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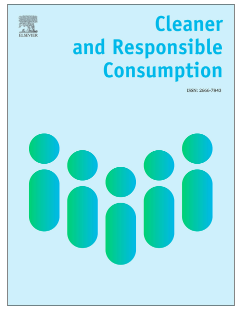

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Abstract

Customers' pressure, social responsibility and government regulations have motivated the companies to consider the reverse logistics (RL) in their operations. Recently, companies frequently outsource RL to third-party reverse logistics providers (3PRLPs) to concentrate on their primary concern and diminish costs. In the present study, relevant sustainability criteria are employed for a decision-making example of sustainable 3PRLP (S3PRLP) selection problem of an Indian Electronics Company. To choose the most suitable S3PRLP, a novel integrated approach by combining Combined Compromise Solution (CoCoSo) approach and CRiteria Importance Through Intercriteria Correlation (CRITIC) method under the context of single-valued neutrosophic sets (SVNSs). In this approach, the weights of the criteria are determined by the CRITIC method. To investigate the efficiency and feasibility of the present approach, a case study of S3PRLPs selection is discussed within SVNSs context. Moreover, sensitivity analysis and comparison with existing methods are presented to highlight the robustness and strength of the proposed method. The result of this study concludes that the introduced methodology can recommend more feasible performance when facing with indeterminate and inconsistent knowledge, and qualitative data.

Keywords: Single-valued neutrosophic sets, Third party reverse logistics provider, CRITIC, MCDM, CoCoSo.

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Abstract

Customers' pressure, social responsibility and government regulations have motivated the enterprises to consider the Reverse Logistics (RL) in their operations. Recently, companies frequently outsource RL to Third-Party Reverse Logistics Providers (3PRLPs) to concentrate on their prime concern and diminish costs. In the present study, relevant sustainability criteria are employed for a decision-making example of Sustainable 3PRLP (S3PRLP) selection problem of an Indian Electronics Company. To choose the most suitable S3PRLP, a novel integrated approach by combining Combined Compromise Solution (CoCoSo) and CRiteria Importance Through Intercriteria Correlation (CRITIC) approaches under the context of Single-Valued Neutrosophic Sets (SVNSs). This approach offers a new procedure for determining the criteria weights with the use of CRITIC technique. The efficiency and practicability of the present approach is numerically demonstrated by solving an illustrative case study of S3PRLPs selection within SVNSs context. Moreover, sensitivity analysis and comparison with previously developed techniques are presented to highlight the robustness and strength of the introduced method. The result of this work concludes that the introduced methodology can recommend more feasible performance when facing with indeterminate and inconsistent knowledge, and qualitative data.

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1. Introduction

Increasing demand of personalized services and potential for the reuse or recycling of redundant stock, growing public concerns over the environment and increasing opportunities for cost savings from returned goods prompted the idea of "Reverse Logistics (RL)". RL is defined as "the procedure of planning, executing, and handling the well-organized, cost effectual flow of raw materials or goods, processing inventory, completed goods and associated information with their final destination to the fact of manufacture for the intention of appropriate disposal

(Govindan et al., 2018). Rogers and Tibben-Lembke (1999) gave the RL as “the trend of design, schedule, planning, controlling and warehousing and also information for returned products in reverse flow of classical supply chain in order to recover the value and get the competitive advantage”.

Over the last few decades, RL has received a lot of interest from academic scholars and entrepreneurs because it can improve the surplus value of End-Of-Life (EOL) materials, satisfy consumers’ desires and reduce the environmental footprint (Ilgin and Gupta, 2010). It incorporates the processes like as remanufacturing, renovation, servicing, warehouse management, recycling and waste management (Govindan et al., 2012). The growing significance of RL has managed several businesses to plan taking to pieces and reestablishment procedures as a portion of their sustainable development enterprises (Mavi et al., 2017).

Nowadays, outsourcing the logistics procedures is the leading management schemes of various firms (Govindan and Murugesan, 2011). Nonetheless, several firms resist with the implementation of RL, because they do not have any satisfactory structures to deal with the reverse supply chain in-house (Jayaraman et al., 1999). Moreover, the backflow of goods is complex process due to the time limitations, uncertainties in volume, and circumstance that may be complicated to expect (Serrato et al., 2007). If the companies desire to outsource their operations, they have to opt a trustworthy Third Party Reverse Logistic Provider (3PRLP) (Govindan et al., 2009). The process of assessment and selection of an optimal 3PRLP is a complicated Multi-Criteria Decision-Making (MCDM) problem because it involves multiple qualitative and quantitative criteria. Copious studies have been presented to evaluate the ideal 3PRLP alternative; however, more studies are needed to handle the prioritizations of diverse expertise, imprecise, indeterminate and inconsistent environments, and different knowledge levels on RL with the consideration of social, environmental and economic dimensions concurrently. However, it is not always possible to explore the priorities more proficiently and accurately in the best 3PRLPs selection.

Single-Valued Neutrosophic Set (SVNS) (Wang et al., 2010) is developed as a pioneering way to handle the imprecise, inconsistent and indeterminate information of the real-life applications. Motivated by this idea, the present study focuses under the environment of SVNSs. It is apparent from the literature that there has been no work regarding a collective MCDM framework based on CRiteria Importance Through Intercriteria Correlation (CRITIC) and Combined Compromise

Solution (CoCoSo) approaches with SVNSs information. Thus, to the best of authors' information, this is the first work which develops an integrated SVN-CRITIC-CoCoSo method by combining the CRITIC and CoCoSo techniques within SVNSs context. As the weight determination of criteria has a momentous impact on the decision outcomes, thus, this paper proposes new SVNSs-based CRITIC technique to calculate the objective criteria weights. In this method, the CoCoSo method offers an easy calculation process with accurate and consistent results for assessing Sustainable 3PRLPs (S3PRLPs). The key novelties of this study can be presented as below:

- Novel integrated SVN-CRITIC-CoCoSo methodology is introduced for solving MCDM problems with SVNSs.
- CRITIC-based framework is employed for evaluating the criteria weights.
- To developed SVN-CRITIC-CoCoSo method is implemented to choose an optimal S3PRLP for an electronics manufacturing company.
- At last, comparison with extant approaches and sensitivity assessment are studied to confirm the reliability and practicability of the outcomes.

The present manuscript is systematized as: Section 2 confers the comprehensive reviews associated to the present study. Section 3 introduces the concepts related to SVNSs. Section 4 develops a novel integrated SVN-CRITIC-CoCoSo method for MCDM problems under SVNSs environment. Section 5 discusses a decision-making example related to S3PRLPs selection problem. Also, comparative and sensitivity analyses are conferred at the end of this section. Lastly, Section 6 offers the conclusions and scope for future research.

2. Related Works

The related works concerning SVNSs, CRITIC method, CoCoSo method and 3PRLPs are discussed in this section.

2.1. Single-Valued Neutrosophic Sets (SVNSs)

In response to deal with the ambiguity and complexity of real-life problems, Zadeh (1965) initiated the concept of Fuzzy Set (FS), which utilizes one real value $\mu_F(z_i) \in [0,1]$ to characterize the membership value of a FS F depicted on universal set Z. As an improvement of FSs, the doctrine of Intuitionistic Fuzzy Sets (IFSs) has been developed (Atanassov, 1986), which are defined by membership and non-membership values. Due to its unique advantages, the theory of IFSs has broadly been studied and utilized for various purposes (He and Wu, 2019; Mishra and Rani, 2019; Son et al., 2020). However, IFSs can simply manage uncertain and imprecise information but unable to tackle inconsistent and indeterminate information which exists in belief system. To overcome these issues, Smarandache (1999) firstly gave the notion of Neutrosophic Sets (NSs), which extends the concept of classic set theory, FS, IFS, tautological set and paraconsistent set (Peng and Liu, 2017). NSs are independently represented by the truth, indeterminacy and falsity-membership values, which are lie in $]0^{-}, 1^{+}[$. Thus, the concept of NS theory is more powerful and effective way to cope with imprecise, inconsistent and indeterminate information.

From scientific and engineering perspectives, the NSs need to be generalized; otherwise it will be tricky to implement the NSs in real-life applications. To conquer the drawbacks of NSs, the notion of SVNSs has been established by Wang et al. (2010), which is the part of NSs. SVNS has been proven as a powerful mathematical tool for dealing with copious practical applications concerning incomplete, indeterminacy, and inconsistent data. Subsequently, several theories and methods have been proposed under SVNSs settings. For example, Pranamik et al. (2017) initiated an innovative cross entropy measure for SVNSs and discussed its enviable characteristics. Karaaslan (2017) gave similarity measure methods for SVN Refined (SVNR) sets with Jaccard, Dice, and Cosine similarity measures and also developed Gaussian SVNNs to solve MCDM problems (Karaaslan, 2018). Karaaslan and Hayat (2018) studied various operations on SVNSs and used to propose new MCDM approach. Vafadarnikjoo et al. (2018) designed a structured framework by integrating fuzzy Delphi technique and SVNSs to buy a remanufactured bike according to customers' and specialists' opinions. Sodenkamp et al. (2018) introduced a single-valued neutrosophic (SVN) aggregation method to combine the numerous experts' preferences in the MCDM process. Liu et al. (2019) studied some Schweizer-Sklar prioritized weighted aggregation operators for SVNSs. Gulistan et al., (2019) gave Neutrosophic cubic Heronian mean operators and Jana et al. (2020) developed Trapezoidal neutrosophic aggregation operators to handle the MCDM problems. Rani and Mishra (2020a) studied an innovative SVN-SWARA (Stepwise-Weight Assessment Ratio Analysis)-VIKOR (VlseKriterijumska optimizcija I kaompromisno resenje in Serbian) approach to estimate the performances of eco-industrial thermal power plants. Garg and Nancy (2020) proposed some novel distance measures for SVNSs and then, developed an extended Technique for Order

Preference by Similarity to Ideal Solution (TOPSIS) method within SVNSs. In a recent study, Rani and Mishra (2020b) introduced a novel SVNS-based CoCoSo methodology for assessing the best Waste of Electrical and Electronic Equipment (WEEE) recycling partner with imprecise, indeterminate and inconsistent information. Smarandache (2020) gave single-valued score, accuracy and certainty functions for determining a total order of SVNSs. Karaaslan and Hunu (2020) defined the concept of Type-2 Single-Valued Neutrosophic Sets (T2SVNSs). Also, they introduced some distance measures based on Hausdorff, Hamming and Euclidean distances to develop an MCDM method based on TOPSIS model on T2SVNSs.

2.2. CRITIC Method

During the process of MCDM, determining the attribute weights is a significant concern for decision experts. Several researchers have proposed different methods for evaluating the attribute/criteria weights (Kersuliene et al., 2010; Diakoulaki et al., 1995; Mishra & Rani, 2019). The attribute weight evaluation procedures are separated into two types: objective and subjective weights (Peng, 2019). The CRITIC method, suggested by Diakoulaki et al. (1995), is an interesting tool to assess the objective attribute weights. To do this, the prime significance of the attributes is achieved by using the contrast intensity of each attribute, which is measured as the Standard Deviation (SD), while the conflicts between the attributes are deliberated as the Correlation Coefficient (CRC). It has effectively been applied to compute the objective attribute weights in numerous real-life problems (Tus & Adali, 2019; Zolfani et al., 2020). For example, Ghorabaee et al. (2018) initiated a framework with CRITIC, SWARA and Evaluation Based on Distance from Average Solution (EDAS) approaches. Peng et al. (2020) utilized CRITIC and CoCoSo methodologies for 5G industry assessment. Wei et al. (2020) used a combination of Grey Relational Analysis (GRA)-CRITIC models to assess the suitable site for electric vehicle charging station. Peng and Huang (2020) gave an integration of CRITIC and CoCoSo models for financial risk assessment. Yet, no one has employed the CRITIC method in the evaluation of attribute weights during S3PRLP selection process.

2.3. CoCoSo Method

Existing studies offer various MCDM approaches for dealing the practical MCDM issues. Though, the preference results obtained by the extant decision-making approaches (Zavadskas et al., 2015; Mishra, 2016; Tus and Adali, 2019; Mishra et al., 2020a) have low reliability and stability due to change of weight distributions of criteria, which may be irrational for DEs to opt ideal option. To surmount this limitation, Yazdani et al. (2019a) initiated a novel CoCoSo method which offers a compendium of aggregated solution using compromise approaches and aggregation strategies. It integrates the two most prominent MCDM models which are Simple Additive Weighting (SAW) and Exponentially Weighted Product (EWP). In recent times, copious scholarly articles have focused their interest on the development and application of the CoCoSo method. For instance, Yazdani et al. (2019b) introduced the DEcision MAking Trial and Evaluation Laboratory (DEMATEL) and Best Worst Method (BWM) based grey extension of CoCoSo approach to select the ideal supplier in construction management. Wen et al. (2019a) proposed a combined method by integrating SWARA and CoCoSo approaches with an application in drug cold chain logistics supplier evaluation problem. In a further study, Wen et al. (2019b) proposed an integrated methodology based on CoCoSo approach and hesitant linguistic fuzzy set, and then applied for a decision-making problem. Rani and Mishra (2020b) studied an innovative SVN-CoCoSo approach for the assessment of WEEE recycling partner. Peng and Smarandache (2020) developed a novel neutrosophic soft CoCoSo method for China's rare earth industry security assessment. Liao et al. (2020) introduced an innovative Pythagorean fuzzy CoCoSo method for the selection of cold chain logistics delivery center. Alrasheedi et al. (2020) suggested a novel IVIF-CoCoSo technique for assessing the green growth indicators to achieve sustainable development in the manufacturing region. From the above-mentioned discussion, we can see that an integrated method based on CRITIC and CoCoSo approaches with SVNSs can additional improve the practicality of the CoCoSo approach with uncertain decision-making settings.

2.4. Sustainable third-party reverse logistic provider (S3PRLP) assessment

The S3PRLP assessment problem is a complex MCDM problem due to participation of numerous decisive factors. To choose the optimal S3PRLP option and enhance the precision and consistency of the outcomes, lots of new MCDM procedures have been considered and utilized to several fields (Li et al., 2017; Yu and Solvang, 2018; Prajapati et al., 2019; Kumari and Mishra, 2020; Mishra et al., 2020b; Rani et al., 2020c). FSs and their generalizations have expansively been employed to manage the uncertain and vague information occurred in realistic MCDM processes. Efendigil et al. (2008) designed a two-way method by integrating artificial neural networks and fuzzy logic for the evaluation of an ideal 3PRLP alternative. Kannan (2009) designed a fuzzy-based procedure for assessing the 3PRLP selection problem. Govindan and Murugesan (2011) used the fuzzy extent assessment approach for choosing the desirable 3PRLP for a battery manufacturing industry. Corresponding to Analytic Hierarchy Process (AHP) and TOPSIS approaches, Senthil et al. (2014) suggested a combined model for evaluating an ideal reverse logistics contractor. Uygun et al. (2015) planned and selected an outsourcing provider for a telecommunications business by employing DEMATEL and Analytic Network Process (ANP) methods for FSs. Mavi et al. (2017) presented SWARA method for weighting the assessment criteria of 3PRLP in the plastics industry and further, ranked the S3PRLP alternatives through Multi-Objective Optimization based on Ratio Analysis (MOORA) model within FSs. Tavana et al. (2018) suggested a combined method with the integration of ANP and grey superiority and inferiority methods on IFSs for the assessment of 3PRLPs selection process. Li et al. (2018) used a combined cumulative prospect doctrine with hybrid-information MCDM methodology for the evaluation of 3PRLPs from sustainability perspectives. Zarbakhshnia et al. (2018) weighted the assessment criteria through fuzzy-SWARA method and ranked the S3PRLPs by employing COmplex PRoportional ASsessment (COPRAS) method under fuzzy environment. Zhang and Su (2020) introduced a dominance degree-based heterogeneous linguistic model to assess the best S3PRLP for a car manufacture industry. On the basis of fuzzy AHP and gray MOORA, Zarbakhshnia et al. (2020) originated a collective MCDM method for assessing the S3PRLP alternatives. Chen et al. (2020) built a multi-perspective MCDM model to offer systematic decision support for companies to choose an ideal 3PRLP alternative. Mishra et al. (2021) gave a combined approach using CRITIC and EDAS models for Fermatean Fuzzy Sets (FFSs) to handle the S3PRLP assessment problem in which the criteria and DEs' weights information are completely unknown.

3. Preliminaries

This section presents the basic notions of single-valued neutrosophic set.

Definition 3.1 (Smarandache, 1999): A discourse set can be symbolized as Z and $z_i \in Z$. $\widehat{N}$ as a NS can be identified by the functions of truth membership $\mathrm{T}_{\widehat{N}}(z_i)$, an indeterminacy membership $\mathrm{I}_{\widehat{N}}(z_i)$, falsity membership $\Gamma_{\widehat{N}}(z_i)$ and is shown like $\widehat{N} = \left\{\left(\mathrm{T}_{\widehat{N}}(z_i), \mathrm{I}_{\widehat{N}}(z_i), \Gamma_{\widehat{N}}(z_i)\right) : z_i \in Z\right\}$. Also the functions of $\mathrm{T}_{\widehat{N}}(z_i)$, $\mathrm{I}_{\widehat{N}}(z_i)$, and $\Gamma_{\widehat{N}}(z_i)$ are real standard subsets of $\left]0^-,1^+\right[$ and are shown as $\mathrm{T},\mathrm{I},\Gamma : Z \to \left]0^-,1^+\right[$. The sum of the functions of $\mathrm{T}_{\tilde{N}}(z_i)$, $\mathrm{I}_{\tilde{N}}(z_i)$ and $\Gamma_{\tilde{N}}(z_i)$ can be defined as $0^- \le \sup \mathrm{T}_{\tilde{N}}(z_i) + \sup \mathrm{I}_{\tilde{N}}(z_i) + \sup \Gamma_{\tilde{N}}(z_i) \le 3^+$.

Definition 3.2 (Wang et al., 2010): The SVNSs are initiated to pact with the real-world problems in uncertain environment. The interval of $[0,1]$ are considered for real-life applications rather than $\left]0^-,1^+\right[$. As SVNS S in Z can be identified as a truth $t_S(z_i)$, an indeterminacy $i_S(z_i)$ and falsity membership functions $f_S(z_i)$, where the functions $t_S(z_i)$, $i_S(z_i)$ and $f_S(z_i)$ are real subsets of $[0,1]$, i.e., $t_S(z_i): Z \to [0,1]$, $i_S(z_i): Z \to [0,1]$ and $f_S(z_i): Z \to [0,1]$. Additionally, the sum of $t_S(z_i)$, $i_S(z_i)$ and $f_S(z_i)$ are in $[0, 3]$ and is given as $0 \le t_S(z_i) + i_S(z_i) + f_S(z_i) \le 3$. For $S \subseteq Z$, the triple (t_S, i_S, f_S) is known the Single-Valued Neutrosophic Number (SVNN).

Definition 3.3 (Wang et al., 2010): For any two SVNNs $\upsilon_1 = (t_{\upsilon_1}, i_{\upsilon_1}, f_{\upsilon_1})$ and $\upsilon_2 = (t_{\upsilon_2}, i_{\upsilon_2}, f_{\upsilon_2})$, and $\gamma > 0$, the basic laws for SVNNs are given by

- $\upsilon_1^c = (f_{\upsilon_1}, 1 - i_{\upsilon_1}, t_{\upsilon_1})$;
- $\upsilon_1 \subseteq \upsilon_2$ if $t_{\upsilon_1} \le t_{\upsilon_2}$, $i_{\upsilon_1} \ge i_{\upsilon_2}$ and $f_{\upsilon_1} \ge f_{\upsilon_2}$;
- $\upsilon_1 = \upsilon_2$ if and only if $\upsilon_1 \subseteq \upsilon_2$ and $\upsilon_2 \subseteq \upsilon_1$;
- $\upsilon_1 \cup \upsilon_2 = \left(\max\{t_{\upsilon_1}, t_{\upsilon_2}\}, \min\{i_{\upsilon_1}, i_{\upsilon_2}\}, \min\{f_{\upsilon_1}, f_{\upsilon_2}\}\right)$;
- $\upsilon_1 \cup \upsilon_2 = \left(\min\{t_{\upsilon_1}, t_{\upsilon_2}\}, \max\{i_{\upsilon_1}, i_{\upsilon_2}\}, \max\{f_{\upsilon_1}, f_{\upsilon_2}\}\right)$;
- $\upsilon_1 + \upsilon_2 = \left(t_{\upsilon_1} + t_{\upsilon_2} - t_{\upsilon_1} t_{\upsilon_2}, i_{\upsilon_1} i_{\upsilon_2}, f_{\upsilon_1} f_{\upsilon_2}\right)$;
- $\upsilon_1 \cdot \upsilon_2 = \left(t_{\upsilon_1} t_{\upsilon_2}, i_{\upsilon_1} + i_{\upsilon_2} - i_{\upsilon_1} i_{\upsilon_2}, f_{\upsilon_1} + f_{\upsilon_2} - f_{\upsilon_1} f_{\upsilon_2}\right)$;
- $\gamma \upsilon_1 = \left(1 - (1 - t_{\upsilon_1})^\gamma, i_{\upsilon_1}^\gamma, f_{\upsilon_1}^\gamma\right)$;
- $\upsilon_1^\gamma = \left(t_{\upsilon_1}^\gamma, 1 - (1 - i_{\upsilon_1})^\gamma, 1 - (1 - f_{\upsilon_1})^\gamma\right)$.

Definition 3.4 (Smarandache, 2020): The score function for a SVNN $\upsilon = (t_\upsilon, i_\upsilon, f_\upsilon)$ is presented as

$$\mathrm{S}(\upsilon) = \frac{2 + t_\upsilon - i_\upsilon - f_\upsilon}{3};\ \mathrm{S}(\upsilon) \in [0,1]. \tag{1}$$

Similarly, accuracy and certainty functions are defined as

$$a(\upsilon) = t_{\upsilon} - f_{\upsilon} \quad \text{and} \quad c(\upsilon) = t_{\upsilon}. \tag{2}$$

Definition 3.5 (Ye, 2014a): Let $\upsilon_i = (t_i, i_i, f_i);\ i = 1(1)m$ be the SVNNs and $\lambda = (\lambda_1, \lambda_2, ..., \lambda_m)^T$ with $\lambda_i \in [0,1]$ and $\sum_{i=1}^{m} \lambda_i = 1$ be the related weight value of υ_i. Then the SVN-Weighted Averaging Operator (SVNWAO) of υ_i is presented as

$$SVNWA(\upsilon_1, \upsilon_2, ..., \upsilon_m) = \overset{m}{\underset{i=1}{\oplus}} (\lambda_j\, \upsilon_j) = \left(1 - \prod_{i=1}^{m} (1 - t_i)^{\lambda_i}, \prod_{i=1}^{m} (i_i)^{\lambda_i}, \prod_{i=1}^{m} (f_i)^{\lambda_i}\right). \tag{3}$$

Definition 3.6 (Majumdar and Samanta, 2014): Let $S, T \in SVNSs(Z)$. Then, the distance between the sets S and T is given by

$$D_h(S,T) = \frac{1}{3n} \sum_{i=1}^{n} \left(|t_S(z_i) - t_T(z_i)| + |i_S(z_i) - i_T(z_i)| + |f_S(z_i) - f_T(z_i)| \right). \tag{4}$$

4. Proposed SVN-CRITIC-CoCoSo Approach

In earlier studies, the CoCoSo technique has widely been utilized for many decision-making problems. This section offers an innovative SVN-CRITIC-CoCoSo technique for solving real-life applications wherein the information about the criteria and DMs are fully unidentified. This method integrates the classical CoCoSo and CRITIC methods under SVNSs context. The proposed SVN-CRITIC-CoCoSo methodology involves the given steps:

Step 1: Create the SVN-Decision Matrix (SVN-DM).

For a MCDM problem under SVNSs environment, consider the sets of alternatives/options $\{N_1, N_2, ..., N_m\}$ and attributes/criteria $\{X_1, X_2, ..., X_n\}$. A panel of Decision Experts (DEs) $\{\beta_1, \beta_2, ..., \beta_l\}$ offers the appraisal information of each option N_i over the attribute X_j in terms of Linguistic Variables (LVs). Suppose $\Omega = \left(\chi_{ij}^{(k)}\right),\ i = 1(1)m,\ j = 1(1)n$ be the linguistic decision-making presented by the DEs, in which $\chi_{ij}^{(k)}$ indicates the appraisal of an option N_i regarding an attribute X_j in terms of LVs for k^{th} DE.

Step 2: Assess crisp DEs weights (ϖ_k)

The computation of DEs' weights is a necessary feature in the decision-making procedure. Let $\xi_k = (t_k, i_k, f_k),\ k = 1(1)\ell$ be the significance rating of DEs given by the experts according to their expertise. For the purpose of showing their relative significance in MCDM process, the weight-determination formula for the k^{th} DE is estimated by

$$\varpi_k = \frac{2+t_k - i_k - f_k}{\sum_{k=1}^{l}\left[2+t_k - i_k - f_k\right]}, \text{ where } \varpi_k \geq 0 \text{ and } \sum_{k=1}^{l}\varpi_k = 1. \tag{5}$$

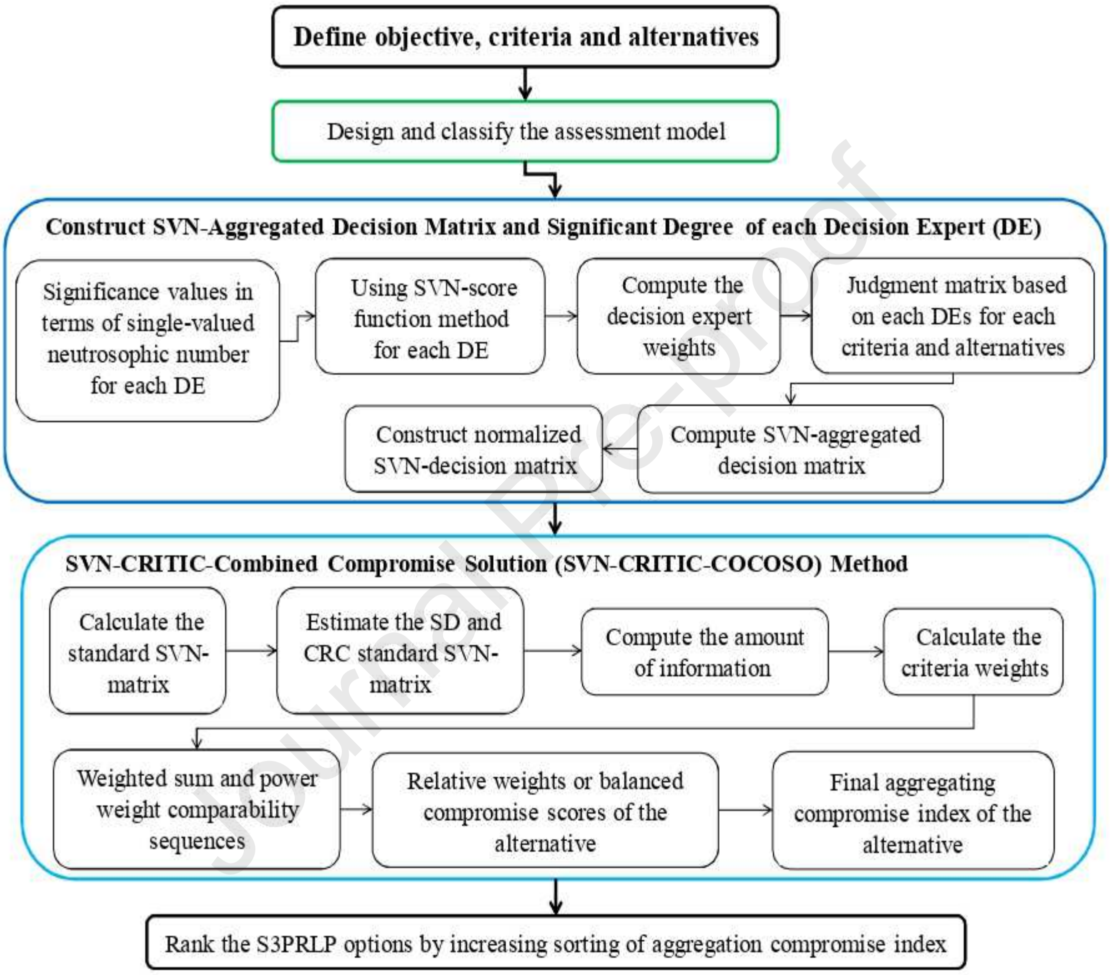

Fig 1: Flowchart of the proposed methods for S3PRLPs selection

Step 3: Aggregation of different decision opinions

To create the Aggregated SVN-DM (A-SVN-DM), all entity opinions require to be mingled into a single group decision matrix according as DEs' preferences. To do this, SVNWAO is utilized by Definition 3.5 and let $\square = \left(\Xi_{ij}\right)_{m\times n}$ be the A-SVN-DM, wherein

$$\Xi_{ij} = SVNWAO\left(\Xi_{ij}^{(1)}, \Xi_{ij}^{(2)}, \ldots, \Xi_{ij}^{(l)}\right) = \left(1-\prod_{k=1}^{l}\left(1-t_k\right)^{\varpi_k}, \prod_{k=1}^{l}\left(i_k\right)^{\varpi_k}, \prod_{k=1}^{l}\left(f_k\right)^{\varpi_k}\right). \tag{6}$$

Step 4: Normalize the A-SVN-DM

To deal with benefit and non-benefit types of attributes in the MCDM process, an A-SVN-DM is converted into normalized A-SVN-DM $\mathbb{N} = \left(\varsigma_{ij}\right)_{m\times n}$ where

$$\varsigma_{ij} = \left(\bar{t}_{ij}, \bar{i}_{ij}, \bar{f}_{ij}\right) = \begin{cases} \varepsilon_{ij} = \left(t_{ij}, i_{ij}, f_{ij}\right), & j \in X_b \\ \left(\varepsilon_{ij}\right)^c = \left(f_{ij}, 1-i_{ij}, t_{ij}\right), & j \in X_n \end{cases}. \tag{7}$$

wherein X_b and X_n indicate the beneficial and non-beneficial types of criteria, respectively.

Step 5: Estimate the criteria weights with the use of CRITIC approach

Suppose all the criteria have different importance. Let $\Psi = \left(\Psi_1, \Psi_2, ..., \Psi_n\right)^T$ be the criteria weight, where $\sum_{j=1}^{n} \Psi_j = 1$ and $\Psi_j \in [0, 1]$. In the MCDM process, the CRITIC model is a procedure to assess the objective weights of the criteria (Diakoulaki et al., 1995). In the following steps, we branch out the CRITIC approach into SVNSs environment:

Step 5.1: With the use of Eq. (8), determine the score matrix $ScoM = \left(\bar{\Lambda}_{ij}\right)_{m\times n}, \forall i, j$ of each SVNN ς_{ij},

$$\bar{\Lambda}_{ij} = \frac{2 + t_{ij} - i_{ij} - f_{ij}}{3}. \tag{8}$$

Step 5.2: Using Eq. (9), change the matrix $ScoM$ into standard SVN-matrix $SScoM = \left(\tilde{\varsigma}_{ij}\right)_{m\times n}$

$$\tilde{\varsigma}_{ij} = \begin{cases} \dfrac{\varsigma_{ij} - \varsigma_j^-}{\varsigma_j^+ - \varsigma_j^-}, & j \in X_b \\ \dfrac{\varsigma_j^+ - \varsigma_{ij}}{\varsigma_j^+ - \varsigma_j^-}, & j \in X_n \end{cases} \tag{9}$$

where $\varsigma_j^+ = \max_i \varsigma_{ij}$ and $\varsigma_j^- = \min_i \varsigma_{ij}$.

Step 5.3: Estimate the criteria SDs using Eq. (10)

$$\sigma_j = \sqrt{\frac{\sum_{i=1}^{m}\left(\tilde{\varsigma}_{ij} - \bar{\varsigma}_j\right)^2}{m}}, \text{ where } \bar{\varsigma}_j = \sum_{i=1}^{m} \tilde{\varsigma}_{ij} \big/ m. \tag{10}$$

Step 5.4: Compute the CRC between criteria by Eq. (11)

$$r_{jt} = \frac{\sum_{i=1}^{m}\left(\tilde{\varsigma}_{ij} - \overline{\varsigma}_{j}\right)\left(\tilde{\varsigma}_{it} - \overline{\varsigma}_{t}\right)}{\sqrt{\sum_{i=1}^{m}\left(\tilde{\varsigma}_{ij} - \overline{\varsigma}_{j}\right)^{2}\left(\tilde{\varsigma}_{it} - \overline{\varsigma}_{t}\right)^{2}}}, \tag{11}$$

Step 5.5: Analyze the amount of information as

$$C_j = \sigma_j \sum_{t=1}^{n}\left(1 - r_{jt}\right). \tag{12}$$

Step 5.6: Find the objective weight of each criteria using Eq. (13)

$$\Psi_j = \frac{C_j}{\sum_{j=1}^{n} C_j}. \tag{13}$$

Step 6: Determine the addition of the weighted comparability sequence and amount of the power weight of comparability sequence

The addition of the weighted comparability sequence or Weighted Sum Measure (WSM) $\square_i^{(1)}$ for each option is evaluated as

$$\square_i^{(1)} = \bigoplus_{j=1}^{n} w_j\, \varsigma_{ij}. \tag{14}$$

The Weighted Product Measure (WPM) $\square_i^{(2)}$ for each option is calculated as

$$\square_i^{(2)} = \bigotimes_{j=1}^{n} w_j\, \varsigma_{ij}. \tag{15}$$

Step 7: Find the relative weights of options

Here, the following three appraisal score strategies are employed to determine the relative weights of the options:

$$\square_i^{(1)} = \frac{\mathrm{S}^*\left(\square_i^{(1)}\right) + \mathrm{S}^*\left(\square_i^{(2)}\right)}{\sum_{i=1}^{m}\left(\mathrm{S}^*\left(\square_i^{(1)}\right) + \mathrm{S}^*\left(\square_i^{(2)}\right)\right)}, \tag{16}$$

$$\square_i^{(2)} = \frac{\mathrm{S}^*\left(\square_i^{(1)}\right)}{\min_i \mathrm{S}^*\left(\square_i^{(1)}\right)} + \frac{\mathrm{S}^*\left(\square_i^{(2)}\right)}{\min_i \mathrm{S}^*\left(\square_i^{(2)}\right)}, \tag{17}$$

$$\square_i^{(3)} = \frac{\gamma \mathrm{S}^*\left(\square_i^{(1)}\right) + (1-\gamma)\mathrm{S}^*\left(\square_i^{(2)}\right)}{\gamma \max_i \mathrm{S}^*\left(\square_i^{(1)}\right) + (1-\gamma)\max_i \mathrm{S}^*\left(\square_i^{(2)}\right)}, \tag{18}$$

wherein $\gamma \in [0,1]$ is the compromise decision mechanism coefficient. Generally, we take $\gamma = 0.5$. Here, Eq. (16) presents the arithmetic mean of addition of WSM and WPM values, whereas Eq. (17) presents the addition of relative degrees of WSM and WPM compared to the optimal one. Eq. (18) presents the balanced compromise measure of WSM and WPM scores.

Step 8: Determination of assessment value $\square_i$

By Eq. (19), calculate the assessment value $\square_i$ for each alternative

$$\square_i = \left(\square_i^{(1)} \square_i^{(2)} \square_i^{(3)}\right)^{1/3} + \frac{1}{3}\left(\square_i^{(1)} + \square_i^{(2)} + \square_i^{(3)}\right). \tag{19}$$

Determine the preferences of the options based on increasing values of assessment index $\square_i$.

5. An Illustrative Case Study

In this section, the introduced SVN-CRITIC-CoCoSo technique is employed to evaluate the S3PRLPs with SVNN information, which exposes its potentiality and usefulness.

To do this, a decision making example of S3PRLP selection problem is presented for an electronics manufacturing company ABC. The considered company is located in southern region of India and currently, it has five S3PRLP options. This company has been working from last 15 years and established as a biggest market frontrunner. In spite of its long-term business success, the manufacturer doesn't have any authentic agenda for the selection of a S3PRLP. In recent years, the company has shown an immense interest toward executing the green initiatives in their supply chain activities toenhance the environmental protection. The managing committee is also looking for the prioritization of the S3PRLP assessment criteria and desires to opt the optimal provider among list of options (see Fig 2).

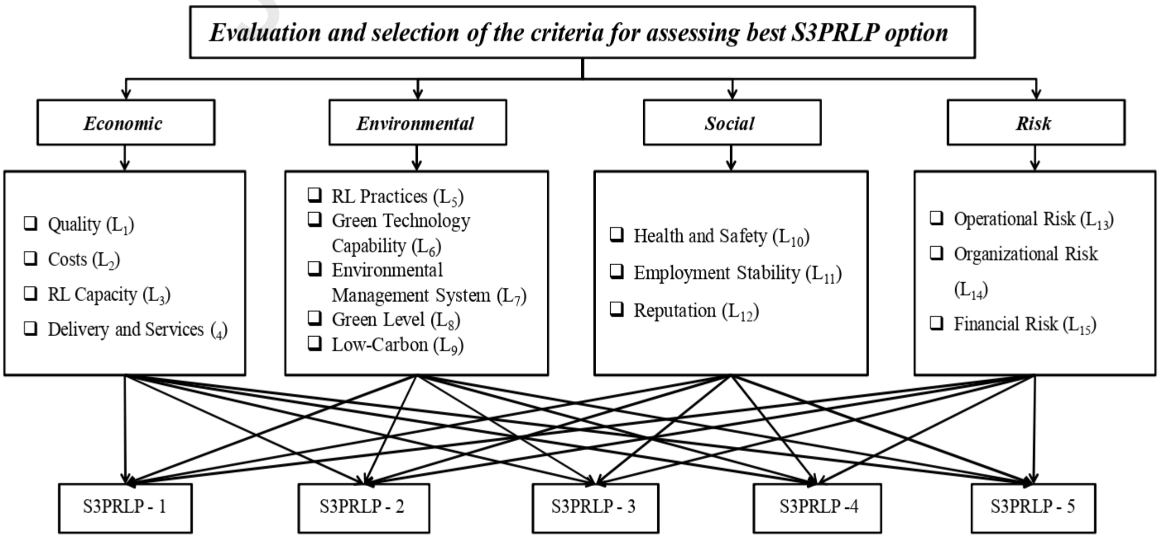

Fig. 2: Hierarchical structure of selecting criteria

After initial screening, we have invited a team of three DEs (β_1, β_2, β_3) from different areas to process this S3PRLP selection problem. Inspired by the literature survey and debate with the specialists, we have preferred five S3PRLPs (S_1, S_2, S_3, S_4, S_5) based on 15assessed criteria which are given in Table 1 (see Fig. 2). Here, the criteria X_2, X_9, X_{13}, X_{14} and X_{15} are non-beneficial attributes and others are beneficial attributes. The computational procedure of SVN-CRITIC-CoCoSo method for the selection of desirable S3PRLP is presented as follows:

Table 1: Assessment criteria for S3PRLPs selection

Aspect	Criteria	Maximizing / minimizing criteria	Optimal References										
			Prakash and Barua (2016a)	Prakash and Barua (2016b)	Tavana et al. (2016b)	Mavi et al. (2017)	Zarbakhshnia et al. (2018)	Bai and Sarkis (2018)	Govindan et al. (2019)	Pamucar et al. (2019)	Zarbakhshnia et al. (2020)	Zhang and Su (2020)	Chen et al. (2020)
Economic	Quality (X_1)	Max		√	√	√	√		√		√	√	√
	Costs (X_2)	Min		√	√	√	√		√	√	√	√	√
	RL Capacity (X_3)	Max							√				
	Delivery and Services (X_4)	Max		√	√	√	√				√	√	
Environmental	RL Practices (X_5)	Max							√				
	Green Technology Capability (X_6)	Max			√	√	√				√	√	
	Environmental Management System (X_7)	Max						√	√			√	
	Green Level (X_8)	Max		√					√		√		
	Low-Carbon (X_9)	Min							√				
Social	Health and Safety (X_{10})	Max		√		√	√	√			√	√	
	Employment Stability (X_{11})	Max					√	√				√	
	Reputation (X_{12})	Max									√		
Risk	Operational Risk (X_{13})	Min		√		√	√				√	√	
	Organizational Risk (X_{14})	Min				√					√		
	Financial Risk (X_{15})	Min				√	√				√	√	

Step 1: Here, the linguistic ratings to assess the relative significance of the DEs and the preferred attributes for S3PRLPs and their corresponding single-valued neutrosophic numbers are expressed in Tables 2-3.

Table 2: LVs for the rating of DEs performances

Linguistic Values	SVNNs
Extremely experienced (EE)	(0.90, 0.10, 0.10)
Very very experienced (VVE)	(0.80, 0.30, 0.20)
Very experienced (VE)	(0.60, 0.40, 0.30)
Experienced (E)	(0.40, 0.50, 0.50)
Less experienced (LE)	(0.30, 0.65, 0.60)
Very less experienced (VLE)	(0.20, 0.90, 0.80)

Table 3: Conversion of the LVs to the SVNNs

Linguistic Values	SVNNs
Extremely high (EH)	(1.00, 0.00, 0.00)
Very very high (VVH)	(0.90, 0.10, 0.10)
Very high (VH)	(0.80, 0.15, 0.20)
High (H)	(0.70, 0.25, 0.30)
Moderately high (MH)	(0.60, 0.35, 0.40)
Fair (F)	(0.50, 0.50, 0.50)
Moderately low (ML)	(0.40, 0.65, 0.60)
Low (L)	(0.30, 0.75, 0.70)
Very low (VL)	(0.20, 0.85, 0.80)
Very very low (VVL)	(0.10, 0.90, 0.90)
Extremely low (EL)	(0.00, 1.00, 1.00)

Table 4 shows the evaluation information of each option over the considered attribute, given by all the three DEs.

Step 2: By employing Table 2 and Eq. (5), the DEs are computed in Table 5.

Step 3: Individual decision opinions of three DEs have been aggregated by utilizing Eq. (6) and the required A-SVN-DM is presented in Table 6.

Table 4: LVs with different experts for S3PRLPs selection

	N_1	N_2	N_3	N_4	N_5
X_1	(H,MH,H)	(F,H,MH)	(MH,F,H)	(F,F,H)	(VH,H,MH)
X_2	(ML,L,L)	(F,L,ML)	(F,ML,F)	(F,ML,VL)	(L,VL,F)
X_3	(VH,H,F)	(VH,F,H)	(F,MH,ML)	(MH,ML,F)	(F,H,F)
X_4	(H, H, F)	(F, VH, ML)	(F,F,MH)	(F,MH,MH)	(F, H, MH)
X_5	(F, H,MH)	(VH,MH,F)	(VH,F,MH)	(MH,H,MH)	(VVH,H,F)
X_6	(VH,H,VVH)	(H,MH,H)	(F,MH,H)	(F, MH,F)	(VVH,MH,MH)
X_7	(H,ML,F)	(ML,F,MH)	(F,F,VH)	(F,H,H)	(F,MH,VH)
X_8	(MH,F,H)	(H,H,ML)	(ML,F,MH)	(MH,F,F)	(MH,H,ML)
X_9	(ML,F,L)	(VL,ML,F)	(F,L,VL)	(ML,VL,ML)	(L,ML,L)
X_{10}	(MH,H,ML)	(VH,MH,F)	(F, ML,H)	(F,ML,H)	(VH,MH,F)

X_{11}	(H,MH,H)	(H,F,MH)	(MH,ML,VH)	(F,MH,H)	(H,F,ML)
X_{12}	(MH,VVH,MH)	(MH,ML,F)	(ML,MH,H)	(F,H,MH)	(H,ML,VH)
X_{13}	(VL,ML,F)	(L,ML,F)	(VL,ML,F)	(F,ML,VL)	(F,L,VL)
X_{14}	(F,ML,F)	(ML,F,VL)	(F,VL,ML)	(ML,F,ML)	(ML,L,ML)
X_{15}	(ML,L,L)	(F,ML,L)	(ML,VL,L)	(F,ML,VL)	(VL,ML,L)

Table 5: DEs' weights for rating the S3PRLPs option

DMs	Linguistic values	SVNNs	Weights
β_1	Very experienced (VE)	(0.60, 0.40, 0.30)	0.3378
β_2	Very very experienced (VVE)	(0.80, 0.30, 0.20)	0.4054
β_3	Experienced (E)	(0.40, 0.50, 0.50)	0.2568

Table 6: A-SVN-DM for S3PRLPs selection

	N_1	N_2	N_3	N_4	N_5
X_1	(0.641, 0.287, 0.337)	(0.584, 0.344, 0.384)	(0.574, 0.371, 0.407)	(0.540, 0.418, 0.439)	(0.694, 0.229, 0.282)
X_2	(0.319, 0.715, 0.664)	(0.385, 0.630, 0.601)	(0.443, 0.556, 0.538)	(0.371, 0.637, 0.607)	(0.312, 0.711, 0.678)
X_3	(0.676, 0.251, 0.298)	(0.663, 0.279, 0.322)	(0.491, 0.463, 0.479)	(0.483, 0.493, 0.499)	(0.559, 0.378, 0.406)
X_4	(0.629, 0.299, 0.342)	(0.597, 0.328, 0.361)	(0.505, 0.456, 0.472)	(0.541, 0.395, 0.431)	(0.584, 0.344, 0.384)
X_5	(0.584, 0.344, 0.384)	(0.643, 0.288, 0.335)	(0.637, 0.304, 0.346)	(0.614, 0.305, 0.356)	(0.744, 0.219, 0.236)
X_6	(0.786, 0.166, 0.197)	(0.641, 0.287, 0.337)	(0.574, 0.362, 0.401)	(0.514, 0.433, 0.457)	(0.734, 0.229, 0.250)
X_7	(0.531, 0.440, 0.453)	(0.474, 0.499, 0.502)	(0.586, 0.367, 0.395)	(0.613, 0.316, 0.357)	(0.616, 0.318, 0.361)
X_8	(0.574, 0.371, 0.407)	(0.611, 0.320, 0.358)	(0.474, 0.499, 0.502)	(0.514, 0.443, 0.464)	(0.571, 0.358, 0.395)
X_9	(0.392, 0.606, 0.580)	(0.347, 0.665, 0.631)	(0.338, 0.675, 0.647)	(0.316, 0.725, 0.674)	(0.319, 0.708, 0.658)
X_{10}	(0.571, 0.358, 0.395)	(0.643, 0.288, 0.335)	(0.511, 0.465, 0.472)	(0.511, 0.465, 0.472)	(0.643, 0.288, 0.335)
X_{11}	(0.641, 0.287, 0.337)	(0.584, 0.361, 0.397)	(0.592, 0.362, 0.395)	(0.574, 0.362, 0.401)	(0.538, 0.423, 0.441)
X_{12}	(0.734, 0.211, 0.228)	(0.483, 0.493, 0.499)	(0.547, 0.396, 0.426)	(0.584, 0.344, 0.384)	(0.629, 0.323, 0.358)
X_{13}	(0.347, 0.665, 0.631)	(0.376, 0.638, 0.603)	(0.347, 0.665, 0.631)	(0.371, 0.637, 0.607)	(0.338, 0.675, 0.647)
X_{14}	(0.443, 0.556, 0.538)	(0.371, 0.626, 0.600)	(0.356, 0.663, 0.634)	(0.416, 0.584, 0.557)	(0.346, 0.689, 0.639)
X_{15}	(0.319, 0.715, 0.664)	(0.392, 0.617, 0.587)	(0.288, 0.752, 0.701)	(0.371, 0.637, 0.607)	(0.288, 0.738, 0.688)

Step 4: As the criteria X_2, X_9, X_{13}, X_{14} and X_{15} are non-beneficial type criteria, and others are beneficial type criteria, therefore, there is a need to normalize the A-SVN-DM given in Table 6 and using Eq. (7). Now, the required normalized A-SVN-DM is given in Table 7.

Table 7: Normalized A-SVN-DM for S3PRLPs selection

	N_1	N_2	N_3	N_4	N_5
X_1	(0.641, 0.287, 0.337)	(0.584, 0.344, 0.384)	(0.574, 0.371, 0.407)	(0.540, 0.418, 0.439)	(0.694, 0.229, 0.282)

X_2	(0.664 , 0.285, 0.319)	(0.60, 0.370, 0.385)	(0.538, 0.444, 0.443)	(0.607, 0.363, 0.371)	(0.678, 0.289, 0.312)
X_3	(0.676, 0.251, 0.298)	(0.663, 0.279, 0.322)	(0.491, 0.463, 0.479)	(0.483, 0.493, 0.499)	(0.559, 0.378, 0.406)
X_4	(0.629, 0.299, 0.342)	(0.597, 0.328, 0.361)	(0.505, 0.456, 0.472)	(0.541, 0.395, 0.431)	(0.584, 0.344, 0.384)
X_5	(0.584, 0.344, 0.384)	(0.643, 0.288, 0.335)	(0.637, 0.304, 0.346)	(0.614, 0.305, 0.356)	(0.744, 0.219, 0.236)
X_6	(0.786, 0.166, 0.197)	(0.641, 0.287, 0.337)	(0.574, 0.362, 0.401)	(0.514, 0.433, 0.457)	(0.734, 0.229, 0.250)
X_7	(0.531, 0.440, 0.453)	(0.474, 0.499, 0.502)	(0.586, 0.367, 0.395)	(0.613, 0.316, 0.357)	(0.616, 0.318, 0.361)
X_8	(0.574, 0.371, 0.407)	(0.611, 0.320, 0.358)	(0.474, 0.499, 0.502)	(0.514, 0.443, 0.464)	(0.571, 0.358, 0.395)
X_9	(0.580, 0.394, 0.392)	(0.631, 0.335, 0.347)	(0.647, 0.325, 0.338)	(0.674, 0.275, 0.316)	(0.658, 0.292, 0.319)
X_{10}	(0.571, 0.358, 0.395)	(0.643, 0.288, 0.335)	(0.511, 0.465, 0.472)	(0.511, 0.465, 0.472)	(0.643, 0.288, 0.335)
X_{11}	(0.641, 0.287, 0.337)	(0.584, 0.361, 0.397)	(0.592, 0.362, 0.395)	(0.574, 0.362, 0.401)	(0.538, 0.423, 0.441)
X_{12}	(0.734, 0.211, 0.228)	(0.483, 0.493, 0.499)	(0.547, 0.396, 0.426)	(0.584, 0.344, 0.384)	(0.629, 0.323, 0.358)
X_{13}	(0.631, 0.335, 0.347)	(0.603, 0.362, 0.376)	(0.631, 0.335, 0.347)	(0.607, 0.363, 0.371)	(0.647, 0.325, 0.338)
X_{14}	(0.538, 0.444, 0.443)	(0.600, 0.374, 0.371)	(0.634, 0.337, 0.356)	(0.557, 0.416, 0.416)	(0.639, 0.311, 0.346)
X_{15}	(0.664, 0.285, 0.319)	(0.587, 0.383, 0.392)	(0.701, 0.248, 0.288)	(0.607, 0.363, 0.371)	(0.688, 0.262, 0.288)

Step 5: Further, CRITIC procedure is used to assess the attribute weight. First, from Eq. (8)- Eq. (9) and Table 6, we estimate the score and standard SVN-matrices, respectively. By employing Eq. (10)-Eq. (12), the SD, CRC and amount of information of attribute are evaluated and portrayed in Table 8. The attribute weights are appraised by implementing Eq. (13) and are specified as (see Fig. 3).

Ψ_j = { 0.0449, 0.0504, 0.0867, 0.0623, 0.0596, 0.0479, 0.0874, 0.0675, 0.0875, 0.0665, 0.0707, 0.0604, 0.0668, 0.0662, 0.0751}.

Table 8: Standard SVN-matrix, SD and attribute weights

	N_1	N_2	N_3	N_4	N_5	σ_j	c_j	Ψ_j
X_1	0.677	0.357	0.232	0.000	1.000	0.350	3.089	0.0449
X_2	0.977	0.463	0.000	0.522	1.000	0.371	3.499	0.0504
X_3	1.000	0.895	0.101	0.000	0.000	0.451	5.948	0.0867
X_4	1.000	0.806	0.000	0.351	0.351	0.357	4.268	0.0623
X_5	0.000	0.396	0.308	0.244	1.000	0.332	4.083	0.0596
X_6	1.000	0.507	0.241	0.000	0.782	0.360	3.282	0.0479
X_7	0.344	0.000	0.741	1.000	1.000	0.391	6.032	0.0874
X_8	0.705	1.000	0.000	0.296	0.296	0.354	4.639	0.0675
X_9	0.000	0.526	0.637	1.000	0.867	0.346	6.020	0.0875
X_{10}	0.565	1.000	0.000	0.000	1.000	0.448	4.586	0.0665

X_{11}	1.000	0.445	0.463	0.413	0.000	0.318	4.860	0.0707
X_{12}	1.000	0.000	0.305	0.472	0.472	0.325	4.148	0.0604
X_{13}	0.713	0.000	0.713	0.050	1.000	0.398	4.666	0.0668
X_{14}	0.000	0.590	0.365	0.221	1.000	0.362	4.577	0.0662
X_{15}	0.708	0.000	1.000	0.168	0.917	0.410	5.187	0.0751

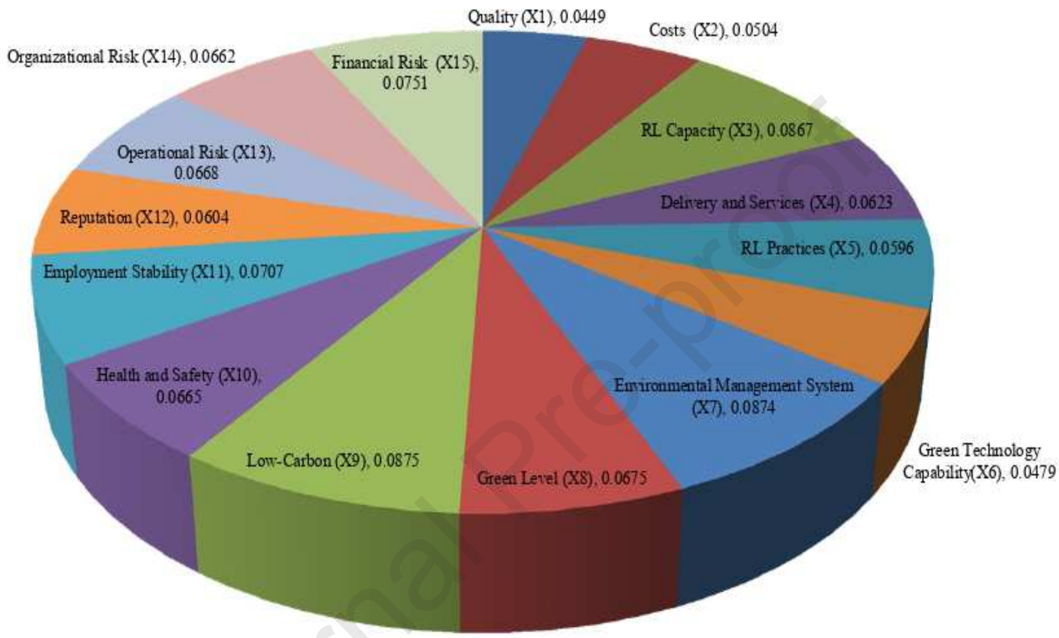

Fig 3: Representation of the criteria weights by using SVN-CRITIC method

Steps 6-8: With the use of Eqs (14)-(19), the whole procedural steps of SVN-CRITIC-CoCoSo methodology has been estimated and shown in Table 9. According to obtained results, the ranking order of the S3PRLP options is $N_5 \succ N_1 \succ N_3 \succ N_2 \succ N_4$ and thus, the option N_5 is the ideal S3PRLP choice.

Table 9: Overall computational outcomes for S3PRLPs selection

Options	$\square_i^{(1)}$	$\square_i^{(2)}$	$S^*(\square_i^{(1)})$	$S^*(\square_i^{(2)})$	$\square_i^{(1)}$	$\square_i^{(2)}$	$\square_i^{(3)}$	$\square_i$	Ranking
N_1	(0.630, 0.315, 0.358)	(0.620, 0.328, 0.356)	0.661	0.523	0.2015	2.1056	0.9555	1.8276	2
N_2	(0.599, 0.350, 0.378)	(0.593, 0.360, 0.384)	0.630	0.521	0.1960	2.0513	0.9294	1.7792	4
N_3	(0.583, 0.374, 0.398)	(0.574, 0.385, 0.406)	0.604	0.548	0.1961	2.0592	0.9300	1.7833	3
N_4	(0.575, 0.376, 0.401)	(0.569, 0.385, 0.407)	0.599	0.548	0.1954	2.0523	0.9266	1.7771	5
N_5	(0.640, 0.306, 0.337)	(0.633, 0.313, 0.344)	0.666	0.573	0.2109	2.2102	1.0000	1.9157	1

5.1. Comparison with existing methods

Here, the feasibility and advantage of the developed MCDM framework are exhibited by comparing it with extant methods. To discuss the comparative study, the above-mentioned S3PRLP selection problem is evaluated by applying SVN-TOPSIS (Ortega et al., 2018) method and SVN-VIKOR (Rani and Mishra, 2020) method with the same weight information.

5.1.1. SVN-TOPSIS method (Ortega et al., 2018)

Steps 1-5: Similar as preceding framework

Step 6: Calculate the SVN-positive ideal solution (SVN-PIS) and SVN-negative ideal solution (SVN-NIS)

Let ι^+ and ι^- presents the SVN-PIS and SVN-NIS, respectively, are determined as below:

ι^+ ={(0.694,0.229,0.282), (0.312, 0.711, 0.678), (0.676, 0.251, 0.298), (0.629, 0.299, 0.342), (0.744, 0.219, 0.236), (0.786, 0.166, 0.197), (0.613, 0.316, 0.357), (0.611, 0.320, 0.358), (0.316, 0.725, 0.674), (0.643, 0.288, 0.335), (0.641, 0.287, 0.337), (0.734, 0.211, 0.228), (0.338, 0.675, 0.647), (0.346, 0.689, 0.639), (0.288, 0.752, 0.701)}

ι^- ={(0.540, 0.418, 0.439), (0.443, 0.556, 0.538), (0.483, 0.493, 0.499), (0.505, 0.456, 0.472), (0.584, 0.344, 0.384), (0.514, 0.433, 0.457), (0.474, 0.499, 0.502), (0.474, 0.499, 0.502), (0.392, 0.606, 0.580), (0.511, 0.465, 0.472), (0.538, 0.423, 0.441), (0.483, 0.493, 0.499), (0.376, 0.638, 0.603), (0.443, 0.556, 0.538), (0.392, 0.617, 0.587)}.

Step 7: With the use of following formula, evaluate the closeness coefficient (CC) of each alternative:

$$CC_i = \frac{D_h\left(\varsigma_{ij}, \iota^-\right)}{D_h\left(\varsigma_{ij}, \iota^+\right) + D_h\left(\varsigma_{ij}, \iota^-\right)}, \; CC_i \in [0, 1].$$

Step 8: Rank the options based on the increasing degrees of $CC_i \in [0, 1]$. Thus, the higher degree means a better option.

Now, the whole computational results of SVN-TOPSIS (Ortega et al., 2018) technique are portrayed in Table 10.

Table 10: Preference order of S3PRLPs selection based on SVN-TOPSIS method

Option	$D_h\left(\varsigma_{ij}, \iota^+\right)$	$D_h\left(\varsigma_{ij}, \iota^-\right)$	CC_i	Ranking
S_1	0.047	0.101	0.683	2
S_2	0.077	0.072	0.483	3
S_3	0.098	0.050	0.340	4

S_4	0.101	0.048	0.321	5
S_5	0.035	0.113	0.762	1

Hence, the desirable S3PRLP alternative (N_5) is the best choice.

5.1.2. SVN-VIKOR (Rani and Mishra, 2020)

Step 1-5: Similar as proposed approach

Step 6: Evaluate the Group Utility Measure (GUM), Individual Regret Measure (IRM) and Compromise Measure (CM) of each option by using SVN-distance measure given by Eq. (4). The formula for GUM, IRM and CM of the options N_i (i= 1, 2,…, m) are defined by

$$G_i = L_{1,i} = \sum_{j=1}^{n} \Psi_j \frac{D_h\left(\iota_j^+, \varepsilon_{ij}\right)}{D_h\left(\iota_j^+, \iota_j^-\right)}, \quad I_i = L_{\infty,i} = \max_{1\le j\le n}\left(\Psi_j \frac{D_h\left(\iota_j^+, \varepsilon_{ij}\right)}{D_h\left(\iota_j^+, \iota_j^-\right)}\right) \text{ and } Q_i = \tau \frac{\left(G_i - G^+\right)}{\left(G^- - G^+\right)} + (1-\tau)\frac{\left(I_i - I^+\right)}{\left(I^- - I^+\right)}.$$

Here, $G^+ = \min_i G_i$, $G^- = \max_i G_i$, $I^+ = \min_i I_i$, $I^- = \max_i I_i$ and $\tau \in [0,1]$ is the weight of the decision strategy.

Step 6: Determine the preference order the options.

Rank the options by sorting the lessening values of G_i, I_i and Q_i. The minimum value of Q_i determines the optimal option.

The entire steps of SVN-VIKOR approach are calculated and shown in Table 11.

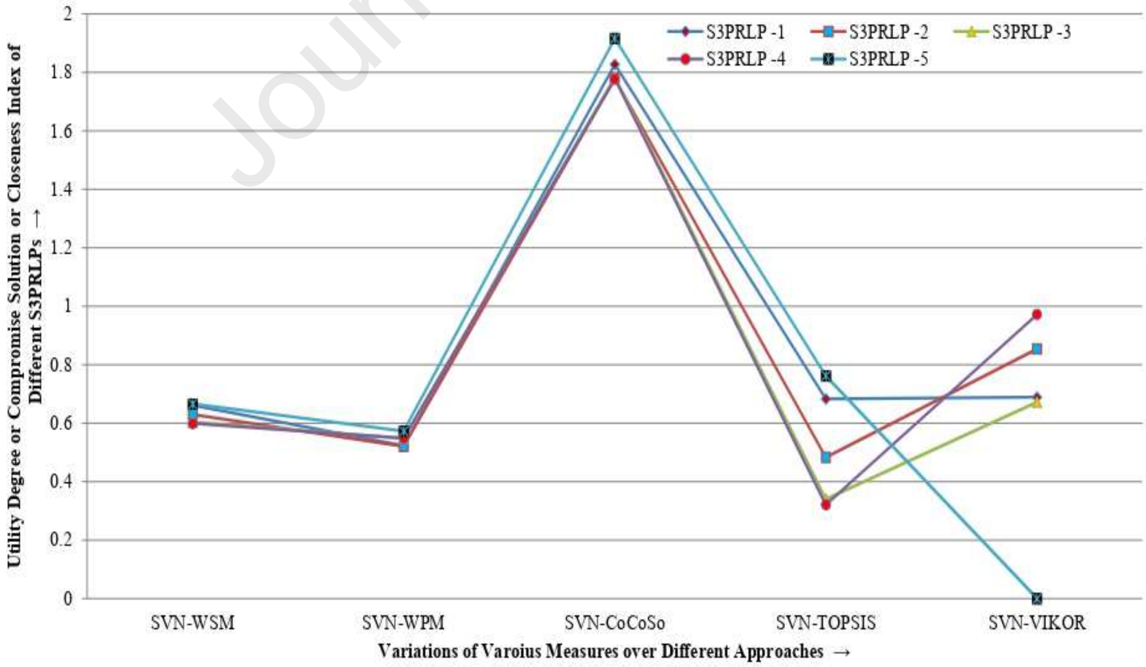

Fig 4: Comparison of proposed with extant methods for S3PRLPs selection

By SVN-VIKOR approach, the desirable S3PRLP alternative N_5 is the best option. The comparative results of proposed and extant approaches are presented in Fig. 4.

Table 11: The value of G_i, I_i and Q_i for S3PRLPs selection

Option	G_i	Ranking	I_i	Ranking	Q_i	Ranking
N_1	0.380	2	0.088	4	0.689	3
N_2	0.534	3	0.087	4	0.854	4
N_3	0.598	4	0.079	2	0.672	2
N_4	0.657	5	0.087	3	0.972	5
N_5	0.211	1	0.071	1	0.000	1

The major distinguishing features of the developed method are presented as below:

- The SVN-CRITIC-CoCoSo technique employs a comparability order and then the weights are aggregated with two procedures under SVNSs environment. It follows the usual multiplication law and the weighted power of the distance from comparability order. To verify the preference order, three diverse aggregation coefficients have been computed for each option. Further, a collective procedure reports the preference ordering. There is no any method which has these types of aggregation procedure.
- The SVN-TOPSIS method (Ortega et al., 2018) and SVN-VIKOR (Rani and Mishra, 2020) determine the solution with minimum discrimination from the SVN-PIS and maximum discrimination from the SVN-NIS, however, these methods are incapable to reflect the relative consequence of these discriminations. Whilst the proposed technique employs comparability sequence and then the weighted aggregation with the usual multiplication law and weighted power of the distance from comparability order.
- The SVN-VIKOR methodology proposed by Rani and Mishra (2020) and the SVN-TOPSIS developed by Ortega et al. (2018) use linear and vector normalization, respectively, to eradicate the sundry units of criterion functions. Whereas, the introduced CoCoSo method uses both linear and vector normalization to eradicate the dissimilar units of criterion functions.
- The CRITIC method is a more simple method with fewer computational steps. Moreover, in the case of principal component analysis, crisp values of inter-criteria correlation coefficients should be identified, in order to decide those attributes considered to be extremely correlated.

This subjective intervention is shunned through the use of CRITIC approach, which makes the introduced SVN-CRITIC-CoCoSo technique more prudent, flexible and well-organized.

5.2. Sensitivity analysis (SA)

The process of SA is utilized to certify the robustness of the developed approach. In addition, this process removes any potential human judgmental biases which may persuade the outcomes (Kannan et al. 2019, Zarbakhshnia et al., 2020). To do this, we process a SA corresponding to the different values of the coefficient 'γ'. Consider that 'γ' fluctuates from 0.0 to 1.0, then, the balanced compromise measures and assessment values of the S3PRLP alternatives are evaluated concerning these dissimilar values of γ, and it is found that the ranking order of the S3PRLPs is similar in each set. The results are shown in Table 12 and graphically presented in Fig. 5. Based on the obtained outcomes, it is observed that the S3PRLP alternatives are dependent and sensitive with respect to diverse values of decision mechanism parameter 'γ'. Therefore, the proposed SVN-CRITIC-CoCoSo framework has an adequate solidity over diverse sets of 'γ'. In addition, the SA is also performed for dissimilar run of attributes weights and S3PRLPs' alternatives. Thus, we found that the alternative N_5 is the top ranked choice, while N_4 is considered as worst ranked S3PRLP. Lastly, it is concluded that the introduced SVN-CRITIC-CoCoSo methodology is free from any biases and the obtained results are robust in nature.

Table 12: The utility degree of alternative w.r.t. diverse values of γ for S3PRLPs selection

Options	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
N_1	1.8020	1.8075	1.8128	1.8179	1.8228	1.8276	1.8323	1.8368	1.8411	1.8454	1.8495
N_2	1.7673	1.7699	1.7723	1.7747	1.7770	1.7792	1.7814	1.7835	1.7855	1.7875	1.7894
N_3	1.7990	1.7957	1.7924	1.7893	1.7862	1.7833	1.7804	1.7776	1.7749	1.7722	1.7696
N_4	1.7950	1.7912	1.7875	1.7839	1.7805	1.7771	1.7738	1.7706	1.7675	1.7645	1.7616
N_5	1.9157	1.9157	1.9157	1.9157	1.9157	1.9157	1.9157	1.9157	1.9157	1.9157	1.9157

5.3. Discussion

The outcomes of the proposed SVN-CRITIC-CoCoSo method shows that the Environmental Management System (X_7) is the most imperative decisive factor with a weight 0.0875, Low-carbon (X_9) is the 2nd significant attribute with a weight 0.0874, while RL capacity (X_3) is the 3rd significant attribute with a weight 0.0867. The other criteria are less significant. The outcomes indicate that Environmental Management System (X_7), Low-carbon (X_9) and RL capacity (X_3)

should be given more consideration in the evaluation of most suitable S3PRLP option (see Fig. 3).

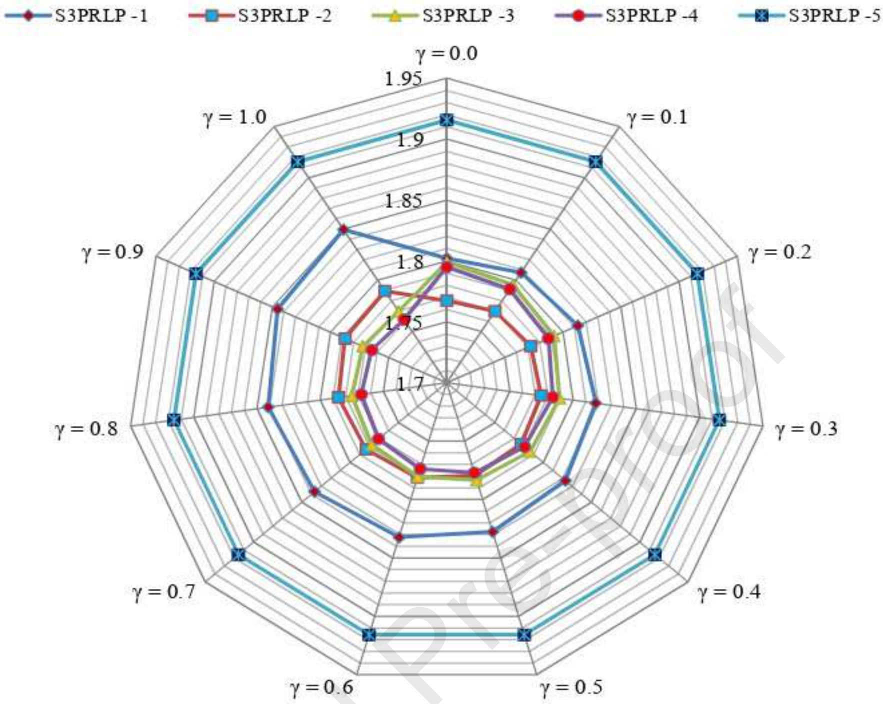

Fig 5: Compromise degree of alternative w.r.t. diverse values of γ

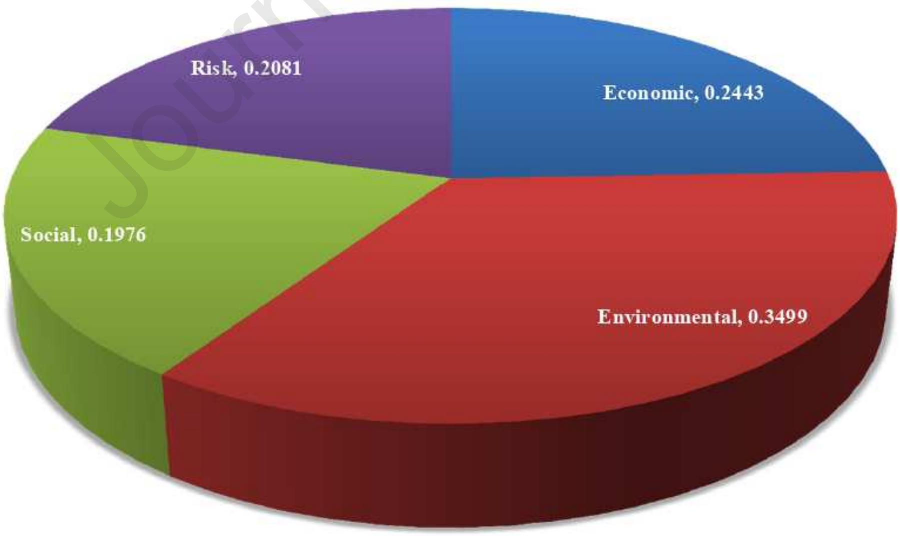

Fig 6: Represents the deviation in the compromise degree of alternative after each different runs

From Table 10, we observe that the option N_5 is the most appropriate choice and the option (N_4) is the worst choice among others. The criteria such as Environmental Management System (X_7), Low-Carbon (X_9), RL Capacity (X_3), Financial Risk (X_{15}) and Employment Stability (X_{11}) have a remarkable effect on the preference ranking of the given S3PRLPs. The obtained outcomes of this case study conclude that the introduced SVN-CRITIC-CoCoSo approach can authentically convey the concepts of the contributed specialists to the outcomes of the ultimate decision.

In general, a glimpse at Fig. 4 demonstrates that the trends of curves for the extant approaches are quite same as the proposed approach. The performance of proposed CoCoSo approach on considered S3PRLP assessment problem with several quantitative and qualitative criteria is more feasible than SVN-TOPSIS and SVN-VIKOR methods. Thus, the developed CoCoSo model suggests an ample range of applications and is more appropriate than the WSM and WPM methods. In addition, the outcomes obviously replicate the fact that the DMs have an immense interest in the environmental aspects of criteria more than other aspects (see Fig. 6), and accordingly, these factors have a significant impact on the obtained outcomes. In fact, the common of the environmental criterion is qualitative and according to the specialists' opinion, which are beyond what the WSM and WPM methods could tackle. Accordingly, the developed approach by combining SVN-CRITIC with CoCoSo performs better than the extant approaches. This is an imperative quality of the proposed method because most of the social and environmental attribute, which consider the cleaner production and sustainable development, are qualitative in nature and entail ambiguity.

6. Conclusions

Increasing environmental awareness and rapidly growing utilization of natural resources have motivated the businesses to focus on SSCM. Because of the restraints related to their technology, own capital or knowledge, some businesses outsource their RL activities. However, the selection of a right S3PRLP alternative among set of alternatives over multiple qualitative and quantitative criteria is an important and uncertain MCDM problem. The objective of the study is to recommend an MCDM methodology for evaluating the S3PRLP assessment problem with SVNNs information. To do this, firstly an innovative SVN-CRITIC-CoCoSo approach is introduced by combining the traditional CoCoSo method, SVNSs’ operators and CRITIC model under SVNSs settings. The weights of the criteria have been assessed by CRITIC-based procedure. Then, a case study of S3PRLP evaluation and selection problem has been discussed within SVNS settings, which expresses the applicability and viability of the present method. The effectiveness of the introduced approach has been justified by comparison with extant methods. Finally, SA has also been discussed to show the stability of introduced approach.

In order to enhance the precision of the decision-making selection problem, the further study can take the large number of attributes set. Also, we will suggest some methods like as GLDS, ORESTE, DNMA, EDAS or ELECTRE to assess the S3PRLP selection problem with SVN-information. In addition, we will apply the developed methodology to other applications, such as sustainable biomass crop selection, renewable energy technology selectionand others.

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Highlights

- Novel integrated SVN-CRITIC-CoCoSo method is developed for solving MCDM problems.
- A sustainable third party reverse logistic provider (S3PRLP) selection and evaluation process is proposed.
- CRITIC approach is used to evaluate the criteria weights.
- To show applicability of proposed method, an empirical case study of S3PRLP selection is discussed.
- Comparative and Sensitivity analyses are also studied to validate the results.

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: