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Evaluation based on Relative Utility and Nonlinear Standardization (ERUNS) Method for Comparing Firm Performance in Energy Sector

Sanjib Biswas[1] , Dragan Pamucar[2*], Satirtha Dawn[3] and Vladimir Simic[4]

[1] Decision Sciences and Operations Management Area, Calcutta Business School, South 24 Parganas, West Bengal, India
[2] University of Belgrade, Faculty of Organizational Sciences, Department of Operations Research and Statistics, Belgrade, Serbia
Dr. B.C. Roy Engineering College, Durgapur, West Bengal, India
[3] University of Belgrade, Faculty of Transport and Traffic Engineering, Belgrade, Serbia

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ABSTRACT

The present paper introduces a new multi-criteria decision making (MCDM) model such as Evaluation based on Relative Utility and Nonlinear Standardization (ERUNS). The proposed method provides a number of unique features such as use of non-linear standardization combined with a new definition for calculating utility values of the alternatives and design flexibility. The new method is applied to compare the firm performances using Economic, Environment, Social and Governance (EESG) framework. Over the last few decades alongside economic gain, the firms have been equally emphasizing on environmental protection, social values and good governance. This paper aims to bring in the economic aspect in terms of market capitalization and enterprise value while uses rating scores for environment, social and governance to put forth an extended performance measurement framework. A set of eight leading firms belonging to the energy sector listed to NSE, India has been considered for the period FY 2022-23 as a case study. The criteria weights are calculated using the Logarithmic Percentage Change-driven Objective Weighting (LOPCOW) method. It is observed that ERUNS provides a stable and reliable ranking result free from the rank reversal issue. This paper shall be of interest to both analysts and practitioners in terms of its robust method and practical performance assessment framework.

1. Introduction

Sustainable development has been a matter of interest to the academicians, industrialists, practitioners, scientists, socialists and policy makers for the last many years. Businesses have been increasingly putting focus on achieving the sustainable development goals (SDG) of UN [1-2]. To achieve the SDGs, environmental, social, and governance (ESG) activities have become a part of the mainstream core business objectives of the firms [3-4]. Investors, politicians, and other stakeholders are increasingly taking environmental, social, and governance (ESG) considerations into account when making choices concerning enterprises. ESG variables can significantly affect a company's

* *Corresponding author.*
E-mail address: dragan.pamucar@fon.bg.ac.rs

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profitability and debt cost [5]. The effects of ESG parameters on the financial health and firm value of 65 Indian public limited businesses listed on the NSE 100 ESG Index from 2015 to 2017 were examined by [6]. Their research shows that strong business ESG performance is positively correlated with financial measures, as seen by higher returns on assets (ROA) and Tobin's Q ratio. The paper emphasizes the necessity of adopting sustainability reporting with ESG disclosure and highlights the practical consequences for businesses, investors, regulators, and politicians. The authors argue that this would greatly promote ethical business practices and, as a result, ensure the long-term survival of shareholder wealth.

The study [7] examined 232 listed companies in the Chinese setting. The study discovered a nonlinear association, depicted by an inverted U-shaped curve, between ESG activities and corporate performance. The main finding emphasized how crucial it is for businesses to choose their ideal ESG activity threshold in order to maximize advantages because going over that barrier results in declining rewards. Egorova *et al.* [8] changed the emphasis to ESG ratings across industries, highlighting that IT businesses have room for progress while not presently dominating in ESG ratings. This shows that creating ESG ratings may, over time, have a favorable effect on the general performance of IT organizations.

Although not on a risk-adjusted basis, Filbeck *et al.* [9] discovered that companies with high ESG ratings statistically beat the S&P 500 index. This suggests that while investing in companies with high ESG ratings entails greater risk, investors should anticipate to get larger returns than the market as a whole. Further analysis indicates that companies with higher governance and social ratings perform better than companies with correspondingly lower ratings. This implies that investors are prepared to pay a premium for businesses that exercise sound corporate governance and social responsibility. However, because environmental efforts can be expensive in the near run, the market penalizes companies with excellent environmental histories. Investors can also be skeptical about the long-term economic advantages these investments would produce.

Arora and Sharma [10]'s research shows a negative link between ESG ratings and the cost of financing for Indian companies using NIFTY 500 data from FY2015 to FY2020. At the 10% level, there is a strong correlation between higher ESG ratings and lower financing costs, suggesting that lenders view companies that take responsibility for the environment, society, and governance as lower risk. Reduced debt costs are also linked to increased female board presence, a lower net debt to equity ratio, and larger market capitalization. The results are consistent with earlier research, supporting the idea that strong ESG performance helps to provide advantageous debt financing conditions that reflect lower risk perceptions.

Though the researchers felt the importance of good ESG practices to improve the firm performance [11], the review of the existing literature reveals that assessment of sustainability performance, specifically, ESG performance suffers from lack of comprehensive objective information and assessment [12]. In most of the cases ESG performance has been assessed using the non-financial indicators and attempts have been made to examine its effect on firm performance. Reig-Mullor *et al.* [13] considered the non-financial indicators grounded on governance and management, environmental practices, human resource, product and CSR to assess the sustainability performance. In the international context, the work of Shaikh [14] revealed that European companies are more ESG compliant while the energy sector firms from Asia perform well. The author used ESG scores and voluntary non-financial disclosures for assessing ESG performance. Maji and Lohia [15] used CRISIL ratings for ESG scores along with accounting and market performance based financial indicators to empirically investigate the association of ESG scores with firm performance. The authors used quantile regression models with OLS estimation.

ESG performance depends on a multiple number of indicators. Hence, it stands out as a candidate for MCDM based analysis [16]. In recent years Quayson *et al.* [17] developed an Ordinal Priority Approach (OPA) based framework to measure ESG performance of the natural resource industry. The author used a subjective opinion based assessment using three main aspects of ESG and 25 sub-criteria derived from sustainability disclosure and literature reviews. It was found that environment is of prime concern while governance, emission, safety and health and risk stood out as significant sub-factors. Nguyen *et al.* [18] proposed a two stage study wherein the authors first used objective financial indicators to determine the efficiency scores of the Vietnamese wire and cable companies applying Data Envelopment Analysis (DEA). In the next stage a Spherical fuzzy based MCDM model using AHP and WASPAS was used to find out ESG performance based on qualitative factors. Camargo *et al.* [19] proposed a new robust MCDM models to assess the financial performance using CAMELS framework and ESG practices separately. The authors attempted to reach at two index measures such as ESG Robust Index (ESGI) and Financial Health Index (FHI). The research was aimed to identify the linkage between the indices. The authors observed a mixed result wherein both significant and non-significant correlations were noticed across the firms.

However, the present work differs from the previous studies. It considers the composite scores on all dimensions of ESG (as rated by an independent agency such as CRISIL) along with economic aspects manifested in terms of market attractiveness, leverage and intrinsic value of the enterprise. In effect, the current work provides an EESG framework. Therefore, the present study seeks answer of the research question: *To what extent the firms differ from each other on EESG performance?* (RQ-1).

It is apparent that EESG performance depends on multiple indicators or variables which are having conflicting objectives to be satisfied. Hence, the present problem is dealt with MCDM models. In order to evaluate complicated real-world challenges, MCDM models entail ranking of the available alternative options subject to the influence of the predetermined criteria set to select the best possible choice [20-21]. The extant literature shows a plethora of applications of MCDM models in solving complex real-life issues [22]. MCDM models are found useful in evaluation, preferential ordering, ranking, sorting and assessment problems and stand out as a structured benchmarking framework [23-24]. Accordingly, there has been a substantial growth in developing and applying a numerous number of new models [25]. Diverse MCDM techniques have been developed throughout the 2010s to fulfill certain goals like evaluation and assessment. These techniques, which are renowned for their adaptability and ease of use, are benchmarking tools. With models differing in decision-matrix construction, normalization techniques, information nature, and computational aspects, the discipline has seen significant expansion, representing a dynamic and expanding landscape of MCDM applications. Table 1 shows some of the widely used MCDM models that have been developed over the years and applied in diverse problems in engineering, basic science, social science, management and other allied areas. In this work a new MCDM model such as ERUNS is proposed to compare the EESG performance of the sample firms during FY 2022-23. The new model brings a number of advantages such as

- The new method is dependent on standardization of the initial decision matrix. Many a times the selection of normalization schemes influence the final outcome. ERUNS uses a new interval based nonlinear standardization scheme to the decision makers a greater flexibility in choosing a best possible alternative.
- In most of the real-life cases (using objective information) the decision makers are deprived of selecting a flexible interval which deems fit to the given problem. ERUNS allows the decision maker to select the values of the left and right limits of the interval depending on the

specifics of the decision making problem and are defined based on the preferences of the decision maker.

- In many cases (especially with large number of criteria and alternatives) normalization does not reflect the true difference in the performance values. The present method (by judicious selection of the interval for standardization) enables to mark the difference among the alternatives subject to the influence of various criteria.
- The present method provides a unique definition of utility degree (expressed by a novel use of soft-max function) along with user-centric non-linear interval standardization.
- It provides reasonably reliable and stable solution and is free from rank reversal phenomenon.

Therefore, the ongoing paper addresses another research question such as: *How can a reliable MCDM model be developed and utilized to compare the EESG performance of the firms?* (RQ 2).

Table 1
Some of the MCDM Methods

MCDM Method	Primary objective	Authors	Year
Simple Additive Weighting (SAW)	Ranking	MacCrimmon [26]	1968
Elimination Et Choice Translating Reality (ELECTRE)	Ranking	Roy [27]	1968
Analytical Hierarchy Process (AHP)	Criteria weight and ranking	Saaty [28]	1980
Više Kriterijumska optimizacija i Kompromisno Rešenje (VIKOR)	Ranking	Duckstein and Opricovic [29]	1980
Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)	Ranking	Hwang and Yoon [30]	1981
Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE)	Ranking	Brans [31]	1982
Complex Proportional Assessment (COPRAS)	Ranking	Zavadskas et al. [32]	1994
Analytic Network Process (ANP)	Ranking	Saaty [33]	2003
Multi-objective Optimization by Ratio Analysis (MOORA)	Ranking	Brauers and Zavadskas [34]	2006
MULTIMOORA	Ranking	Brauers and Zavadskas [35]	2010
Additive Ratio Assessment (ARAS)	Ranking	Zavadskas and Turskis [36]	2010
Step-wise Weight Assessment Ratio Analysis (SWARA)	Criteria weight	Keršuliene et al. [37]	2010
Weighted Aggregated Sum Product Assessment (WASPAS)	Ranking	Zavadskas et al. [38]	2012
Multi-Attributive Border Approximation Area Comparison (MABAC)	Ranking	Pamučar and Ćirović [39]	2015
Evaluation based on Distance from Average Solution (EDAS)	Ranking	Keshavarz Ghorabaee et al. [40]	2015
Combinative Distance-based Assessment (CODAS)	Ranking	Keshavarz Ghorabaee et al. [41]	2016
Pivot Pairwise Relative Criteria Importance Assessment (PIPRECIA)	Criteria weight	Stanujkic et al. [42]	2017
Full Consistency Method (FUCOM)	Criteria weight	Pamučar et al. [43]	2018
Combined Compromise Solution (CoCoSo)	Ranking	Yazdani et al. [44]	2019
Level Based Weight Assessment (LBWA)		Žižović and Pamučar [45]	2019
Measurement of Alternatives and Ranking according to COmpromise Solution (MARCOS)	Ranking	Stević et al. [25]	2020
Ranking of Alternatives through Functional mapping of criterion sub-intervals into a Single Interval (RAFSI)	Ranking	Žižović et al. [46]	2020
Logarithm Methodology of Additive Weights (LMAW)	Criteria weight and ranking	Pamučar et al. [47]	2021

MCDM Method	Primary objective	Authors	Year
Preference Ranking on the Basis of Ideal-Average Distance Method (PROBID)	Ranking	Wang et al. [48]	2021
Compromise Ranking of Alternatives from Distance to Ideal Solution (CRADIS)	Ranking	Puška et al. [49]	2022
Multiple criteria ranking by alternative trace (MCRAT)	Ranking	Abdulaal and Bafail [50]	2022
Simple Ranking Process (SRP)	Ranking	Zakeri et al. [51]	2023
Alternative Ranking Order Method Accounting for Two-Step Normalization (AROMAN)	Ranking	Bošković et al. [52]	2023

In this paper the authors have used the LOPCOW method for determining the criteria weights. LOPCOW is a recently introduced model for calculating the objective weights of the criteria [53]. LOPCOW is advantageous and preferred by several authors already in various domains of social science, engineering, management and basic science [54-63] for several reasons like ability to combat the highly skewed distribution of the criteria weights influencing the true ranking positions, to deal with negative and zero values in the initial performance or decision matrix and to work with a large group of criteria and alternatives.

The contributions of the present paper are as follows. First, the present paper proposes a novel MCDM model for ranking that uses non-linear interval standardization with flexibility for the decision makers to select the intervals given the problem. Second, a novel use of soft-max function for additive utility for MCDM models is made. Third, a new EESG framework (using MCDM based analysis) is proposed for comparing firm performance. Fourth, in Indian context, the EESG performance of the energy sector firms are compared.

The reminder of the paper is exhibited as follows. In section 2 the procedural steps of the newly developed ERUNS method is described in detail with necessary explanations. Section 3 provides a brief description of the LOPCOW method used for determining the criteria weights. In section 4 the case study is explained in brief while providing the data and criteria details. Section 5 highlights the key findings resulted from the data analysis by using the newly proposed ERUNS method. Besides, the results of validity and sensitivity analysis are also provided. In section 6 a brief discussion on the results is included. Finally, section 7 concludes the paper while throwing light on some of the apparent future scope.

2. Proposed Method: ERUNS

This is a novel hybrid approach that leverages the utility degrees and uses a new interval based nonlinear standardization scheme to the decision makers a greater flexibility in choosing a best possible alternative. Primarily this method is defined for objective information based analysis while the analysts enjoy the flexibility to select the desired interval for standardization depending on the problem.

Steps

Step 1. Formation of the decision matrix $X = \left[x_{ij} \right]_{m \times n}$

Step 2. Standardization. The standardization of the elements of the matrix *X* was performed using a function that enables the mapping of criterion intervals into an arbitrarily chosen interval $[\alpha, \beta]$, where α represents the left limit of the interval, while β represents the right limit of the interval.

The standardization of the elements of the initial decision matrix $X = \left[x_{ij} \right]_{m \times n}$ is carried out in two steps:

a) In the first step, by applying expression (1), the elements of the decision matrix are mapped into the interval $[\alpha, \beta]$, according to the following:

$$\varphi_{ij} = \left(\frac{x_j^{\min}}{x_{ij}} \right)^3 \beta + \frac{\alpha}{x_j^{\min}} \tag{1}$$

where $x_j^{\min} = \min_{1 \le i \le m} (x_{ij})$ represents the absolute minimum values from the matrix $X = \left[x_{ij} \right]_{m \times n}$, while α and β represent the left and right limits of the standardized interval.

The values of the left and right limits of the interval $[\alpha, \beta]$ depend on the specifics of the decision making problem and are defined based on the preferences of the decision maker. For example, if we want to map the elements of the matrix $X = \left[x_{ij} \right]_{m \times n}$ to the interval [1, 9], we will adopt the values $\alpha = 1$ and $\beta = 9$, so expression (1) is transformed into expression (2), as follows:

$$\varphi_{ij} = \left(\frac{x_j^{\min}}{x_{ij}} \right)^3 \times 9 + \frac{1}{x_j^{\min}} \tag{2}$$

It is recommended that in decision problems where there are a large number of alternatives, an interval with a larger range should be adopted, since the standardized interval should have a sufficient range so that the standardized values could be distributed proportionally to their influence in the original criterion interval. Applying expression (1), we obtain a modified decision matrix (MDM) $X^N = \left[\varphi_{ij} \right]_{m \times n}$.

b) In the second step, if the criterion is of the *max* type, the values of $X^N = \left[\varphi_{ij} \right]_{m \times n}$ are modified by applying the expression (3):

$$\xi_{ij} = -\varphi_{ij} + \max_{1 \le i \le m} \left(\varphi_{ij} \right) + \min_{1 \le i \le m} \left(\varphi_{ij} \right) \tag{3}$$

where the values of φ_{ij} are obtained by applying the expression (1).

If the criterion is of the *min* type, it is assumed that $\xi_{ij} = \varphi_{ij}$. Thus, we get the final standardized decision matrix (SDM) $\mathbb{Q} = \left[\xi_{ij} \right]_{m \times n}$.

Step 3. Formation of the weighted standardized decision matrix (WSDM)

The weighted standardized decision matrix is represented by $V = [v_{ij}]_{m \times n}$ where the elements are derived using soft-max function to provide a concise representation of weighted relations between criteria:

$$v_{ij} = \frac{\exp\left(f(\xi_{ij})/k\right)w_j}{\sum_{j=1}^{n}\exp\left(f(\xi_{ij})/k\right)w_j} \tag{4}$$

Where $f(\xi_{ij}) = \xi_{ij} \Big/ \sum_{j=1}^{n}\xi_{ij}$, $j \in \{1,2,3...n\}$ w_j is the weight of j^{th} criterion and k>0 is modulation parameter. We suggest for easier calculation to adopt k=1 and this parameter can be used for simulation of different scenarios in sensitivity analysis.

Step 4. Derive the utility degrees with respect to the ideal and anti-ideal solutions

The utility degrees of the i^{th} alternative with respect to the ideal and anti-ideal solutions are given by

$$U^{+} = \frac{\prod_{j=1}^{n}\left(\xi_{ij}\right)^{v_{ij}}}{\sum_{j=1}^{n} v_j^{+}} \tag{5}$$

$$U^{-} = -\frac{\sum_{j=1}^{n} v_j^{-}}{\prod_{j=1}^{n}\left(\xi_{ij}\right)^{v_{ij}}} + \max_{1\le i\le m}\left(\frac{\sum_{j=1}^{n} v_j^{-}}{\prod_{j=1}^{n}\left(\xi_{ij}\right)^{v_{ij}}}\right) + \min_{1\le i\le m}\left(\frac{\sum_{j=1}^{n} v_j^{-}}{\prod_{j=1}^{n}\left(\xi_{ij}\right)^{v_{ij}}}\right) \tag{6}$$

Where $v_j^{+} = \max_{1\le i\le m}(\xi_{ij}\cdot w_j)$ and $v_j^{-} = \min_{1\le i\le m}(\xi_{ij}\cdot w_j)$ $(i=1,2...m;\ j=1,2...n)$.

Step 5. Find out the utility function values

Based on the aggregated levels of utility, we can define the final utility functions derived as

$$f(U_i^{+}) = \frac{U_i^{+}}{U_i^{+}+U_i^{-}} \tag{7}$$

$$f(U_i^{-}) = \frac{U_i^{-}}{U_i^{+}+U_i^{-}} \tag{8}$$

The utility functions are additive in nature.

Step 6. Find out the appraisal score

Using the values of the utility functions rank the alternatives. The appraisal scores of the alternatives are calculated using expression (9).

$$AS_i = (U_i^{+}+U_i^{-})\frac{\left(1+f(U_i^{+})\right)^{\delta}\left(1+f(U_i^{-})\right)^{1-\delta} - \left(1-f(U_i^{+})\right)^{\delta}\left(1-f(U_i^{-})\right)^{1-\delta}}{\left(1+f(U_i^{+})\right)^{\delta}\left(1+f(U_i^{-})\right)^{1-\delta} + \left(1-f(U_i^{+})\right)^{\delta}\left(1-f(U_i^{-})\right)^{1-\delta}} \tag{9}$$

The appraisal score has a parameter δ which is defined from the interval [0,1]. Using the parameter δ, the influence of utility function values (expression (7) and (8)) in the final decision is defined. It is recommended that δ =0.5 be adopted for the calculation of the final appraisal score. Thus, the equal influence of utility function values in the final decision is simulated. The final ranking of the alternatives is defined on the basis of the final appraisal score, where it is desirable that the alternative has the highest possible value (9).

3. LOPCOW Method

The procedural steps of the LOPCOW method [53] are described below.

Step 1. Normalization of the decision-matrix

LOPCOW applies the linear max-min type of normalization approach to normalize the initial decision matrix. Accordingly, the elements of the normalized decision matrix are obtained as

$R=\left[r_{ij}\right]_{m\times n}$ Where,

$$r_{ij}=\frac{x_{ij}-x_{\min}^{j}}{x_{\max}^{j}-x_{\min}^{j}} \text{ (When } j\in j^{+}\text{, effect direction: maximize)} \tag{10}$$

$$r_{ij}=\frac{x_{\max}^{j}-x_{ij}}{x_{\max}^{j}-x_{\min}^{j}} \text{ (When } j\in j^{-}\text{, effect direction: minimize)} \tag{11}$$

Step 2. Obtain the Percentage Value (PV) for the criteria

The PV for each criterion is calculated as

$$P_{j}=\left|\ln\left(\frac{\sqrt{\frac{\sum_{i=1}^{m} r_{ij}^{2}}{m}}}{\sigma}\right).100\right| \tag{12}$$

σ is the standard deviation of the performance values of the alternatives under a specific criterion.

Step 3. Deduce the criteria weights

The weight for the j^{th} criterion is calculated by using

$$w_{j}=\frac{P_{j}}{\sum_{j=1}^{n} P_{j}} \tag{13}$$

Where, $\sum_{j=1}^{n} w_{j}=1$

4. Case Study

The newly developed MCMDM has been applied in a real-life case study to compare the performance of leading firms from the energy sector listed to NSE, India. The firms are listed in Table 2. Over the last few years these firms have been investing significantly in renewable energy such as solar energy, hydrogen fuel and so on.

Table 2
List of companies under study (Listed to Nifty Energy Index)

S/L	Company Name	Industry	Symbol
A1	Adani Green Energy Ltd.	Power	ADANIGREEN
A2	Bharat Petroleum Corporation Ltd.	Power	BPCL
A3	Indian Oil Corporation Ltd.	Oil Gas & Consumable Fuels	IOC
A4	NTPC Ltd.	Oil Gas & Consumable Fuels	NTPC
A5	Oil & Natural Gas Corporation Ltd.	Power	ONGC
A6	Power Grid Corporation of India Ltd.	Oil Gas & Consumable Fuels	POWERGRID
A7	Reliance Industries Ltd.	Power	RIL
A8	Tata Power Co. Ltd.	Power	TATAPOWER

To compare the performance we consider four aspects such as economic, environmental, social, and governance (EESG). In line with the past studies we consider three features to measure the economic conditions of the firms such as market attractiveness (proxy variable: market capitalization), valuation (proxy variable: enterprise value) and leverage (variable: debt-to-equity ratio). These variables are taken from the annual financial statements of the firms. The values of these variables are obtained from CMIE Prowess IQ (version 3.0) database. To measure the environmental, social, and governance (ESG) performance, the rating scores on these dimensions given by an independent agency such as CRISIL have been considered. The criteria description is exhibited in Table 3. The study period is taken as FY 2022-23.

Table 3
List of criteria

S/L	Criteria	UOM	Dimension	Effect direction
C1	Environmental Score	Value	Environmental	(+)
C2	Social Score	Value	Social	(+)
C3	Governance score	Value	Governance	(+)
C4	Debt to equity ratio	Times	Economic	(-)
C5	Market Capitalization	Rs. Billion	Economic	(+)
C6	Enterprise Value	Rs. Billion	Economic	(+)

Accordingly, the initial decision matrix $X = \left[x_{ij}\right]_{m\times n}$ is constructed. In this work, $m=8$ and $n=6$. The decision matrix is given in Table 4. The analysis is carried out following the procedural steps of the LOPCOW method (for determining the criteria weights) and ERUNS model (for ranking).

Table 4
Initial Decision Matrix

	Criteria					
Alternatives	C1	C2	C3	C4	C5	C6
A1	74	57	64	2.4	1395.77	1526.54
A2	46	59	68	0.86	746.87	1013.54
A3	43	70	68	1.2	1100.04	2138.67
A4	45	63	66	1.34	1697.89	3518.15
A5	35	55	61	0.1	1900.25	1622.89
A6	56	58	62	1.57	1574.36	2805.05
A7	44	67	73	0.46	15772.10	17040.29
A8	51	46	58	2.1	607.91	864.37
	(+)	(+)	(+)	(-)	(+)	(+)

5. Findings

In this section a demonstration of the step-by-step decision analysis and key findings are recorded. First, we calculate the criteria weights using the procedural steps of the LOPCOW method. The initial decision matrix $X=\left[x_{ij}\right]_{m\times n}$ as given in Table 4 is normalized using the expressions (10) and (11). Accordingly, we construct the normalized decision matrix $R=\left[r_{ij}\right]_{m\times n}$

For example,

$$r_{21}=\frac{x_{21}-x_{\min}^{1}}{x_{\max}^{1}-x_{\min}^{1}}=\frac{46-35}{74-35}=\frac{11}{39}=0.2821$$

$$r_{24}=\frac{x_{\max}^{4}-x_{24}}{x_{\max}^{4}-x_{\min}^{4}}=\frac{2.4-0.86}{2.4-0.1}=\frac{1.54}{2.3}=0.6696$$

In the similar way all other elements of the normalized decision matrix R are found and recorded in Table 5.

Table 5
Normalized Decision Matrix

Company	Criteria					
	C1	**C2**	**C3**	**C4**	**C5**	**C6**
A1	1.0000	0.4583	0.4000	0.0000	0.0520	0.0409
A2	0.2821	0.5417	0.6667	0.6696	0.0092	0.0092
A3	0.2051	1.0000	0.6667	0.5217	0.0325	0.0788
A4	0.2564	0.7083	0.5333	0.4609	0.0719	0.1641
A5	0.0000	0.3750	0.2000	1.0000	0.0852	0.0469
A6	0.5385	0.5000	0.2667	0.3609	0.0637	0.1200
A7	0.2308	0.8750	1.0000	0.8435	1.0000	1.0000
A8	0.4103	0.0000	0.0000	0.1304	0.0000	0.0000

Next, the percentage values (PV) of the criteria for all alternatives are determined using the expression (12). For example, PV for the 4^{th} criterion is calculated as

$$P_4=\left|\ln\left(\frac{\sqrt{\frac{\sum_{i=1}^{8}r_{i4}^{2}}{8}}}{\sigma}\right).100\right|=\left|\ln\left(\frac{\sqrt{\frac{2.7916}{8}}}{0.3390}\right).100\right|=55.52$$

$$\sigma=Std.Dev(r_{14},r_{24},......r_{84})=0.3390$$

The criteria weights are now deduced using the expression (13) and final calculations are exhibited in Table 6. Example of calculation,

$$w_4=\frac{P_4}{\sum_{j=1}^{6}P_j}=\frac{55.52}{237.605}=0.234$$

Table 6
Criteria weight calculation

	Criteria						
Values	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	
Mean Square	0.212	0.395	0.306	0.349	0.128	0.131	
σ	0.300	0.311	0.317	0.339	0.339	0.335	**Σ**
P_j	42.858	70.389	55.690	55.522	5.214	7.932	237.605
w_j	0.1804	0.2962	0.2344	0.2337	0.0219	0.0334	1.0000

It is seen that as per the calculated weight values the preferential order of the criteria is $C_2 \succ C_3 \succ C_4 \succ C_1 \succ C_6 \succ C_5$. Moreover, it is noted that C_3 and C_4 hold almost same weight. It is observed that social, governance and leverage assume superiority over the others.
Next, we move to rank the firms using the newly developed ERUNS method. First, we go for standardization of the initial decision matrix X. For this purpose, the interval is selected as $[1,100]$, i.e. $\alpha = 1; \beta = 100$. This is the advantage of the ERUNS method that allows the decision maker to map the performance values of the initial decision matrix to a range based on the given problem. In this study, the performance values for the criteria are differing in scale and range. Hence, we decide to go by the lower limit =1 and upper limit = 100. Then by applying the expression (1) the elements of the modified decision matrix (MDM) $X^N = \left[\varphi_{ij}\right]_{m\times n}$ are derived. For example,

$$\varphi_{11} = \left(\frac{x_1^{\min}}{x_{11}}\right)^3 \beta + \frac{\alpha}{x_1^{\min}} = \left(\frac{35}{74}\right)^3 \times 100 + \frac{1}{35} = 10.609$$

$$\varphi_{14} = \left(\frac{x_4^{\min}}{x_{14}}\right)^3 \beta + \frac{\alpha}{x_4^{\min}} = \left(\frac{0.1}{2.4}\right)^3 \times 100 + \frac{1}{0.1} = 10.007$$

$$\varphi_{25} = \left(\frac{x_5^{\min}}{x_{25}}\right)^3 \beta + \frac{\alpha}{x_5^{\min}} = \left(\frac{607.913}{746.874}\right)^3 \times 100 + \frac{1}{607.913} = 53.926$$

In similar way we calculate all other φ_{ij} values and formulate the MDM (see Table 7).

Table 7
Modified Decision Matrix

	max	max	max	min	max	max
Criteria/ Alternative	C1	C2	C3	C4	C5	C6
A1	10.609	52.581	74.447	10.007	8.264	18.155
A2	44.077	47.415	62.069	10.157	53.926	62.028
A3	53.955	28.400	62.069	10.058	16.879	6.603
A4	47.079	38.949	67.883	10.042	4.592	1.484
A5	100.029	58.526	85.977	110.000	3.276	15.110
A6	24.443	49.909	81.884	10.026	5.759	2.927
A7	50.361	32.385	50.172	11.027	0.007	0.014
A8	32.350	100.022	100.017	10.011	100.002	100.001

To get the final standardized matrix (SDM), $\mathbb{Q} = \left[\xi_{ij}\right]_{m\times n}$. we apply the expression (3) and follow the step 2(b). Examples of calculation are given below. Accordingly, we get the final SDM as given in Table 8.

$\xi_{12} = -\varphi_{12} + \max_{1\le i\le m}(\varphi_{12}) + \min_{1\le i\le m}(\varphi_{12}) = -52.581 + 100.022 + 28.400 = 75.840$

$\xi_{14} = \varphi_{14} = 10.007$

Now we proceed for getting the weighted SDM (WSDM) using the expression (4). The WSDM is given in Table 9. Example of calculation (assuming k=1)

$$f(\xi_{11}) = \xi_{11} \Big/ \sum_{j=1}^{6} \xi_{1j} = \frac{100.029}{435.225} = 0.2298$$

$$v_{11} = \frac{\exp\left(f(\xi_{11})/k\right) w_1}{\sum_{j=1}^{6} \exp\left(f(\xi_{1j})/k\right) w_j} = \frac{1.258 \times 0.1804}{1.165} = 0.195$$

Table 8
Final standardized decision matrix (SDM)

Criteria/ Alternative	C1	C2	C3	C4	C5	C6
A1	100.029	75.840	75.743	10.007	91.745	81.860
A2	66.561	81.006	88.120	10.157	46.083	37.988
A3	56.683	100.022	88.120	10.058	83.130	93.412
A4	63.558	89.472	82.306	10.042	95.418	98.531
A5	10.609	69.896	64.213	110.000	96.733	84.905
A6	86.195	78.512	68.305	10.026	94.250	97.088
A7	60.277	96.037	100.017	11.027	100.002	100.001
A8	78.287	28.400	50.172	10.011	0.007	0.014

The next step is to calculate the utility degrees of the alternatives with respect to the ideal and anti-ideal solutions. The expressions (5) and (6) are utilized for this purpose.

Table 9
Weighted standardized decision matrix (WSDM)

Criteria/ Alternative	C1	C2	C3	C4	C5	C6
A1	0.195	0.303	0.239	0.205	0.023	0.035
A2	0.183	0.313	0.253	0.199	0.021	0.031
A3	0.175	0.318	0.245	0.204	0.023	0.035
A4	0.179	0.312	0.243	0.206	0.023	0.036
A5	0.158	0.297	0.232	0.256	0.023	0.035
A6	0.190	0.307	0.237	0.207	0.024	0.036
A7	0.176	0.312	0.249	0.205	0.023	0.035
A8	0.229	0.279	0.251	0.197	0.017	0.027

Examples of calculation

$$U_1^+ = \frac{\prod_{j=1}^{n} \left(\xi_{1j}\right)^{v_{1j}}}{\sum_{j=1}^{n} v_j^+} = \frac{(0.195^{0.1804}) \times (0.303^{0.2962}) \times .... \times (0.035^{0.0334})}{18.042 + 29.631 + ... + 3.338} = \frac{53.179}{102.3952} = 0.5196$$

$$U_1^- = -\frac{\sum_{j=1}^{6} v_j^-}{\prod_{j=1}^{6}\left(\xi_{1j}\right)^{v_{1j}}} + \max_{1\le i\le m}\left(\frac{\sum_{j=1}^{6} v_j^-}{\prod_{j=1}^{6}\left(\xi_{1j}\right)^{v_{1j}}}\right) + \min_{1\le i\le m}\left(\frac{\sum_{j=1}^{6} v_j^-}{\prod_{j=1}^{6}\left(\xi_{1j}\right)^{v_{1j}}}\right) = 0.9868$$

$$v_1^+ = \max_{1\le i\le m}(\xi_{1j}\cdot w_j) = 18.042; v_2^+ = \max_{1\le i\le m}(\xi_{2j}\cdot w_j) = 29.631; v_3^+ = \max_{1\le i\le m}(\xi_{3j}\cdot w_j) = 23.442$$

$$v_4^+ = \max_{1\le i\le m}(\xi_{4j}\cdot w_j) = 25.704; v_5^+ = \max_{1\le i\le m}(\xi_{5j}\cdot w_j) = 2.195; v_6^+ = \max_{1\le i\le m}(\xi_{6j}\cdot w_j) = 3.338$$

$$v_1^- = \min_{1\le i\le m}(\xi_{1j}\cdot w_j) = 1.9136; v_2^- = \min_{1\le i\le m}(\xi_{2j}\cdot w_j) = 8.4132; v_3^- = \min_{1\le i\le m}(\xi_{3j}\cdot w_j) = 11.7954$$

$$v_4^- = \min_{1\le i\le m}(\xi_{4j}\cdot w_j) = 2.3384; v_5^- = \min_{1\le i\le m}(\xi_{5j}\cdot w_j) = 0.0002; v_6^- = \min_{1\le i\le m}(\xi_{6j}\cdot w_j) = 0.0005$$

Now, by using the expressions (7), (8) and (9) we calculate the utility function values and final appraisal score for each alternative to rank them. Table 10 exhibits the final calculations and ranking of the alternatives. Examples of calculation

$$f(U_1^+) = \frac{U_1^+}{U_1^+ + U_1^-} = \frac{0.5196}{0.5196+0.9868} = 0.3449$$

$$f(U_1^-) = \frac{U_1^-}{U_1^+ + U_1^-} = \frac{0.9868}{0.5196+0.9868} = 0.6551$$

$$AS_1 = (U_1^+ + U_1^-)\frac{\left(1+f(U_1^+)\right)^{0.5}\left(1+f(U_1^-)\right)^{1-0.5} - \left(1-f(U_1^+)\right)^{0.5}\left(1-f(U_1^-)\right)^{1-0.5}}{\left(1+f(U_1^+)\right)^{0.5}\left(1+f(U_1^-)\right)^{1-0.5} + \left(1-f(U_1^+)\right)^{0.5}\left(1-f(U_1^-)\right)^{1-0.5}}$$

$$= (0.5196+0.9868)\frac{((1+0.3449)^{0.5}(1+0.6551)^{0.5}) - ((1-0.3449)^{0.5}(1-0.6551)^{0.5})}{((1+0.3449)^{0.5}(1+0.6551)^{0.5}) + ((1-0.3449)^{0.5}(1-0.6551)^{0.5})}$$

$$= 0.7784$$

(Assuming δ=0.5)

Table 10
Utility degrees, utility function values, appraisal scores and ranking of the alternatives

Alternative	U+	U-	f(U+)	f(U-)	Appraisal Score	Rank
A1	0.5196	0.9868	0.3449	0.6551	0.7784	4
A2	0.4979	0.9667	0.3399	0.6601	0.7585	7
A3	0.5336	0.9988	0.3482	0.6518	0.7908	3
A4	0.5163	0.9839	0.3442	0.6558	0.7755	5
A5	0.5669	1.0251	0.3561	0.6439	0.8188	1
A6	0.4997	0.9685	0.3404	0.6596	0.7603	6
A7	0.5617	1.0212	0.3549	0.6451	0.8146	2
A8	0.2328	0.4210	0.3561	0.6439	0.3363	8

It is seen that $A_5 \succ A_7 \succ A_3 \succ A_1 \succ A_4 \succ A_6 \succ A_2 \succ A_8$, as per final appraisal score. It is observed that the appraisal scores are very closely distributed (for example, A_5 and A_7, A_1 and A_4). It sounds interesting as the result invokes for an analysis of stability and reliability.

5.1 Comparative Analysis

Validation of the ranking result obtained by using a specific MCDM model is of utmost importance for reliability checking. The results vary because of changes in the underlying assumptions, selection of the alternatives and criteria, weights of the criteria and so on [64-65]. To check the reliability of the result obtained by using the newly proposed ERUNS method, we compare the ranking outcome with other MCDM models such as MABAC, CRADIS, TOPSIS, COPRAS, CoCoSo and SAW. The comparative analysis of ranking has been generally used in the past studies on MCDM models for ascertaining the reliability (for example, [66-70]). Table 11 shows the result of Spearman's Rank Correlation (SRC) test among the various MCDM models which indicate that the result obtained by using ERUNS method is comparable and maintains statistically significant correlation with others. Hence, we can consider ERUNS to provide a reliable result.

Table 11
SRC test for comparing the MCDM models

MCDM model	MABAC	CRADIS	TOPSIS	COPRAS	CoCoSo	SAW
ERUNS	0.976*	0.976*	0.667*	0.929*	0.714*	0.976*

*Correlation coefficients are significant at 0.05 level (two-tailed)

5.2 Sensitivity Analysis

Stability of the results obtained by using MCDM models is of importance to the decision makers. A change in the external conditions, for instance, normalization schemes, criteria and alternative sets, distance or similarity measures, criteria weights, parameter values among others may lead to gross instability in the final result [71-75]. The sensitivity analysis is conducted to examine the effect of the changing conditions on the stability of the ranking result. In this work we conduct a number of experiments by varying the parameter values (i.e., the values of α, β, δ and k) and observe the ranking results. Table 12 exhibits the experimental cases and Figure 1 shows the ranking orders of the alternatives under various experimental cases. It is observed that there are minor variations. Therefore, it may be contended that the result of ERUNS is quite stable.

Table 12
Experimental cases under the sensitivity analysis

Cases	α	β	δ	k	Cases	α	β	δ	k	Cases	α	β	δ	k
Initial	1	100	0.5	1	Exp.7	1	20	0.5	1	Exp.14	1	100	0.2	1
Exp.1	2	100	0.5	1	Exp.8	1	30	0.5	1	Exp.15	1	100	0.3	1
Exp.2	5	100	0.5	1	Exp.9	1	50	0.5	1	Exp.16	1	100	1	2
Exp.3	10	100	0.5	1	Exp.10	1	80	0.5	1	Exp.17	1	100	1	3
Exp.4	20	100	0.5	1	Exp.11	1	100	0.6	1	Exp.18	1	100	1	5
Exp.5	50	100	0.5	1	Exp.12	1	100	0.7	1	Exp.19	1	100	1	8
Exp.6	1	10	0.5	1	Exp.13	1	100	0.9	1	Exp.20	1	100	1	10

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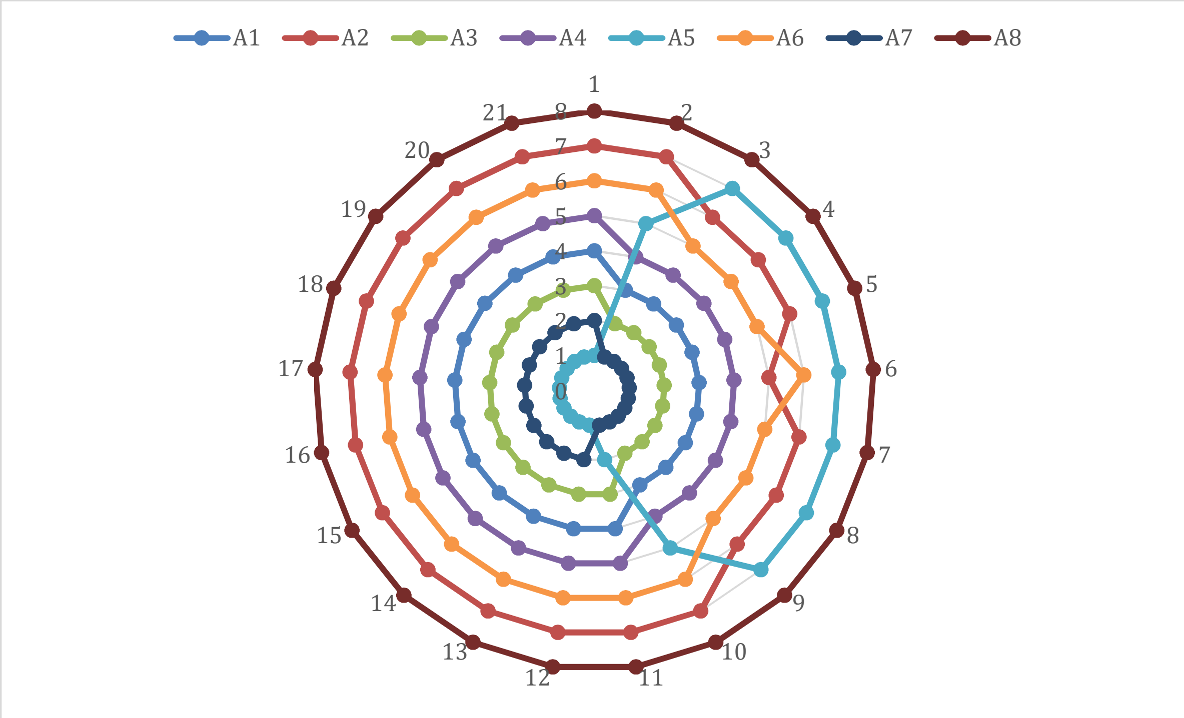

Fig. 1. Result of sensitivity analysis

5.3 Rank Reversal Test

Most often the MCDM models suffer from abrupt changes in the initial ranking orders because sudden inclusion and/exclusion of the alternatives and/or criteria. This incident, as known as rank reversal phenomenon (RRP) causes instability in the ranking result [76-78]. Therefore, in this work we conduct the RRP test wherein deliberately the sub-optimal alternatives are deleted at each stage and ranking orders of the remaining options are checked (see Table 13). It is noted that the ERUNS method does not show any apparent susceptibility to RRP based on the case we present here.

Table 13
Result of RRP test

Case	Ranking order
Initial	$A_5 \succ A_7 \succ A_3 \succ A_1 \succ A_4 \succ A_6 \succ A_2 \succ A_8$
Exclusion of A8	$A_5 \succ A_7 \succ A_3 \succ A_1 \succ A_4 \succ A_6 \succ A_2$
Exclusion of A2, A8	$A_5 \succ A_7 \succ A_3 \succ A_1 \succ A_4 \succ A_6$
Exclusion of A2, A8, A6	$A_5 \succ A_7 \succ A_3 \succ A_1 \succ A_4$
Exclusion of A2, A8, A6, A4	$A_5 \succ A_7 \succ A_3 \succ A_1$
Exclusion of A2, A8, A6, A4, A1	$A_5 \succ A_7 \succ A_3$
Exclusion of A2, A8, A6, A4, A3	$A_5 \succ A_7$
Exclusion of A2, A8, A6, A4, A3, A7	A_5

6. Discussion

The present work reveals some interesting observations. First it shows that based on the calculated weights using the objective information, social aspect stands out as the most important criterion followed by governance and debt to equity (i.e., leverage). The result reinstates the need to have a social touch with good governance to prosper. Good governance is supposed to improve the profitability and reduce the debt. For an organization to grow it is important to effectively manage the debts. In that way the firm can ensure net profitability, improve the liquidity and protects the interest of the stakeholders. It may be interesting to note that the weights of the criteria C3 and C4 are very close to each other. Looking into the ranking of the firms it is observed that power sector organizations such as ONGC and RIL secure the top two positions. These two firms in recent times have invested significantly in hydrogen fuel energy. Also, they have earned good reputation from society and possess good governance. Further, it is notable that these organizations do have a lower debt position.

Technically speaking in this paper ERUNS assume the interval 1 to 100 for standardization of the initial decision matrix to give the decision maker a wide spectrum. However, the result is found consistent with the other established MCDM models. The sensitivity analysis reveals that despite changes in the intervals the ranking results do not undergo significant changes. Only variations in the parameter values (such as δ and k) there is a minor alteration in the ranking order noticed. Therefore, it sounds that ERUNS provide a considerably stable result. Further, it is also found not to prone to the rank reversal phenomenon. The proposed model may possess minor limitations like a slightly higher number of steps and a little bit of dependency on the parameter values. However, this is the first application. To conclude on the apparent limitations, the model needs to be applied for other real-life issues.

The current work has distinct implications. First, from managerial point of view it provides a simple yet structured evaluation of the firm performance considering EESG dimensions. Secondly, it shows that traditional public sector firm in the energy segment may be challenged in near future by private sector counterpart. Third, technically the present paper introduces a new reliable and flexible MCDM model to the decision makers that shall help to solve complex problems.

7. Conclusion

The present study has been undertaken to introduce a new MCDM model such as ERUNS for application into ranking or evaluation problems dealing with objective information. The said method uses an interval based non-linear standardization and soft-max function based novel additive utility functions. The proposed method provides the analysts a greater flexibility (even working with objective information) to select the interval appropriate to the given problem. In this paper the newly introduced MCDM model has been applied to address a topical issue such as sustainability performance evaluation of eight leading energy sector firms listed on NSE, India. The current work has integrated the ESG dimensions with economic aspects to develop a new EESG framework. The criteria like environment, social and governance scores along with leverage (debt to equity), market capitalization and enterprise value have been selected for comparing the firms. Based on the results of the data analysis it is observed that social and governance scores and leverage hold the higher weights while the firms like ONGC and RIL secured the top positions. The newly introduced model is seen providing considerably reliable and stable output and not suffering from the rank reversal phenomenon.

The current work has a number of scope for further extensions. First, the model is newly proposed for a real-life case dealing with objective information. Hence, the model may be tested with subjective information (typically in a group decision making set up) with a larger number of criteria and alternatives. Second, the newly introduced model may be applied to various other real-life complex problem of heterogeneous nature to ascertain its efficacy. Thirdly, the current work has considered a handful of criteria to assess the EESG performance wherein the environmental, social and governance aspects have been seen through an external agency. It may be interesting future work wherein the researchers may define some robust indicators to comprehensively establish the EESG framework. Fourth, the horizon of the present study may be expanded by including the other sectors. A future work might consider to undertake a cross-sectoral analysis. Nevertheless, looking at the usefulness of the technical model proposed and the approach followed to evaluate the sustainability performance of the firms, we do believe that the current work shall be of importance to the analysts, researchers and decision makers in industry.

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Conflicts of Interest
The authors declare no conflicts of interest.

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