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EVALUATING ESG CORPORATE PERFORMANCE USING A NEW NEUTROSOPHIC AHP-TOPSIS BASED APPROACH

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Abstract. Corporate sustainability reports' credibility of environmental, social, and governance (ESG) information has received a significant focus of attention in the businesses landscape. Over the last years, various methodologies and multicriteria approaches have been developed to assess the ESG performance of companies. To consider the uncertainty that arises from imprecision and subjectivity in evaluating ESG criteria, this paper proposes to develop a novel hybrid methodology that combines AHP and TOPSIS techniques under a neutrosophic environment. We test the suggested proposal through a real case study of the leading companies in the oil and gas industry. Moreover, we conduct a sensitivity analysis for evaluating any discrepancies in the ranking due to using different fuzzy numbers and weighting vectors.

Keywords: fuzzy sets, triangular neutrosophic numbers, possibility measures, sustainability reporting, greenwashing, ESG.

JEL Classification: C61, D81, L71.

Introduction

Assessing corporate sustainability entails that financial accounts are not enough to suit the needs of shareholders, and additional sustainability reports are needed (Wulf et al., 2014). The interest in environmental, social and governance (ESG) metrics and disclosures has become a major focus of attention in the businesses landscape aiming to demand transparency on sustainable and socially responsible practices. In this context, there exists a growing concern about the phenomenon of greenwashing associated with sustainability reporting. The term of greenwashing appeared in the mid of 80s and it describes the practice of making sustainability and environmental claims regarded as unjustified or exaggerated with the purpose of increasing market share (Dahl, 2010).

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As highlighted by Chowdhury and Paul (2020), multicriteria decision making (MCDM) methods have demonstrate their effectiveness for investigating, evaluating and ranking corporate sustainability. These authors also found that the Analytic Hierarchy Process (AHP) developed by Saaty (1980) and the technique for order preference by similarity to ideal solution (TOPSIS) initially formulated by Hwang and Yoon (1981) TOPSIS were the most used methods and that they have been most frequently applied in an integrated basis. In recent years other MCDM methods gained popularity among researchers, as for example, to cited but a few: the Simplified Best Worst Method (SBWM) (Amiri et al., 2021), the VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) (Opricovic, 1998), the Multi-Attributive Border Approximation Area Comparison (MABAC) (Keshavarz-Ghorabaee et al., 2021a), the Elimination Et Choice Translating Reality (ELECTRE) (B. Roy, 1996), the Weighted Aggregates Sum Product Assessment (WASPAS) (Zavadskas et al., 2012), the Simultaneous Evaluation of Criteria and Alternatives (SECA) (Keshavarz-Ghorabaee et al., 2018), the Preference Ranking Organisation Methods for Enrichment Evaluations (PROMETHEE) (Brans et al., 1984), the Stepwise Weight Assessment Ratio Analysis II (SWARA II) (Keshavarz-Ghorabaee, 2021), the Method based on the Removal Effect of Criteria (MEREC) (Keshavarz-Ghorabaee et al., 2021b) and the Evaluation based on Distance from Average Solution (EDAS) (Ghorabaee et al., 2015). The merit of integrating AHP to incorporate subjective decision-maker preferences in a fuzzy approach is that it allows assigning the relative importance of attributes using fuzzy numbers instead of precise numbers.

Uncertainty about the veracity of the information disclosed in the sustainability reports, combined with the fact that there is no single and widely accepted procedure for the measurement of sustainability performance (Dahlsrud, 2008; De Bakker et al., 2005; Ilinitch et al., 1998; van Marrewijk, 2003), has favoured the implementation of fuzzy MCDM approaches in the field of evaluating ESG corporate performance (Mardani et al., 2015). Indeed, the use of MCDM methodologies to measure ESG performance has risen significantly during the last twenty years. The uncertainty that arises from imprecision and subjectivity in evaluating ESG criteria renders conventional AHP unsuitable in situations of imprecise linguistic usage (Tavana et al., 2016). To overcome this problem, fuzzy logic is incorporated into the AHP method in what is known as Fuzzy AHP. Several authors have applied Fuzzy AHP techniques to derive fuzzy priorities (see for example, Van Laarhoven & Pedrcyz, 1983 and Buckley, 1985). In contrast, other authors such as Chang (1996) and Mikhailov and Tsvetinov (2004) compute crisp priorities using fuzzy comparison judgments. Recently, this technique has been applied in Lu et al. (2021).

Within the context of fuzzy theory, various types of fuzzy numbers, including neutrosophic numbers, are seen as a valuable tool for assessing the reliability of data. On the basis that fuzzy sets are useful for dealing with imprecise information provided by the decision-maker, it is assumed that they are not suitable to treat inconsistent and indeterminate information. To overcome this problem Smarandache (1999) introduced the concept of neutrosophic fuzzy sets (NFS), which are classified based on the degree of truthiness, indeterminacy, and falsity. This set of NFS numbers has been tested with relevant results in Giri et al. (2020). In recent years, the NFS approach has been integrated to extend fuzzy AHP, approaches. In Abdel-Basset et al. (2017) the neutrosophic set theory was proposed to deal with the AHP approach in which each pairwise comparison judgement was represented as a single-value triangular neutrosophic number (SVTN). According to this author, Neutrosophic AHP (N-AHP) has the same advantages as classical/fuzzy AHP and besides it implies the following benefits: (i) Offers users a structure framework richer than classical AHP (ii) Describes the decision maker's preference judgement values more efficiently; (iii) Allows for a more appropriate handling of vagueness and uncertainty through three distinct levels, namely, "membership degree, indeterminacy degree and non-membership degree". The possibility mean and possibility standard deviation are two significant characteristics of fuzzy numbers in mathematical terms. However, to date there was no investigation about the incorporation of new approaches of them in neutrosophic sets. The use of different neutrosophic methodologies have been developed and applied to different fields of science. In particular, Nafei et al. (2021) proposed an application for hotels location problems; Ahmad (2021) developed a pharmaceutical supply chain management proposal. In Luo, Pedrycz, and Xing (2021) the authors work on the pricing problems of satellite image data products; Deveci et al. (2021) present an approach for offshore wind farm site selection in USA; Wei et al. (2021) deal with the assessment of the safety in construction projects; Kilic, Yurdaer, and Aglan (2021) suggested an application for leanness assessment.

The aim of this paper is twofold. Theoretically, we extend the integrated AHP-TOPSIS approach to the fuzzy environment using a new possibility score of SVTN to assess the reliability of ESG data reported in corporate sustainability reports. Empirically, we test the proposed approach on a realistic case study, to evaluate the ESG performance of leading oil and gas energy firms worldwide.

The rest of this paper has the following structure. Section 1 summarizes basic concepts related to neutrosophic fuzzy theory. The proposed approach to derive the possibility score function of a SVTN and its use in AHP combined with TOPSIS is formulated in Section 2. Section 3 offers the practical application of the presented methodology employing a case study of leading companies in the oil and gas industry. The last Section summarizes the main conclusions.

1. Preliminaries

Since the pioneering work of Zadeh (1965) who proposed the fuzzy set theory, this theory is broadly employed in various research areas involving uncertainty. In recent years, several authors have attempted to expand the classical fuzzy set theory by developing alternative fuzzy sets (FS) as interval-valued fuzzy set (IVFS) (Turksen, 1986; Zadeh, 1975), intuitionistic fuzzy sets (IFS) (Atanassov, 1986) or interval-valued intuitionistic fuzzy set (IVIFS) (Atanassov & Gargov, 1989). However, some authors point out that FS and IFS are not able to correctly address uncertainty and indeterminacy in complex systems (Garg & Nancy, 2020). Smarandache (1999) proposed the neutrosophic set (NS) concept as a generalization of fuzzy sets. A NS is composed of (i) the truth membership function (T); (ii) the indeterminacy membership function (I), (iii) the falsity membership function (F). In NS, indeterminacy (hesitancy) is used as an independent measure of the membership and non-membership information (Das et al., 2020). In what follows, we provide some basic and fundamental concepts related to the theoretical foundations of neutrosophic sets.

Definition 1 (Smarandache, 1999)**.** Let X be a universe of discourse with a generic element in X denoted by x. A single valued neutrosophic set (SVNS) A over X is characterized by a truth membership (T_A), an indeterminacy membership (I_A) and a falsity membership (F_A). For each point x in X, $T_A(x)$, $I_A(x)$, $F_A(x) \in [0, 1]$.

Where

$$0 \le T_A(x) + I_A(x) + F_A(x) \le 3. \tag{1}$$

Definition 2 (Deli & Şubaş, 2017)**.** Let $\tilde{A} = ((\underline{a}, a, \overline{a}); w_{\tilde{A}}, y_{\tilde{A}}, u_{\tilde{A}})$ denoted as a SVTN, which is a special SVNS on the real numbers R, whose $T_{\tilde{A}}(x)$, $I_{\tilde{A}}(x)$ and $F_{\tilde{A}}(x)$ functions are given as follows:

$$T_{\tilde{A}}(x) = \begin{cases} \dfrac{x-\underline{a}}{a-\underline{a}} w_{\tilde{A}}, & \text{if } \underline{a} \le x \le a \\ w_{\tilde{A}}, & \text{if } x = a \\ \dfrac{\overline{a}-x}{\overline{a}-a} w_{\tilde{A}}, & \text{if } a < x \le \overline{a} \\ 0, & \text{Otherwise} \end{cases}; \tag{2}$$

$$I_{\tilde{A}}(x) = \begin{cases} \dfrac{a-x+(x-\underline{a})y_{\tilde{A}}}{a-\underline{a}}, & \text{if } \underline{a} \le x \le a \\ y_{\tilde{A}}, & \text{if } x = a \\ \dfrac{x-a+(\overline{a}-x)y_{\tilde{A}}}{\overline{a}-a}, & \text{if } a < x \le \overline{a} \\ 1, & \text{Otherwise} \end{cases}; \tag{3}$$

$$F_{\tilde{A}}(x) = \begin{cases} \dfrac{a-x+(x-\underline{a})u_{\tilde{A}}}{a-\underline{a}}, & \text{if } \underline{a} \le x \le a \\ u_{\tilde{A}}, & \text{if } x = a \\ \dfrac{x-a+(\overline{a}-x)u_{\tilde{A}}}{\overline{a}-a}, & \text{if } a < x \le \overline{a} \\ 1, & \text{Otherwise} \end{cases}. \tag{4}$$

If $\underline{a} > 0$ and at least $\overline{a} > 0$, then $\tilde{A} = ((\underline{a}, a, \overline{a}); w_{\tilde{A}}, y_{\tilde{A}}, u_{\tilde{A}})$ is called a positive SVTN. Likewise, if $\overline{a} \le 0$ and at least $\underline{a} < 0$, then $\tilde{A} = ((\underline{a}, a, \overline{a}); w_{\tilde{A}}, y_{\tilde{A}}, u_{\tilde{A}})$ is called a negative SVTN.

A SVTN is depicted in Figure 1.

Definition 3. (Deli & Subas, 2014; Khatter, 2020). Let $\tilde{A} = ((\underline{a}, a, \overline{a}); w_{\tilde{A}}, y_{\tilde{A}}, u_{\tilde{A}})$ and $\tilde{B} = ((\underline{b}, b, \overline{b}); w_{\tilde{B}}, y_{\tilde{B}}, u_{\tilde{B}})$ be two SVTNs and λ a real number, then:

$$\tilde{A} \oplus \tilde{B} = ((\underline{a}+\underline{b}, a+b, \overline{a}+\overline{b}); \min[w_{\tilde{A}}, w_{\tilde{B}}], \max[y_{\tilde{A}}, y_{\tilde{B}}], \max[u_{\tilde{A}}, u_{\tilde{B}}]); \tag{5}$$

$$\tilde{A} - \tilde{B} = ((\underline{a}-\overline{b}, a-b, \overline{a}-\underline{b}); \min[w_{\tilde{A}}, w_{\tilde{B}}], \max[y_{\tilde{A}}, y_{\tilde{B}}], \max[u_{\tilde{A}}, u_{\tilde{B}}]); \tag{6}$$

$$\tilde{A} \otimes \tilde{B} = \begin{cases} ((\underline{a}\times\underline{b}, a\times b, \overline{a}\times\overline{b}); \min[w_{\tilde{A}}, w_{\tilde{B}}], \max[y_{\tilde{A}}, y_{\tilde{B}}], \max[u_{\tilde{A}}, u_{\tilde{B}}]) \text{ if } \tilde{A} > 0 \text{ and } \tilde{B} > 0 \\ ((\underline{a}\times\overline{b}, a\times b, \overline{a}\times\underline{b}); \min[w_{\tilde{A}}, w_{\tilde{B}}], \max[y_{\tilde{A}}, y_{\tilde{B}}], \max[u_{\tilde{A}}, u_{\tilde{B}}]) \text{ if } \tilde{A} < 0 \text{ and } \tilde{B} > 0; \\ ((\overline{a}\times\overline{b}, a\times b, \underline{a}\times\underline{b}); \min[w_{\tilde{A}}, w_{\tilde{B}}], \max[y_{\tilde{A}}, y_{\tilde{B}}], \max[u_{\tilde{A}}, u_{\tilde{B}}]) \text{ if } \tilde{A} < 0 \text{ and } \tilde{B} < 0 \end{cases} \tag{7}$$

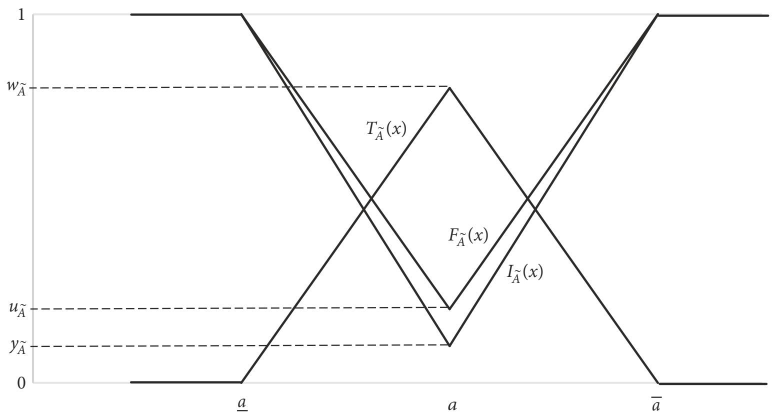

Figure 1. Single-valued triangular neutrosophic number (SVTN)

$$\frac{\tilde{A}}{\tilde{B}}=\begin{cases}((\frac{\underline{a}}{\overline{\overline{b}}},\frac{a}{b},\frac{\overline{a}}{\underline{b}});\ \min\left[w_{\tilde{A}},w_{\tilde{B}}\right],\ \max\left[y_{\tilde{A}},y_{\tilde{B}}\right],\max\left[u_{\tilde{A}},u_{\tilde{B}}\right])\ \text{if } \tilde{A}>0 \text{ and } \tilde{B}>0\\((\frac{\overline{a}}{\overline{\overline{b}}},\frac{a}{b},\frac{\underline{a}}{\underline{b}});\ \min\left[w_{\tilde{A}},w_{\tilde{B}}\right],\ \max\left[y_{\tilde{A}},y_{\tilde{B}}\right],\max\left[u_{\tilde{A}},u_{\tilde{B}}\right])\ \text{if } \tilde{A}<0 \text{ and } \tilde{B}>0;\\((\frac{\overline{a}}{\underline{b}},\frac{a}{b},\frac{\underline{a}}{\overline{b}});\ \min\left[w_{\tilde{A}},w_{\tilde{B}}\right],\ \max\left[y_{\tilde{A}},y_{\tilde{B}}\right],\max\left[u_{\tilde{A}},u_{\tilde{B}}\right])\ \text{if } \tilde{A}<0 \text{ and } \tilde{B}<0\end{cases} \tag{8}$$

$$\lambda\tilde{A}=\begin{cases}((\lambda\underline{a},\lambda a,\lambda\overline{a});w_{\tilde{A}},y_{\tilde{A}},u_{\tilde{A}})\ \text{ if } \lambda>0\\((\lambda\overline{a},\lambda a,\lambda\underline{a});w_{\tilde{A}},y_{\tilde{A}},u_{\tilde{A}})\ \text{ if } \lambda<0\end{cases}; \tag{9}$$

$$\tilde{A}^{-1}=((\frac{1}{\overline{a}},\frac{1}{a},\frac{1}{\underline{a}});w_{\tilde{A}},y_{\tilde{A}},u_{\tilde{A}}). \tag{10}$$

Definition 4 (Khatter, 2020)**.** For a SVTN $\tilde{A}=((\underline{a},a,\overline{a});w_{\tilde{A}},y_{\tilde{A}},u_{\tilde{A}})$, the (α,β,γ) cut set is defined as:

$$\tilde{A}_{(\alpha,\beta,\gamma)}=\left\{\left\langle x,\ T_{\tilde{A}}(x)\geq\alpha,\ I_{\tilde{A}}(x)\leq\beta,\ F_{\tilde{A}}(x)\leq\gamma\right\rangle\ :\ x\in\mathbb{R}\right\},$$

where

$$0\leq\alpha\leq w_{\tilde{A}};y_{\tilde{A}}\leq\beta\leq 1;u_{\tilde{A}}\leq\gamma\leq 1 \text{ and } \alpha+\beta+\gamma\leq 3.$$

Any (α,β,γ)-cut set of SVTN $\tilde{A}$, represented by $\tilde{A}_{(\alpha,\beta,\gamma)}$ is a crip subset of the real number set $\mathbb{R}$:

$$\tilde{A}_{(\alpha,\beta,\gamma)}=\left\langle\tilde{A}_{(\alpha)};\tilde{A}_{(\beta)};\tilde{A}_{(\gamma)}\right\rangle$$

(α)-cut set of SVTN $\tilde{A}$, represented by $\tilde{A}_{(\alpha)}$ is a closed interval, defined by

$$\tilde{A}_{(\alpha)}=\left[T_{\tilde{A}}^{L}(\alpha),T_{\tilde{A}}^{U}(\alpha)\right]=\left[\underline{a}_{\tilde{A}}+\frac{\alpha}{w_{\tilde{A}}}(a_{\tilde{A}}-\underline{a}_{\tilde{A}}),\overline{a}_{\tilde{A}}-\frac{\alpha}{w_{\tilde{A}}}(\overline{a}_{\tilde{A}}-a_{\tilde{A}})\right]. \tag{11}$$

(β)-cut set of SVTN $\tilde{A}$, represented by $\tilde{A}_{(\beta)}$ is a closed interval, defined by

$$\tilde{A}_{(\beta)}=\left[I_{\tilde{A}}^{L}(\beta),I_{\tilde{A}}^{U}(\beta)\right]=\left[\frac{a_{\tilde{A}}-y_{\tilde{A}}\underline{a}_{\tilde{A}}-\beta(a_{\tilde{A}}-\underline{a}_{\tilde{A}})}{1-y_{\tilde{A}}},\frac{a_{\tilde{A}}-y_{\tilde{A}}\overline{a}_{\tilde{A}}+\beta(\overline{a}_{\tilde{A}}-a_{\tilde{A}})}{1-y_{\tilde{A}}}\right]. \tag{12}$$

(γ)-cut set of SVTN $\tilde{A}$, represented by $\tilde{A}_{(\gamma)}$ is a closed interval, defined by

$$\tilde{A}_{(\gamma)} = \left[F_{\tilde{A}}^{L}(\gamma), F_{\tilde{A}}^{U}(\gamma)\right] = \left[\frac{a_{\tilde{A}} - u_{\tilde{A}}\underline{a}_{\tilde{A}} - \gamma(a_{\tilde{A}} - \underline{a}_{\tilde{A}})}{1-u_{\tilde{A}}}, \frac{a_{\tilde{A}} - u_{\tilde{A}}\overline{a}_{\tilde{A}} + \gamma(\overline{a}_{\tilde{A}} - a_{\tilde{A}})}{1-u_{\tilde{A}}}\right]. \quad (13)$$

To derive the fuzzy score functions from the SVTN numbers, several authors have proposed the following definitions:

Definition 5. Abdel-Basset et al. (2017), proposed the following score function to transform a SVTN in a real number. Let $\tilde{A} = ((\underline{a}, a, \overline{a}); w_{\tilde{A}}, y_{\tilde{A}}, u_{\tilde{A}})$ a SVTN, then, the score function $S_1(\tilde{A})$ is derived by:

$$S_1(\tilde{A}) = \frac{\underline{a} + a + \overline{a}}{16} \times (2 + w_{\tilde{A}} - y_{\tilde{A}} - u_{\tilde{A}}); \quad (14)$$

$$S_1(\frac{1}{\tilde{A}}) = \frac{1}{\frac{\underline{a} + a + \overline{a}}{16} \times (2 + w_{\tilde{A}} - y_{\tilde{A}} - u_{\tilde{A}})}. \quad (15)$$

Definition 6. Li and Huang (2019). Let $\tilde{A} = ((\underline{a}, a, \overline{a}); w_{\tilde{A}}, y_{\tilde{A}}, u_{\tilde{A}})$ a SVTN, the score function $S_2(\tilde{A})$ is defined as follows:

$$S_2(\tilde{A}) = \frac{\underline{a} + a + \overline{a}}{9} \times (2 + w_{\tilde{A}} - y_{\tilde{A}} - u_{\tilde{A}}); \quad (16)$$

$$S_2(\frac{1}{\tilde{A}}) = \frac{1}{\frac{\underline{a} + a + \overline{a}}{9} \times (2 + w_{\tilde{A}} - y_{\tilde{A}} - u_{\tilde{A}})}. \quad (17)$$

Definition 7. Junaid et al. (2020). Let $\tilde{A} = ((\underline{a}, a, \overline{a}); w_{\tilde{A}}, y_{\tilde{A}}, u_{\tilde{A}})$ a SVTN, then the score function $S_3(\tilde{A})$ is defined as follows.

$$S_3(\tilde{A}) = \frac{\underline{a} + a + \overline{a}}{3} + w_{\tilde{A}} - y_{\tilde{A}} - u_{\tilde{A}}; \quad (18)$$

$$S_3(\frac{1}{\tilde{A}}) = \frac{1}{\frac{\underline{a} + a + \overline{a}}{3} + w_{\tilde{A}} - y_{\tilde{A}} - u_{\tilde{A}}}. \quad (19)$$

2. Proposed method

2.1. The possibility measures of SVTN

Here, we derive a new possibility score function of SVTN using the possibility mean value, the possibility variance and the possibility standard deviation.

2.1.1. Possibility mean value of SVTN

Definition 8. Let $\tilde{A} = ((\underline{a}, a, \overline{a}); w_{\tilde{A}}, y_{\tilde{A}}, u_{\tilde{A}})$ a SVTN, the possibility mean value of $T_{\tilde{A}}(x)$ ($M_T(\tilde{A})$) is

$$M_T(\tilde{A}) = \frac{(\underline{a} + 4a + \overline{a})w_{\tilde{A}}}{6}. \quad (20)$$

Proof. The f weighted lower and upper possibility means of $T_{\tilde{A}}(x)$ for the SVTN $\tilde{A}$ are, respectively, denoted as:

$$\underline{M}_T(\tilde{A}) = \int_0^{w_{\tilde{A}}} f(Pos[\tilde{A} \le \mathrm{T}_{\tilde{A}}^{L}])\mathrm{T}_{\tilde{A}}^{L} d\alpha = \int_0^{w_{\tilde{A}}} f(\alpha)\mathrm{T}_{\tilde{A}}^{L} d\alpha; \quad (21)$$

$$\overline{M}_T(\tilde{A}) = \int_0^{w_{\tilde{A}}} f(Pos[\tilde{A} \geq \mathrm{T}_{\tilde{A}}^U])\mathrm{T}_{\tilde{A}}^U d\alpha = \int_0^{w_{\tilde{A}}} f(\alpha)\mathrm{T}_{\tilde{A}}^U d\alpha. \quad (22)$$

As proposed by (Wan et al., 2013), from Eqs (11), (21) and (22), we can check that for $f(\alpha) = \dfrac{2\alpha}{w_{\tilde{A}}}$, $\alpha \in [0, w_{\tilde{A}}]$, then

$$\underline{M}_T(\tilde{A}) = \frac{(\underline{a} + 2a)w_{\tilde{A}}}{3}; \quad (23)$$

$$\overline{M}_T(\tilde{A}) = \frac{(\overline{a} + 2a)w_{\tilde{A}}}{3}. \quad (24)$$

The f weighted possibility mean of $T_{\tilde{A}}(x)$ is denoted as:

$$M_T(\tilde{A}) = \frac{\underline{M}_T(\tilde{A}) + \overline{M}_T(\tilde{A})}{2}. \quad (25)$$

By substituing Eqs (23) and (24) in Eq. (25), then

$$M_T(\tilde{A}) = \frac{(\underline{a} + 4a + \overline{a})w_{\tilde{A}}}{6}. \quad (26)$$

Definition 9. Let $\tilde{A} = ((\underline{a}, a, \overline{a}); w_{\tilde{A}}, y_{\tilde{A}}, u_{\tilde{A}})$ a SVTN, the possibility mean value of $I_{\tilde{A}}(x)$ ($M_I(\tilde{A})$) is

$$M_I(\tilde{A}) = \frac{(\underline{a} + 4a + \overline{a})(1 - y_{\tilde{A}})}{6}.$$

Proof. The g weighted lower and upper possibility means of $I_{\tilde{A}}(x)$ for the SVTN $\tilde{A}$ are, respectively, denoted as:

$$\underline{M}_I(\tilde{A}) = \int_{y_{\tilde{A}}}^1 g(Pos[\tilde{A} \leq I_{\tilde{A}}^L])I_{\tilde{A}}^L d\beta = \int_{y_{\tilde{A}}}^1 g(\beta)I_{\tilde{A}}^L d\beta; \quad (27)$$

$$\underline{M}_I(\tilde{A}) = \int_{y_{\tilde{A}}}^1 g(Pos[\tilde{A} \geq I_{\tilde{A}}^U])I_{\tilde{A}}^U d\beta = \int_{y_{\tilde{A}}}^1 g(\beta)I_{\tilde{A}}^U d\beta. \quad (28)$$

According to (Wan et al., 2013), from Eqs (12), (27) and (28) we can see that for $g(\beta) = \dfrac{2(1-\beta)}{(1 - y_{\tilde{A}})}$, $\beta \in [y_{\tilde{A}}, 1]$, then

$$\underline{M}_I(\tilde{A}) = \frac{(\underline{a} + 2a)(1 - y_{\tilde{A}})}{3}; \quad (29)$$

$$\overline{M}_I(\tilde{A}) = \frac{(\overline{a} + 2a)(1 - y_{\tilde{A}})}{3}. \quad (30)$$

The g weighted possibility mean of $I_{\tilde{A}}(x)$ is denoted as:

$$M_I(\tilde{A}) = \frac{\underline{M}_I(\tilde{A}) + \overline{M}_I(\tilde{A})}{2}. \quad (31)$$

By substituting Eqs (29) and (30) in Eq. (31), then

$$M_I(\tilde{A}) = \frac{(\underline{a} + 4a + \overline{a})(1 - y_{\tilde{A}})}{6}. \quad (32)$$

Definition 10. Let $\tilde{A} = ((\underline{a}, a, \overline{a}); w_{\tilde{A}}, y_{\tilde{A}}, u_{\tilde{A}})$ a SVTN, the possibility mean value of $F_{\tilde{A}}(x)$ ($M_F(\tilde{A})$) is

$$M_F(\tilde{A}) = \frac{(\underline{a} + 4a + \overline{a})(1 - u_{\tilde{A}})}{6}.$$

Proof. The h weighted lower and upper possibility means of $F_{\tilde{A}}(x)$ for the SVTN $\tilde{A}$ are, respectively, denoted as:

$$\underline{M}_F(\tilde{A}) = \int_{u_{\tilde{A}}}^{1} h(Pos[\tilde{A} \le F_{\tilde{A}}^{L}])F_{\tilde{A}}^{L}d\gamma = \int_{u_{\tilde{A}}}^{1} h(\gamma)F_{\tilde{A}}^{L}d\gamma; \quad (33)$$

$$\overline{M}_F(\tilde{A}) = \int_{u_{\tilde{A}}}^{1} h(Pos[\tilde{A} \ge F_{\tilde{A}}^{U}])F_{\tilde{A}}^{U}d\gamma = \int_{u_{\tilde{A}}}^{1} h(\gamma)F_{\tilde{A}}^{U}d\gamma. \quad (34)$$

In accordance with (Wan et al., 2013), from Eqs (13), (33) and (34) we can check that for $h(\gamma) = \frac{2(1-\gamma)}{(1-u_{\tilde{A}})}$, $\gamma \in [u_{\tilde{A}}, 1]$, then

$$\underline{M}_F(\tilde{A}) = \frac{(\underline{a}+2a)(1-u_{\tilde{A}})}{3}; \quad (35)$$

$$\overline{M}_F(\tilde{A}) = \frac{(\overline{a}+2a)(1-u_{\tilde{A}})}{3}. \quad (36)$$

The h weighted possibility mean of $F_{\tilde{A}}(x)$ is denoted as:

$$M_F(\tilde{A}) = \frac{\underline{M}_F(\tilde{A}) + \overline{M}_F(\tilde{A})}{2}. \quad (37)$$

Then, by integrating Eq. (35) and (36) in (37), we get:

$$M_F(\tilde{A}) = \frac{(\underline{a}+4a+\overline{a})(1-u_{\tilde{A}})}{6}. \quad (38)$$

2.1.2. Possibility variance of SVTN

Definition 11. Let $\tilde{A} = ((\underline{a}, a, \overline{a}); w_{\tilde{A}}, y_{\tilde{A}}, u_{\tilde{A}})$ a SVTN, the possibility variance values of $T_{\tilde{A}}(x)$ $(V_T(\tilde{A}))$, $I_{\tilde{A}}(x)\,(V_I(\tilde{A}))$ and $F_{\tilde{A}}(x)\,(V_F(\tilde{A}))$ are

$$V_T(\tilde{A}) = \frac{(\overline{a}-\underline{a})^2}{24} w_{\tilde{A}},$$

$$V_I(\tilde{A}) = \frac{(\overline{a}-\underline{a})^2}{24}(1-y_{\tilde{A}}),$$

$$V_F(\tilde{A}) = \frac{(\overline{a}-\underline{a})^2}{24}(1-u_{\tilde{A}}).$$

Proof. Then, we can define the f weighted possibility variance of $T_{\tilde{A}}(x)$ as:

$$V_T(\tilde{A}) = \int_{0}^{w_{\tilde{A}}} f(Pos[\tilde{A} \le \mathrm{T}_{\tilde{A}}^{L}] + Pos[\tilde{A} \ge \mathrm{T}_{\tilde{A}}^{U}]) \left(\frac{\mathrm{T}_{\tilde{A}}^{U} - \mathrm{T}_{\tilde{A}}^{L}}{2} \right)^2 d\alpha = \frac{1}{4}\int_{0}^{w_{\tilde{A}}} f(\alpha)(\mathrm{T}_{\tilde{A}}^{U} - \mathrm{T}_{\tilde{A}}^{L})^2 d\alpha. \quad (39)$$

Analogously, we can define the g weighted possibility variance of $I_{\tilde{A}}(x)$ as:

$$V_I(\tilde{A}) = \int_{y_{\tilde{A}}}^{1} g(Pos[\tilde{A} \le I_{\tilde{A}}^{L}] + Pos[\tilde{A} \ge I_{\tilde{A}}^{U}]) \left(\frac{I_{\tilde{A}}^{U} - I_{\tilde{A}}^{L}}{2} \right)^2 d\beta = \frac{1}{4}\int_{y_{\tilde{A}}}^{1} g(\beta)(I_{\tilde{A}}^{U} - I_{\tilde{A}}^{L})^2 d\beta. \quad (40)$$

Finally, the h weighted possibility variance of $F_{\tilde{A}}(x)$ is denoted as:

$$V_F(\tilde{A}) = \int_{u_{\tilde{A}}}^{1} h(Pos[\tilde{A} \le F_{\tilde{A}}^L] + Pos[\tilde{A} \ge F_{\tilde{A}}^U])\left(\frac{F_{\tilde{A}}^U - F_{\tilde{A}}^L}{2}\right)^2 d\gamma =$$

$$\frac{1}{4}\int_{u_{\tilde{A}}}^{1} h(\gamma)(F_{\tilde{A}}^U - F_{\tilde{A}}^L)^2 d\gamma. \tag{41}$$

We can check that ($T_{\tilde{A}}^U - T_{\tilde{A}}^L$), ($I_{\tilde{A}}^U - I_{\tilde{A}}^L$) and ($F_{\tilde{A}}^U - F_{\tilde{A}}^L$) are just about the lengths of the intervals $\tilde{A}_{(\alpha)}$, $\tilde{A}_{(\beta)}$ and $\tilde{A}_{(\gamma)}$, respectively. So, $V_T(\tilde{A})$, $V_I(\tilde{A})$ and $V_F(\tilde{A})$ may be considered the global spreads of $T_{\tilde{A}}(x)$, $I_{\tilde{A}}(x)$ and $F_{\tilde{A}}(x)$. Clearly, $V_T(\tilde{A})$, $V_I(\tilde{A})$ and $V_F(\tilde{A})$ basically measure how much uncertainty and vagueness there is in the SVTN $\tilde{A}$.

In accordance with (Wan et al., 2013), from Eqs (11) and (39), we can see that for $f(\alpha) = \frac{2\alpha}{w_{\tilde{A}}}$, $\alpha \in [0, w_{\tilde{A}}]$, then

$$V_T(\tilde{A}) = \int_0^{w_{\tilde{A}}} f(\alpha)\left(\frac{T_{\tilde{A}}^U - T_{\tilde{A}}^L}{2}\right)^2 d\alpha = \frac{(\overline{a} - \underline{a})^2}{24} w_{\tilde{A}}. \tag{42}$$

In accordance with (Wan et al., 2013), from Eqs (12) and (40), for $g(\beta) = \frac{2(1-\beta)}{(1-y_{\tilde{A}})}$, $\beta \in [y_{\tilde{A}}, 1]$, then

$$V_I(\tilde{A}) = \int_{y_{\tilde{A}}}^{1} g(\beta)\left(\frac{I_{\tilde{A}}^U - I_{\tilde{A}}^L}{2}\right)^2 d\beta = \frac{(\overline{a} - \underline{a})^2}{24}(1 - y_{\tilde{A}}). \tag{43}$$

In accordance with (Wan et al., 2013), from Eqs (13) and (41), for $h(\gamma) = \frac{2(1-\gamma)}{(1-u_{\tilde{A}})}$, $\gamma \in [u_{\tilde{A}}, 1]$, then

$$V_F(\tilde{A}) = \int_{w_{\tilde{A}}}^{1} h(\gamma)\left(\frac{F_{\tilde{A}}^U - F_{\tilde{A}}^L}{2}\right)^2 d\gamma = \frac{(\overline{a} - \underline{a})^2}{24}(1 - u_{\tilde{A}}). \tag{44}$$

2.1.3. Possibility standard deviation of SVTN

Definition 12. Let $\tilde{A} = ((\underline{a}, a, \overline{a}); w_{\tilde{A}}, y_{\tilde{A}}, u_{\tilde{A}})$ a SVTN

The possibility standard deviation of $T_{\tilde{A}}(x)$ is defined as follows:

$$D_T(\tilde{A}) = \sqrt{V_T(\tilde{A})}. \tag{45}$$

By substituting (42) in (45) we derive,

$$D_T(\tilde{A}) = \sqrt{\frac{(\overline{a} - \underline{a})^2}{24} w_{\tilde{A}}} = \frac{(\overline{a} - \underline{a})}{\sqrt{24}}\sqrt{w_{\tilde{A}}}. \tag{46}$$

Analogously, the possibility standard deviation of $I_{\tilde{A}}(x)$ is defined as follows:

$$D_I(\tilde{A}) = \sqrt{\frac{(\overline{a} - \underline{a})^2}{24}(1 - y_{\tilde{A}})} = \frac{(\overline{a} - \underline{a})}{\sqrt{24}}\sqrt{(1 - y_{\tilde{A}}}. \tag{47}$$

The possibility standard deviation of $F_{\tilde{A}}(x)$ is defined as follows:

$$D_F(\tilde{A}) = \sqrt{\frac{(\overline{a} - \underline{a})^2}{24}(1 - u_{\tilde{A}})} = \frac{(\overline{a} - \underline{a})}{\sqrt{24}}\sqrt{(1 - u_{\tilde{A}}}. \tag{48}$$

In the next subsection, we provide a new score function of SVTN based on the previous possibility mean and standard deviation.

2.2. New possibility score function of SVTN

Definition 13. Let $\tilde{A}=((\underline{a},a,\overline{a});w_{\tilde{A}},y_{\tilde{A}},u_{\tilde{A}})$ a SVTN a possibility score function $PS(\tilde{A})$ is given as follows:

$$PS(\tilde{A})=\frac{(\underline{a}+4a+\overline{a})(2+w_{\tilde{A}}-y_{\tilde{A}}-u_{\tilde{A}})}{18}+\frac{(\overline{a}-\underline{a})(\sqrt{w_{\tilde{A}}}+\sqrt{(1-y_{\tilde{A}})}+\sqrt{(1-u_{\tilde{A}})})}{\sqrt{72}}.$$

Proof. The proposed possibility score function $PS(\tilde{A})$ is derived from the arithmetic mean of the possibility score functions for the components of the SVTN. It is also in line with other score functions approaches, based on the aggregation or arithmetic mean of the score functions $T_{\tilde{A}}(x)$, $I_{\tilde{A}}(x)$ and $F_{\tilde{A}}(x)$ (Abdel-Basset et al., 2017; Broumi et al., 2019; Deli & Subas, 2014; Li & Huang, 2019; Ye, 2017).

$$PS(\tilde{A})=\frac{PS_T(\tilde{A})+PS_I(\tilde{A})+PS_F(\tilde{A})}{3}. \quad (49)$$

The possibility score function $PS_T(\tilde{A})$ of $T_{\tilde{A}}(x)$ is denoted as follows:

$$PS_T(\tilde{A})=M_T(\tilde{A})+D_T(\tilde{A}). \quad (50)$$

Combining Eq. (26) and (46) in (50), we get:

$$PS_T(\tilde{A})=\frac{(\underline{a}+4a+\overline{a})w_{\tilde{A}}}{6}+\frac{(\overline{a}-\underline{a})}{\sqrt{24}}\sqrt{w_{\tilde{A}}}. \quad (51)$$

Similarly, the possibility score function $PS_I(\tilde{A})$ of $I_{\tilde{A}}(x)$, is denoted as follows:

$$PS_I(\tilde{A})=\frac{(\underline{a}+4a+\overline{a})(1-y_{\tilde{A}})}{6}+\frac{(\overline{a}-\underline{a})}{\sqrt{24}}\sqrt{(1-y_{\tilde{A}})}. \quad (52)$$

By the same way, the possibility score function $PS_F(\tilde{A})$ of $F_{\tilde{A}}(x)$, yields:

$$PS_F(\tilde{A})=\frac{(\underline{a}+4a+\overline{a})(1-u_{\tilde{A}})}{6}+\frac{(\overline{a}-\underline{a})}{\sqrt{24}}\sqrt{(1-u_{\tilde{A}})}. \quad (53)$$

For $T_{\tilde{A}}(x)$, $I_{\tilde{A}}(x)$ and $F_{\tilde{A}}(x)$, the mean and the variance or standard deviation are bigger, then $T_{\tilde{A}}(x)$, $I_{\tilde{A}}(x)$ and $F_{\tilde{A}}(x)$ are bigger. Obviously, $T_{\tilde{A}}(x)$, $I_{\tilde{A}}(x)$ and $F_{\tilde{A}}(x)$ be greater as $PS_T(\tilde{A})$, $PS_I(\tilde{A})$ and $PS_F(\tilde{A})$ grows greater.

Let $\tilde{A}=((\underline{a},a,\overline{a});w_{\tilde{A}},y_{\tilde{A}},u_{\tilde{A}})$ and $\tilde{B}=((\underline{b},b,\overline{b});w_{\tilde{B}},y_{\tilde{B}},u_{\tilde{B}})$ are two positive SVTNs.

$PS_T(\tilde{A})>PS_T(\tilde{B})$ if and only $T_{\tilde{A}}(x)\succ T_{\tilde{B}}(x)$,

$PS_I(\tilde{A})>PS_I(\tilde{B})$ if and only $I_{\tilde{A}}(x)\succ I_{\tilde{B}}(x)$,

$PS_F(\tilde{A})>PS_F(\tilde{B})$ if and only $F_{\tilde{A}}(x)\succ F_{\tilde{B}}(x)$.

By substituting (51), (52) and (53) in (49) the SVTN $\tilde{A}$ a possibility score function $PS(\tilde{A})$ is given by:

$$PS(\tilde{A})=\frac{(\underline{a}+4a+\overline{a})(2+w_{\tilde{A}}-y_{\tilde{A}}-u_{\tilde{A}})}{18}+\frac{(\overline{a}-\underline{a})(\sqrt{w_{\tilde{A}}}+\sqrt{(1-y_{\tilde{A}})}+\sqrt{(1-u_{\tilde{A}})})}{\sqrt{72}}. \quad (54)$$

2.3. The new neutrosophic analytic hierarchy process (N-AHP) methodology

AHP developed by Saaty (1980), has been used extensively during the last years as a MCDM tool in solving complex decision problems. Nevertheless, this methodology has been the subject of criticism as it uses an unbalanced judgement scale and both uncertainty and imprecision in the pairwise comparison cannot be properly handled (Deng, 1999). In order to tackle these shortcomings, the development of Fuzzy AHP helped solve the hierarchy problems which originated from the fact that decision makers deem it more accurate to offer interval judgements than fixed value judgements. N-AHP relies on the FAHP technique and incorporates it into the neutrosophic sets put forward by Smarandache (1999). A neutrosophic scale is utilized in N-AHP to bring criteria preferences whereas neutrosophic numbers are employed to show the relative preference of criteria, subcriteria and alternatives. Then, the generation of crisp values through neutrosophic number conversion is performed by score functions, which also include SVTN.

Specifically, Abdel-Basset et al. (2017) presents an N-AHP based on the score function defined by the Eq. (14) by planting an application to choose the best candidates, Abdel-Basset et al. (2018) proposes an integrated S.W.O.T. analysis model with the N-AHP. Junaid et al. (2020) present an N-AHP based on the score function formulated in expression (18).

In what follows, in Figure 2, a step-by-step procedure to describe the new neutrosophic analytic hierarchy process (N-AHP) approach is presented.

Step 1. Representation of the expert opinion. To assign the preference of criterion *i* over **j**, expert *k* uses the semantic scale proposed by (Abdel-Basset et al., 2018), and the kth expert opinion is represented by $\tilde{a}_{ijk} = ((\underline{a}_{ijk}, a_{ijk}, \overline{a}_{ijk});\ w_{ijk}, y_{ijk}, u_{ijk})$ as shown in Table 1.

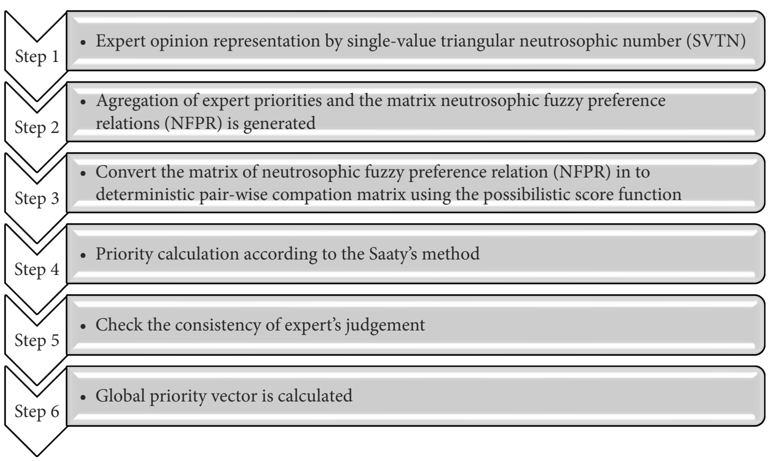

Figure 2. The schematic diagram of the N-AHP approach

Table 1. Linguistic terms and SVTN according to (Abdel-Basset et al., 2018)

Saaty Scale	Explanation	Neutrosophic Triangular Scale
1	Equally influential	$\tilde{1} = \left((1,1,1); 0.50, 0.50, 0.50 \right)$
3	Slightly influential	$\tilde{3} = \left((2,3,4); 0.30, 0.75, 0.70 \right)$
5	Strongly influential	$\tilde{5} = \left((4,5,6); 0.80, 0.15, 0.20 \right)$
7	Very strongly influential	$\tilde{7} = \left((6,7,8); 0.90, 0.10, 0.10 \right)$
9	Absolutely influential	$\tilde{9} = \left((9,9,9); 1.00, 0.00, 0.00 \right)$
2	Sporadic values between to close scale	$\tilde{2} = \left((1,2,3); 0.40, 0.65, 0.60 \right)$
4		$\tilde{4} = \left((3,4,5); 0.60, 0.35, 0.40 \right)$
6		$\tilde{6} = \left((5,6,7); 0.70, 0.25, 0.30 \right)$
8		$\tilde{8} = \left((7,8,9); 0.85, 0.10, 0.15 \right)$

Step 2. Expert priorities aggregation: The opinions of the k experts will be added according to the following formulation, from Eqs (5) and (9).

$$\tilde{r}_{ij} = \left(\left(\underline{r}_{ij}, r_{ij}, \overline{r}_{ij} \right); w_{\tilde{r}_{ij}}, y_{\tilde{r}_{ij}}, u_{\tilde{r}_{ij}} \right) = \left(\left(\frac{1}{K} \sum_{k=1}^{K} \underline{a}_{ij}, \frac{1}{K} \sum_{k=1}^{K} a_{ijk}, \frac{1}{K} \sum_{k=1}^{K} \overline{a}_{ijk} \right); \min_{k=1}^{K} w_{ijk}, \max_{k=1}^{K} y_{ijk}, \max_{k=1}^{K} u_{ijk} \right). \quad (55)$$

From (55) the matrix $\widetilde{R}(\tilde{r}_{ij})$ of neutrosophic fuzzy preferences relations (NFPR) is generated.

Step 3. We first convert the matrix $\tilde{R}$ into a deterministic pair-wise comparison matrix R, through the possibility score function ($PS(\tilde{r}_{ij})$).

Step 4. Priority calculation. We determine each criterion weight from the deterministic pair-wise comparison matrix R. According to the methodology developed by Saaty and Vargas (2006).

$$\omega^* = \left(\omega^*_1, \omega^*_2, .., \omega^*_Q \right)^T.$$

Step 5. Check the consistency of experts' judgements. We check the matrix consistency based on the judgement of the expert. We proceed dividing consistency the index (CI) by the random index (RI). The value must be less than 0.1 (Saaty & Vargas, 2006).

Step 6. Global priority vector.

The optimal priority vector for criteria in the practical case is:

$$\omega^* = \left(\omega^*_1, \omega^*_2, .., \omega^*_Q \right)^T. \quad (56)$$

The weights for each indicator can be formulated using the following equation:

$$\omega^*_j = \left(\omega^*_{j1}, ..., \omega^*_{jS_i} \right)^T, \quad (57)$$

where ω^*_{js} is the weight of the indicator s in the criterion j, with $s = 1,\ldots, S_j$ and S_j is the total indicators belonging to the criterion j, being $\sum_{s=1}^{S_j} \omega^*_{js} = 1$. Then, the described procedure will be repeated for each criterion of the considered indicators.

In order to estimate the overall weights, the eigenvector of the criterion is multiplied by the relative weight of the group to which belongs (Stankevičiene & Mencaite, 2012). The global weight of the indicator s in the criterion j is obtained by multiplying the weight calculated for each criterion in (56) (ω^*_j) by the weight corresponding to the indicator s in the criterion j (ω^*_{js}) obtained in (57) with $s = 1,\ldots, S_j$. This procedure allows us to obtain a matrix representing all the weights. This is,

$$\upsilon^* = \left(\upsilon^*_1,\ldots,\upsilon^*_Q\right)^T,$$

where $\sum_{q=1}^{Q} \upsilon^*_q = 1$.

2.4. Ranking corporate sustainability using N-AHP and TOPSIS approaches

Once the N-AHP weights are obtained, they can be integrated into the corresponding stage of an MCDM approach and where aggregation using subjective weights derived from expert opinions is required.

Among the most widely applied and successful ranking MCDM techniques is the technique for order preference by similarity to ideal solution (TOPSIS) initially formulated by Hwang and Yoon (1981). Based on a compromise philosophy, this method allows choosing the alternatives that should simultaneously have the closest distance to the ideal solution and the farthest distance to the anti-ideal solution with an established order of preference. In Figure 3 we briefly summarize the main steps of the N-AHP and TOPSIS approaches.

In recent years, extended TOPSIS approaches have been widely applied in the literature to rank and select companies according to their ESG performance due to its ease of implementation in a wide variety of situations, with no restrictions on the number of alternatives or criteria, see, for example, Escrig-Olmedo et al. (2017), Liern and Pérez-Gladish (2018), Roy and Shaw (2022) and Kamran et al. (2021).

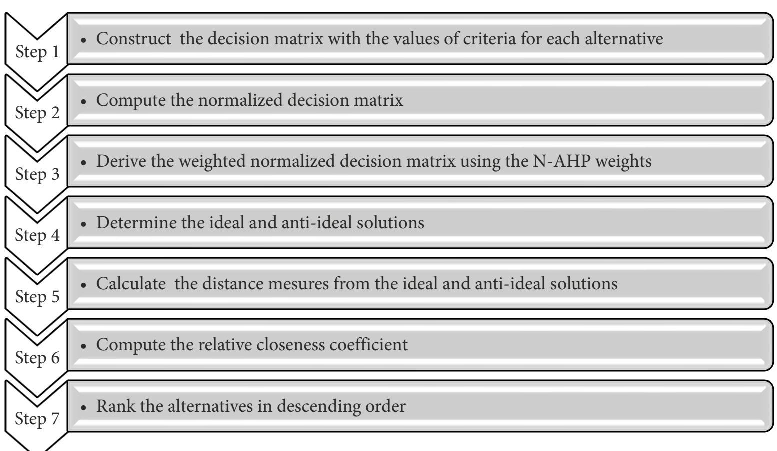

Figure 3. Step by step diagram of N-AHP TOPSIS method

3. Real case study: evaluating ESG corporate performance in the gas and oil energy sector

In this paper we test the proposed methodology to evaluate the ESG performance of leading oil and gas energy firms worldwide. For this purpose, we have selected the firms with a turnover of more than 100 billion dollars in 2019 (Table 2). In this step, only non-financial criteria are considered, specifically sustainability indicators, which are defined in the subsection 3.1. We consider the subjective experts' opinion to derive the local and global weights to apply the new N-AHP methodology in subsection 3.2. Finally, we rank the companies using TOPSIS in subsection 3.3.

Table 2. Name of oil and gas energy firms and total revenue (2019) (source: Eikon database)

Name of Firm	Revenue (billion USD) 2019
China Petroleum & Chemical Corp	426
PetroChina Co Ltd	367
Saudi Arabian Oil Co	329
Exxon Mobil Corp	181
Royal Dutch Shell PLC	180.5
BP PLC	180.3
NK Lukoil PAO	127
Gazprom PAO	124
Total SE	120

3.1. ESG sustainability framework

The non-financial sustainability indicators were obtained from the EIKON database, which is compiled by the company Thomson Reuter, on the basis of an internal balanced scorecard system. Figure 4 shows the ESG sustainability hierarchy of ESG criteria and sub-criteria that we used for assessing the sustainability performance of the above nine companies. The proposed structure initially differentiates between three categories of indicators based on the ESG sustainability framework and ten sub-criteria, the definition of which is included as follows:

- *Resource use*: This criterion measures company's efforts in reducing the use of water, energy and materials and improving sustainability in the supply chain.
- *Emissions*: This indicator evaluates the company's contribution to cutting its carbon footprint.
- *Environmental innovation*: This criterion assesses the capacity to develop of innovative and sustainable technologies including eco-designed products.
- *Workforce*: Measures a company's effectiveness with respect to work-related issues such as health and safety, diversity and training opportunities.
- *Human rights*: The indicator assesses the company's commitment to respect fundamental human rights conventions.

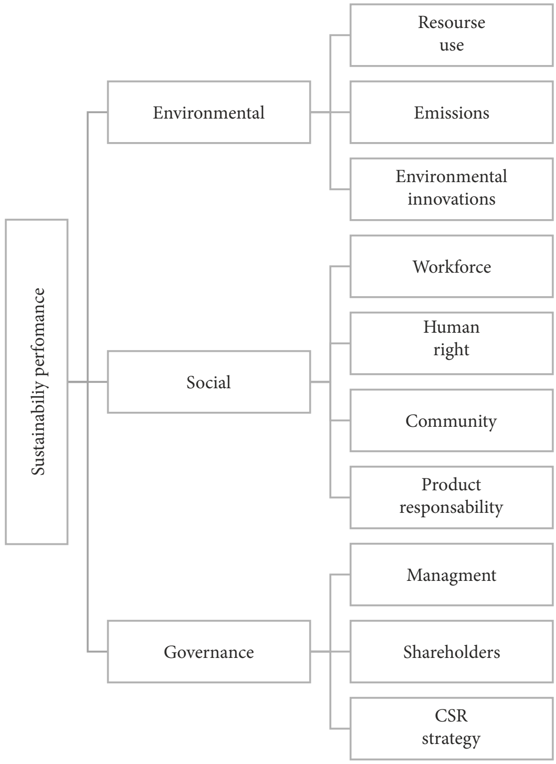

Figure 4. ESG hierarchy of the problem based on EIKON database

- *Community*: Company's commitment towards protecting public health and respecting business ethics is measured.
- *Product responsibility*: This criterion is used to determine the ability to produce high quality goods and services by addressing data integrity and privacy, as well as customer health and safety issues.
- *Management*: This criterion measures the commitment and effectiveness of corporate governance practices.
- *Shareholders*: Company's effectiveness towards equal treatment of shareholders and the use of anti-takeover devices is assessed.
- *CSR strategy*: This indicator reflects company's practices to communicate the economic (financial), social and environmental strategy.

3.2. Prioritization of criteria

Step 1. Initially 3 experts are invited to express their judgements in accordance with the relevance of the criteria. The experts will formulate their opinions as SVTN (see Table 1).

Step 2. Aggregation of expert priorities. From Eq. (55) we proceed to add the judgements proposed by the 3 experts, obtaining the four neutrosophic pair-wise comparison matrices as displayed in Table 3.

Table 3. Neutrosophic pair-wise comparison matrix for ESG criteria

	Environmental	Social	Governace
Environmental	$\tilde{1}$	((3,4,5); 0.55, 0.40, 0.45)	((4,5,6); 0.8 0.15,0.2)
Social	$\frac{1}{((3,4,5);0.55,0.4,0.45)}$	$\tilde{1}$	((3,4,5);0.40,0.65,0.60)
Governance	$\frac{1}{((4,5,6);0.8,0.15,0.2)}$	$\frac{1}{((3,4,5);0.40,0.65,0.6)}$	$\tilde{1}$

Step 3. Transform the neutrosophic pair-wise comparison matrix into a deterministic pair-wise comparison matrix, through the possibility score function (54). In Table 4 these values are displayed.

Table 4. Deterministic pair-wise comparison matrix for ESG criteria

	Environmental	Social	Governace
Envronmental	1	2.57	4.45
Social	0.39	1	1.40
Governance	0.22	0.71	1

Step 4. Local priority vector calculation. To compute the local weight of each criterion from corresponding deterministic pair-wise comparison matrix. Table 5 includes the global and local priority weights.

Table 5. Global and Local Priority and Consistency Ratio (CR) of the criteria and sub-criteria

Criteria (C)	ω^*_c	CR Criteria	Subcriteria (S)	ω^*_s	CR Sub-criteria	υ^*_s
E	0.226	0.004	Resourse use	0.221	0.000	0.050
			Emissions	0.257		0.058
			Environmental innovation	0.522		0.118
S	0.623		Workforce	0.273	0.032	0.170
			Human right	0.397		0.247
			Community	0.122		0.076
			Product responsability	0.208		0.130
G	0.150		Management	0.561	0.021	0.084
			Shareholders	0.277		0.042
			CSR strategy	0.162		0.024

Step 5. Check the consistency of experts' judgements. In Table 5, the obtained value of Consistency Ratios (CR) is less than 0.1, then, the pairwise comparations are consistency.

Step 6. Compute the global priority weight vector for each ESG criteria:

$$\omega^* = \left(\omega^*_E, \omega^*_S, \omega^*_G\right)^T,$$
$$\omega^*_E = \left(\omega^*_{RE}, \omega^*_{EM}, \omega^*_{EI}\right)^T,$$
$$\omega^*_S = \left(\omega^*_{WO}, \omega^*_{HR}, \omega^*_{CO}, \omega^*_{PR}\right)^T,$$
$$\omega^*_G = \left(\omega^*_{MA}, \omega^*_{SH}, \omega^*_{CS}\right)^T.$$

Finally, the global weight $\upsilon^* = \left(\upsilon^*_1, \ldots, \upsilon^*_S\right)^T$ is computed by multiplying the priorities obtained for each criterion and sub-criterion. Their aggregation allows us to obtain a matrix representing every weight. That in a simplified way, could be:

$$\upsilon^* = \left(\upsilon^*_1, \ldots, \upsilon^*_S\right)^T; \ s=1,\ldots,10,$$

where,

$$\sum_{s=1}^{10} \upsilon^*_s = 1.$$

In the case study, for the purpose of describing the calculation of the global priority vector, we use the Workforce criteria as follows:

$$\upsilon^*_{WORKFORCE} = \omega^*_S \times \omega^*_{WORKFORCE}.$$

In Table 5 the global priorities for each ESG criteria are shown.

Next, we propose to compare the results obtained considering that the opinions expressed by the experts are formulated in different types of fuzzy numbers and real number. It can be seen that for any x ∈ R, if $0 \le w_{\tilde{A}} + u_{\tilde{A}} \le 1$, and $y_{\tilde{A}} = 0$. Therefore, the SVTN $\tilde{A} = ((\underline{a}, a, \overline{a}); w_{\tilde{A}}, y_{\tilde{A}}, u_{\tilde{A}})$ becomes a intuitionistic triangular fuzzy number (ITFN) $\tilde{A} = ((\underline{a}, a, \overline{a}); w_{\tilde{A}}, u_{\tilde{A}})$ (Atanassov, 1986). Similarly, for any x ∈ R, if $w_{\tilde{A}} = 1$, $u_{\tilde{A}} = 0$, $y_{\tilde{A}} = 0$ the SVTN derives a triangular fuzzy number (TFN). Equally, for any x ∈ R, if $w_{\tilde{A}} = 1$, $u_{\tilde{A}} = 0$, $y_{\tilde{A}} = 0$ and $\underline{a} = a = \overline{a}$ becomes a real number (RN) *a*, in the latter case, it would be the classical formulation of Saaty's model.

In accordance with the previous paragraph and the linguistic scale of Table 1, the results obtained for the global priority according to the type of fuzzy number and real number are displayed in Table 6. As can be noticed, the highest weights correspond to Human right (24.7%), Workforce (17%) and Product Responsibility (13%). Conversely, the last positions refer to CSR strategy (2.4%), Shareholders (4.2%) and Resource Use (5%).

Table 6. Global priority by type of fuzzy number

Sub-criteria (S)	SVTN	ITFN	TFN	RN
Resourse use	0.050	0.040	0.028	0.032
Emissions	0.058	0.061	0.057	0.059
Environmental innovation	0.118	0.131	0.143	0.140
Workforce	0.170	0.175	0.179	0.181
Human right	0.247	0.285	0.339	0.321
Community	0.076	0.063	0.048	0.059
Product responsibility	0.130	0.122	0.111	0.105
Management	0.084	0.074	0.062	0.066
Shareholders	0.042	0.033	0.023	0.026
CSR strategy	0.024	0.017	0.010	0.012

From the results obtained in Table 6, it is necessary to specify the formulation that will represent the preferences expressed by the experts for each criterion. Thus, the results will differ, depending on whether it is a neutrosophic, intuitionistic, fuzzy, or real number.

3.3. Ranking Oil and Gas energy sector

In Table 7, the closeness coefficient CC_i and the final ranking of companies are displayed by different types of fuzzy number and real number.

Table 7. TOPSIS. CC_i and ranking Oil and Gas energy firm

Name of firms	SVTN		ITFN		TFN		RN	
	CC_i	R	CC_i	R	CC_i	R	CC_i	R
China Petroleum & Chemical Corp	0.601	8	0.639	8	0.684	8	0.669	8
PetroChina Co Ltd	0.565	7	0.584	7	0.604	7	0.602	7
Saudi Arabian Oil Co	0.770	9	0.807	9	0.849	9	0.835	9
Exxon Mobil Corp	0.460	5	0.489	5	0.526	6	0.515	5
Royal Dutch Shell PLC	0.191	1	0.183	2	0.172	2	0.172	2
BP PLC	0.192	2	0.185	3	0.172	3	0.174	3
NK Lukoil PAO	0.245	4	0.250	4	0.254	4	0.254	4
Gazprom PAO	0.493	6	0.506	6	0.520	5	0.518	6
Total SE	0.196	3	0.158	1	0.116	1	0.136	1

As can be noticed in Table 7, the rankings of oil and gas energy firms obtained differ depending on the formulation representing the experts' judgments. These differences reiterate the need to use methodologies that adequately represent the uncertainty, subjectivity and imprecision of the information provided by experts regarding ESG criteria.

We compare TOPSIS with WASPAS (Zavadskas et al., 2012) and TOPSIS with EDAS (Ghorabaee et al., 2015) methods to show the validity of the outranking results in Table 8 and Table 9, respectively.

Table 8. WASPAS ($\lambda = 0.5$). WPS_i and ranking Oil and Gas energy firm

Name of firms	SVTN		ITFN		TFN		RN	
	WPS_i	R	WPS_i	R	WPS_i	R	WPS_i	R
China Petroleum & Chemical Corp	0.567	8	0.556	8	0.539	8	0.546	8
PetroChina Co Ltd	0.585	7	0.588	7	0.590	7	0.587	7
Saudi Arabian Oil Co	0.386	9	0.382	9	0.376	9	0.376	9
Exxon Mobil Corp	0.731	5	0.725	5	0.712	5	0.716	5
Royal Dutch Shell PLC	0.884	2	0.883	3	0.882	3	0.884	3
BP PLC	0.888	1	0.888	2	0.889	2	0.891	2
NK Lukoil PAO	0.836	4	0.839	4	0.844	4	0.842	4
Gazprom PAO	0.626	6	0.627	6	0.628	6	0.627	6
Total SE	0.875	3	0.894	1	0.915	1	0.905	1

Table 9. EDAS. AS_i and ranking Oil and Gas energy firm

Name of firms	SVTN		ITFN		TFN		RN	
	AS_i	R	AS_i	R	AS_i	R	AS_i	R
China Petroleum & Chemical Corp	0.337	7	0.318	8	0.289	8	0.301	8
PetroChina Co Ltd	0.323	8	0.324	7	0.325	7	0.321	7
Saudi Arabian Oil Co	0.092	9	0.073	9	0.051	9	0.057	9
Exxon Mobil Corp	0.586	5	0.572	5	0.540	5	0.550	5
Royal Dutch Shell PLC	0.927	3	0.914	3	0.885	3	0.896	3
BP PLC	0.960	1	0.955	2	0.932	2	0.943	2
NK Lukoil PAO	0.797	4	0.796	4	0.785	4	0.788	4
Gazprom PAO	0.421	6	0.415	6	0.408	6	0.410	6
Total SE	0.929	2	0.957	1	0.968	1	0.962	1

In Table 10, we present the Spearman's correlation coefficient (r_s) obtained by applying TOPSIS and the ones by using WASPAS and EDAS methodologies for different neutrosophic numbers.

Table 10. Values of Spearman's correlation coefficient (r_s) in different type numbers

	SVTN	ITFN	TFN	RN
WASPAS	0.983	0.983	0.967	0.983
EDAS	0.933	0.983	0.967	0.983

Since all the values of r_s are close to 1, we can validate the reliability of our proposal. Additionally, the stability of the classification obtained by applying the TOPSIS method also reinforces its robustness.

3.4. Comparative analysis

This section presents a brief yet comprehensive comparative analysis of some of the latest studies in this field as well as our proposed method. Thus, the advantages and effectiveness of the proposed N-AHP approach with the possibility score function $PS(\upsilon^*_s)$ is proven by means of comparison with three methods based on score functions such as:

1. Abdel-Basset et al. (2017) $S_1(\upsilon^*_s)$.
2. Li and Huang (2019) $S_2(\upsilon^*_s)$.
3. Junaid et al. (2020) $S_3(\upsilon^*_s)$.

In Table 11 as can be seen, the weights obtained by the score functions $S_1(\upsilon^*_s)$ is significantly different from those generated by the score functions based on various alternatives in the formulation of the possibility mean $S_2(\upsilon^*_s)$, $S_3(\upsilon^*_s)$ and $PS(\upsilon^*_s)$ although the latter proposal incorporates the risk aversion of the linguistic variables of the experts' opinion through the standard deviation possibility.

Table 11. Comparison of weightages (υ^*_s) obtained through different methodologies

Sub-criteria (S)	$S_1(\upsilon^*_s)$	$S_2(\upsilon^*_s)$	$S_3(\upsilon^*_s)$	$PS(\upsilon^*_s)$
Resourse use	0.102	0.059	0.035	0.050
Emissions	0.069	0.059	0.049	0.058
Environmental innovation	0.089	0.111	0.125	0.118
Workforce	0.113	0.162	0.188	0.170
Human right	0.115	0.215	0.296	0.247
Community	0.103	0.085	0.061	0.076
Product responsibility	0.124	0.138	0.134	0.130
Management	0.113	0.092	0.070	0.084
Shareholders	0.088	0.049	0.028	0.042
CSR strategy	0.083	0.031	0.013	0.024

Pearson correlation coefficient (r_p) is determined by using weightage or the value used to determine the ranking for analyzing the correlation between the $PS(\upsilon^*_s)$ method and $S_1(\upsilon^*_s)$, $S_2(\upsilon^*_s)$ and $S_3(\upsilon^*_s)$ methods in 4 sets of different criteria weights. The results of this analysis are shown in Table 12.

Table 12. Values of Pearson correlation coefficient (r_p) using different score functions

	$S_1(\upsilon^*_s)$	$S_2(\upsilon^*_s)$	$S_3(\upsilon^*_s)$
SET 1	0.620	0.993	0.997
SET 2	0.547	0.991	0.996
SET 3	0.303	0.991	0.994
SET 4	0.721	0.991	0.995

It can be observed that the results of $S_2(\upsilon^*_s)$ and $S_3(\upsilon^*_s)$ methods present a high correlation while in the case of $S_1(\upsilon^*_s)$ method, it can be concluded that it has a very low consistency with our proposal.

After conducting this comparison, it is important to highlight that our proposed SVTN score function improves those previous approaches as it not only considers the possibility mean, but also incorporates the possibility standard deviation, which implies reflecting the risk that the expert gathers in his opinion, thus improving the information represented by the scoring function.

Conclusions

We have proposed a new Neutrosophic Analytic Hierarchy Process combined with TOPSIS (N-AHP-TOPSIS) for decision making using a SVTN score, which is based on the possibility mean and standard deviation.

Our proposal has several features that stand out with respect to previous works. First, the proposed SVTN improves previous recent approaches as it not only considers the possibility mean, but also incorporates the possibility standard deviation, which implies reflecting the risk that the expert gathers in his opinion, thus improving the information represented by the scoring function. Second, this work improves on previous studies in the corporate sustainability literature with the use of non-financial indicators, in particular ESG criteria. In addition, its evaluation takes into consideration the subjective experts' opinion adding uncertainty about the veracity of the information disclosed in the sustainability reports to derive the criteria subjective weights. Finally, once the weights from the N-AHP have been obtained, they are integrated into the corresponding stage of the TOPSIS technique and achieve the overall ranking. An advantage of including uncertainty about the veracity of the information disclosed in sustainability reports is that the solutions obtained by using N-AHP TOPSIS are richer than classical integrated AHP TOPSIS as they allow for handling of the vagueness and uncertainty of expert's subjective judgements.

We have tested the applicability of our proposal through a realistic case study, to evaluate the ESG performance of leading oil and gas energy firms worldwide. From a sample of subjective experts's judgement on ESG criteria reported from Eikon database we have computed the global priority vector of ESG criteria using the new neutrosophic single value number, that incorporates the risk aversion of the linguistic variables of the experts' opinion through the standard deviation possibility. Next, these weights have been integrated into TOPSIS to rank the companies. Moreover, the robustness of our solutions has been tested by comparing the results of our proposal with other multicriteria methods such as WASPAS and EDAS, and we have obtained similar solutions, which reinforces the validity of our proposal.

Future lines of research include on the one hand the extension of this methodology (N-AHP) in combination with other methodologies such as VIKOR, COPRAS, PROMETHEE or ELECTRE. On the other hand, to generalize the N-AHP by means of the use of non-linear neutrosophic numbers.

Author contributions

Javier Reig-Mullor: Conceptualization. Methodology and Investigation.

Ana Garcia-Bernabeu: Formal Analysis. Investigation. Writing- Original draft preparation.

David Pla-Santamaria: Formal analysis. Investigation. Writing- Original draft preparation.

Maria Luisa Vercher-Ferrandiz: Investigation and Writing- Reviewing and Editing.

Disclosure statement

We have any competing financial, professional or personal interests from other parties.

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