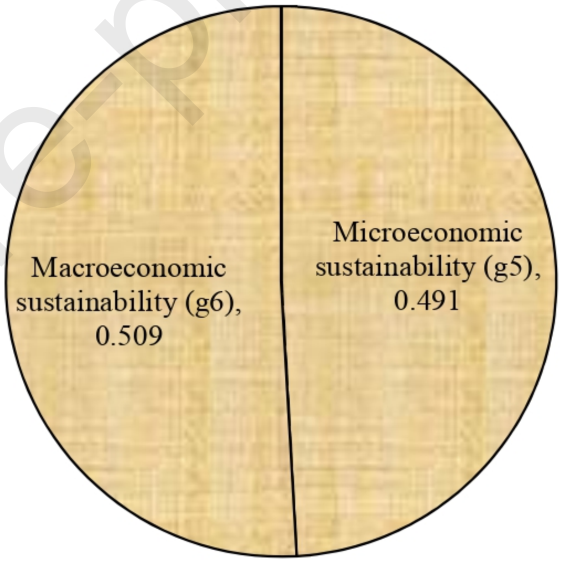


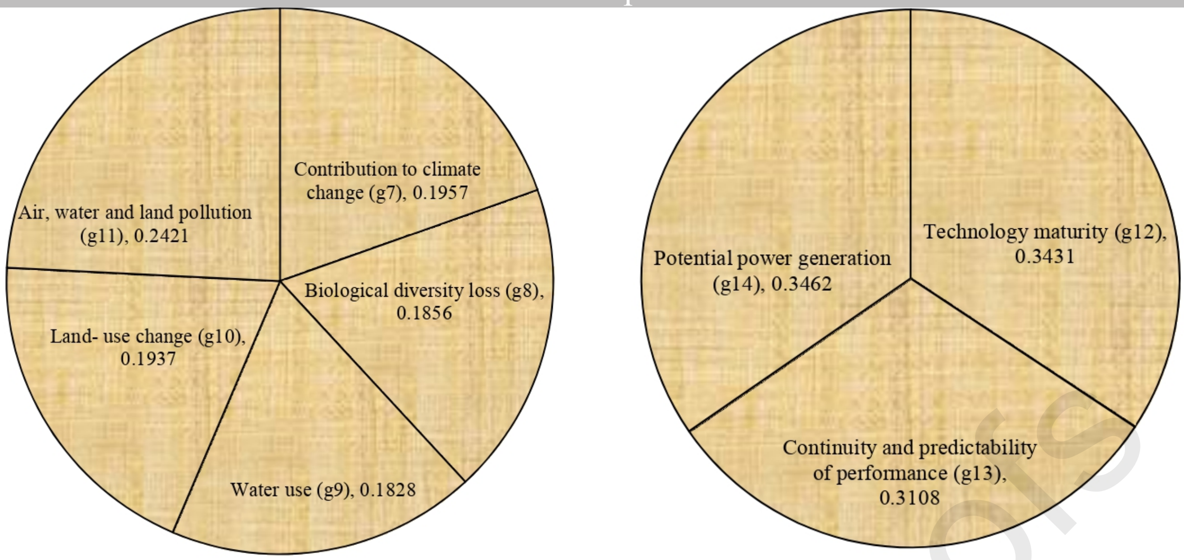
Fig. 8: Final weights for sustainable SEET dimensions using MASWIP



(a)



(b)



(c) **(d)**

Fig. 9: Weights of SEET dimensions indicators: (a) social indicators, (b) economic indicators, (c) environmental indicators, and (d) technological indicators.

This study pursued to evaluate and choose the most suitable BPT and recognized the prime SEET aspects and their indicators. There are several managerial and concrete implications of the proposed work: a) The study gave an elegant decision-analysis procedure that associates SVNSs with MCDM models to support DEs to obtain suitable outcomes on uncertain and inconsistent circumstances, b) The developed methodology can assist stockholders in the area of bioenergy to select the BPTs, which achieves the highest SEET efficiency, c) This study discusses the important SEET aspects and their indicators, which are applied to assess sustainable BPTs, and d) The introduced approach offers adequate material for energy policy makers, as it considers the SEET aspects.

5. Conclusions

Due to the intricacy and multi-dimensionality of bioenergy concerns, a comprehensive methodology is introduced to recognize the SEET aspects of different BPTs assessment. An assessment with the use of quantitative data cannot efficiently handle the sustainable BPTs but also express the inconsistent and imprecise information in the processing of qualitative data. The developed framework permits multiple strategy makers to contribute in MCDM procedure and assess the BPTs based on their practices and knowledge with the use of the SVNNs. In this study, six BPTs are taken including the oil crops to biodiesel (d_1), wet biomass to biogas (d_2), forest residues to ethanol (d_3), forest residues to biodiesel (d_4), wet biomass to biodiesel (d_5) and agricultural and municipal wastes to biogas (d_6), which are assessed over SEET aspects and 14 indicators. The core aspects are the social (S), economic (E), environmental (E) and technical (T). The assessment procedure applied the developed SVN-MASWIP-COPRAS methodology, where MASWIP is applied to calculate the objective, subjective and integrated weights of the sustainable SEET aspects and their indicators, and the COPRAS is used to prioritize the BPTs with SVN information. The outcomes of this work specify that agricultural and municipal wastes to biogas (d_6) is the suitable BPT from sustainability perspective.

In future, linear diophantine set, plithogenic set, bipolar fuzzy set and q-rung orthopair fuzzy rough set can be used for proposed hybrid method to express the multiple uncertainty and subjectivity of human minds. The developed MCDM method can also be used to address different realistic problems such as digital technology selection for disabled persons, sustainable cities and communities' assessment, transport planning strategies management, wearable healthcare technology selection and sustainable transportation.

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Highlights

- An integrated MCDM approach is proposed
- A neutrosophic setting is used for treating uncertainty
- The methodology takes into account various conflicting indicators and SEET aspects
- The novel weighting integrated procedure is applied to determine weights
- Comparison discussion illustrate the benefits of the developed methodology

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