Heliyon 10 (2024) e21700

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research on the evaluation of green suppliers of high energy-consuming enterprises--based on rough number-grey correlation TOPSIS method

Xiaoxi Wang [a], Zhangfan Liu [b], Haining Kong [b,*], Geng Peng [a]

[a] School of Economics and Management, University of Chinese Academy of Sciences, Beijing, 100190, China
[b] College of Business Administration, Capital University of Economics and Business, Beijing, 100071, China

A R T I C L E I N F O

Keywords:
High energy-consuming enterprises
Green suppliers
Rough number
Grey correlation method
TOPSIS

A B S T R A C T

With the Goal-Establishment of “carbon compliance” and “carbon neutrality”, enterprises should upgrade “green development” to a strategic position and implement it through all aspects of business operations. Green supplier selection is the initial phase of supply chain management, therefore a green supplier evaluation system is needed to achieve green development. Based on a literature analysis, We selected 45 metrics as candidates for evaluating suppliers. Then through expert interviews, some indicators were revised and supplemented, and finally a green supplier evaluation index system for high energy-consuming enterprises was constructed. A unique aspect of this paper is the introduction of rough number theory into the supplier evaluation process to improve the indicator assignment and the grey correlation TOPSIS method, which optimizes the processing of uncertain semantic information in the evaluation process. The rough number-grey correlation TOPSIS supplier evaluation model developed in this paper has been verified to be applicable and stable in case studies and successfully implemented.

1. Introduction

Currently, the concept of green development is gaining more and more attention from all countries [1]. With the establishment of “zero-carbon” and “carbon-neutral” development goals, the green development model has also become a necessary path for China to enter the stage of high-quality development [2]. According to the analysis of IEA’s 2019 data, China’s electricity and heat production sector contributes 51.4 % of carbon emissions, which is about 22.4 % higher than the world average. The contribution of industrial carbon emissions is 27.9 %, which is 51.6 % higher than the world average. It is not difficult to find that most of China’s carbon emission contribution belongs to high-energy-consuming enterprises. Therefore, how to realize the green development of China’s high-energy-consuming industries has also become an issue of concern for scholars in various fields.

Green supply chain management helps to improve the operational performance of companies in terms of quality, cost, flexibility, and delivery [3]. Supplier evaluation is at the beginning of the supply chain. Strengthening the focus on green suppliers can help create a bullwhip effect on the supply chain as a whole, which in turn optimizes the supply chain compatibility and the environmental performance of the company. Green supplier evaluation, as an essential core component of green supplier management [4], plays a significant role in reducing environmental pollution and resource consumption in R&D and production processes [5], improving

* Corresponding author. 121 Zhangjia Road, Huaxiang, Fengtai District, Beijing, China.
E-mail address: konghaining@cueb.edu.cn (H. Kong).

https://doi.org/10.1016/j.heliyon.2023.e21700
Received 5 May 2023; Received in revised form 23 October 2023; Accepted 26 October 2023
Available online 10 November 2023
2405-8440/

financial performance [6], and improving corporate flexibility and delivery performance [3]. Therefore, theoretical research should actively promote the establishment of a scientific green supplier evaluation mechanism for high energy-consuming enterprises to enhance the green development of high energy-consuming enterprises from the source of the supply chain, and to promote the environmental performance and green development capability of high energy-consuming enterprises with the green attributes of suppliers and the environmental friendliness of products.

Because most existing research focuses on the supplier selection issue of specific enterprises or industries, there is little research that explores the key evaluation points of green suppliers from the perspective of overall demand of high-energy-consuming industry enterprises. Therefore, the practical value of existing research results is limited. At the same time, there is relatively less attention paid to the handling of uncertain semantic information in the evaluation of green suppliers for high-energy-consuming enterprises. Based on relevant evaluation methods and decision-making theories, this study further explores the methods of handling uncertain semantic information in the evaluation criteria and models of green suppliers for high-energy-consuming enterprises. This research focuses on four aspects: the basis of green supplier selection, the determination of index weights, the determination of decision-maker weights, and the method of evaluation selection. The purpose is to provide solutions and scientific decision-making references for high-energy-consuming enterprises to efficiently and conveniently evaluate candidate schemes of green suppliers.

2. Literature review

2.1. Research on the green supplier evaluation system

Since Noci [7]first incorporated environmental sustainability into supplier evaluation, a plethora of scholars have expanded both the content [8,9] and evaluation methods [10,11]of green supplier evaluation. Green supplier evaluation research in developed countries has been extended to many industries, such as the automotive industry [12,13], footwear industry [14], metal machinery industry [15], and the electronic product industry [16]. With the growing emphasis on green development, companies not only need to consider price, quality, and delivery time in supplier selection but also need to fully consider the environmental impact of their products. The index system with environmental elements, a crucial component of green supplier evaluation, has garnered significant attention in numerous studies. Table 1 showcases the primary green supplier evaluation indicators. However, existing green supplier evaluation studies focus more on specific enterprises or a certain industry, lacking consideration of the common needs for green supplier evaluation among high energy-consuming enterprises [17–19]. The results of these studies offer limited applicability to other enterprises, particularly high energy-consuming ones, reducing their reference value for green supplier evaluation.

Table 1
Green supplier evaluation criteria.

Author	Selection criteria for green suppliers	Contribution
Noci [7]	Green Capability, Current Environmental Efficiency, Green Image and Net Life Cycle Cost	First integration of environmental sustainability factors into a supplier evaluation system
Humphreys et al. [20]	Environmental certification, recycling, energy use, waste generation, air and water pollution, reuse of materials, clean technology, environmental stress	Integrating environmental factors into the supplier selection process
Buyukozkan and Cifci [21]	Quality, cost, price, flexibility, green practices, reverse logistics, recycling, material reuse, production, clean technology	Research and recommendations on hybrid models (DEMATEL, ANP and TOPSIS) for evaluating green suppliers
Shen et al. [22]	Production pollution, sustainable resource consumption, green image, environmental management system, management commitment, clean technology, use of green materials, environmental training	Suggestions for a fuzzy multifaceted approach to suppliers
Zakeri and Keramati [19]	Sustainable transportation, branding, product quality, pricing, customer relations, green shopping	Grey correlation analysis (GRA) method and fuzzy numerical supplier selection
Afful-Dadzie et al. [17]	Efficiency index, sustainable investment assets, renewable electricity and energy, recycling, energy use, water use, environmental stress	Three aspects of assessing sustainability using the TOPSIS methodology
Tsai et al. [18]	Ecology, use of green materials, reduction of waste, reduction of air pollution, waste disposal, use of hazardous substances, environmental management system, green image, green transportation	Experimental analysis of the network process model for evaluation to calculate the level of impact between green supplier criteria and the relationship between criteria
Vanalle et al. [9]	Government regulation, in-house environmental management, green procurement, customer collaboration, eco-design, investment recovery, environmental, operational and economic performance	The study provides a management and theoretical approach to different industries in Brazil, focusing on environmental management through the adoption of global supply chain management practices
Garg et al. [8]	Eco-design, recycling, environmental policy, environmental regulations, green packaging, green procurement, supplier training, energy use, use of environmentally friendly materials	The study recommends the use of 13 performance indicators and 70 new sub-indicators responsible for the implementation of the GSCM

2.2. Study of supplier evaluation methods

The current supplier evaluation methods can be broadly classified into the following categories: multi-attribute decision-making, multi-objective decision-making, mathematical programming, and hybrid methods [23]. Table 2 provides examples of how each method has been applied in green supplier selection studies.

Multi-attribute decision methods, which typically lack utility functions, derive evaluation results through comparison and ranking, presenting certain disadvantages. For instance, methods like AHP and ANP struggle to accommodate multiple evaluation criteria; TOPSIS ranking can only determine the order of indicators without indicating the correlation degree between evaluation indicators and results. Such ranking methods are primarily suited for initial classification of indicators, among other limitations. The mathematical programming method demands expertise from decision-makers due to its high theoretical application ability and complex operations, thus, it's less suited for routine business decisions and struggles with qualitative content. Conversely, the hybrid model, which amalgamates various methods, capitalizes on their individual strengths to yield more comprehensive and scientific results.

Moreover, some scholars have begun focusing on the treatment of uncertain evaluation information, introducing both fuzzy and rough theories to enhance the science of supplier evaluation and selection [26,31]. The fuzzy method represents subjective and ambiguous factors in the indicator evaluation value analysis using a fixed interval-based fuzzy number. Conversely, the rough interval number, adapting to expert knowledge, experience, and preference, more accurately captures the uncertainty of semantic information in evaluation results. However, while fuzzy theory is widely adopted, the use of rough number and rough set theories is less common in green supplier evaluation. Additionally, fuzzy theory requires manual selection of fuzzy membership functions, making it challenging to clearly delineate element characteristics in boundary regions. Consequently, this approach to uncertain information processing has inherent drawbacks of subjectivity and limited interpretability.

Building on existing green supplier evaluation theories and methods, this paper devises a green supplier evaluation index system tailored to the needs of high energy-consuming enterprises. By integrating the rough number theory, we aim to mitigate the subjective bias in evaluation index assignments and enhance the processing of uncertain semantic information. The overarching goal is to offer a robust and scientific decision-making reference for the green supplier evaluation of high energy-consuming enterprises.

3. Methodology

3.1. Evaluation index system construction method

3.1.1. Indicator screening methodology

This paper uses literature analysis and statistical analysis to screen out candidate evaluation indicators, on top of which expert interviews are used to screen, summarize, supplement and optimize the candidate evaluation indicators in order to further prove the availability of sample data, the completeness of the indicators and their suitability for the research object, so as to enhance the scientificity of the evaluation indicator system.

3.1.2. Reliability test of the indicator system

Based on expert interviews, this study conducted a reliability test to further verify the indicator system constructed in this research. Reliability is an important criterion for measure the quality of the indicator system. High reliability indicates that the indicator system can accurately detect the phenomenon and the survey data can reflect the actual attitude of the respondents. In order to verify and guarantee the consistency, stability and reliability of the evaluation index system constructed based on the results of expert interviews, this paper uses the classical method of reliability testing–the internal consistency of the evaluation index system by Cronbach's α coefficient. The coefficient of a is in the range of 0–1. Generally, the closer the coefficient of a is to 1, the higher the reliability; if the coefficient of a is greater than 0.7, the reliability test is passed.

Table 2
Classification of supplier selection methods.

Category	Methods	Examples of supplier evaluation applications
Multi-attribute/multi-objective decision making	AHP	Kar [24]
	ANP	Hsu et al. [25]
	VIKOR	You et al. [26]
	GRA	Haeri and Rezaei [11]
	TOPSIS	Wang and Chen [27]
Mathematical Planning	LP	Shaw et al. [28]
	GP	Fallahpour et al. [12]
	MIP	Harridan and Cheaitou [13]
	DEA	Dobos and Vorosmarty [14]
Intelligent Methods	Neural Networks	Kar [24]
	Case-based reasoning	Gupta et al. [15]
Hybrid model	ANP-MOORA	Liou et al. [16]
	GRA-TOPSIS	Shi et al. [29]
	AHP-TOPSIS	Çalık [10]
	QFD - MCDM	Yazdani et al. [30]

3.2. Method of determining indicator weights

Currently, there are many methods available for the assignment of evaluation indicators, including subjective assignment methods (e.g., AHP, etc.), objective assignment methods (e.g., principal component analysis, entropy method, etc.), comprehensive evaluation methods (e.g., DEA, GRA, etc.), and combined assignment methods.

Since the assignment results of the subjective assignment method alone may be subjective, the objective assignment method assigns indicators based on the nature and differences of the data itself, thus not reflecting the importance of the indicators in the specific evaluation needs [32]. Meanwhile, the weights obtained by different objective assignment methods make the evaluation results vary greatly [33], and the indicator weights may change significantly when changing the evaluation object or sample data. Therefore, this paper does not use the objective and subjective weighting methods or a combination of them to assign indicators.

In this paper, we choose the rough number assignment method to determine the index weights based on the results of the importance scores of the evaluation indexes by the candidate supplier evaluation subjects, which can fully consider the evaluation objectives of the decision makers in the decision-making process. At the same time, it helps to fully consider the intrinsic connection between the scoring data of each decision maker and ensure the completeness and accuracy of the result information. Specifically, U is the theoretical domain that contains all evaluation objects. There are n classes in the thesis domain, denoted as $= (c_1 \quad c_2 \quad \dots \quad c_n)$, and there is an ordered relationship, and the geometric mean is used to assemble the importance evaluation of indicators by each decision maker. When any of then $c_i^k \in R$, $Y \in U$, the upper and lower approximations of c_i^k are defined as:

$$\text{Lower approximate limit:}\underline{Lim}\left(c_i^k\right) = \frac{1}{M_L}\sum R(Y) \,/\, Y \in \underline{Apr}\left(c_i^k\right) \tag{1}$$

$$\text{Upper approximation limit:}\overline{Lim}\left(c_i^k\right) = \frac{1}{M_U}\sum R(Y) \,/\, Y \in \overline{Apr}\left(c_i^k\right) \tag{2}$$

The M_L and M_U respectively represent the number of objects contained in the lower and upper approximation limits of c_i^k. This yields the rough number expression of c_i^k in the form $RN(c_i^k)$:

$$RN\left(c_i^k\right) = \left[c_i^k\right] = \left[\underline{Lim}\left(c_i^k\right), \overline{Lim}\left(c_i^k\right)\right] = \left[c_i^{kL}, c_i^{kU}\right] \tag{3}$$

Then, the evaluation index c_i^k rough weight $RN(c_i)$ can be calculated according to the following formula:

$$RN(c_i) = \left[\underline{RN}(c_i), \overline{R}\,N(c_i)\right] = \left[c_i^L, c_i^U\right] \tag{4}$$

$$c_i^L = \left(\prod_{k=1}^{z} c_i^{kL}\right)^{1/z} \tag{5}$$

$$c_i^U = \left(\prod_{k=1}^{z} c_i^{kU}\right)^{1/z} \tag{6}$$

Where z is the number of decision makers. Also using the standardized formula, one obtains the standardized rough number criterion weights $[\omega] = ([\omega_1]_{,}[\omega_2]_{,}\dots_{,}[\omega_n])$:

$$[\omega_i] = \left[\underline{\omega}_i, \overline{\omega}_i\right] = \frac{\left[\underline{RN}(c_i), \overline{R}\,N(c_i)\right]}{MAX\overline{R}\,N(c_i)} \tag{7}$$

The exact indicator weight value $S_{RST} = (s_1, s_2, \dots, s_n)$ is calculated by introducing a risk preference coefficient α. α greater than 0.5 indicates that the decision maker is risk-averse, α less than 0.5 indicates that the decision maker is risk-averse, and α equal to 0.5 indicates that the decision maker is risk-neutral.

$$w_i = (1-\alpha)\underline{\omega}_i + \alpha\overline{\omega}_i \quad, i = 1, 2 \dots n \tag{8}$$

$$s_i = \frac{w_i}{\sum_i w_i} \tag{9}$$

3.3. Evaluation expert weighting determination method

Since experts have different knowledge structures and professional backgrounds, they bring different decision information for supplier selection and have different reference values for evaluation results. For this reason, this paper assigns a combination of expert weights based on uncertainty and deviation.

3.3.1. Uncertainty-based objective weights of experts

The uncertainty of the individual decision matrix $Z^k = [Z_{ij}^k]_{m\times n}$ given by expert k is calculated as $\varphi(z^k)$ using the combined weights S of the indicators. The smaller the uncertainty of the individual decision matrix given by the expert, the more accurate the expert's decision is, and a larger weight should be assigned to it. Thus, the formula for calculating the uncertainty-based weights of the experts is given as:

$$\lambda_k^1 = \frac{1}{\varphi(z^k)} \Big/ \sum_{k=1}^{z} \frac{1}{\varphi(z^k)} \tag{10}$$

3.3.2. Objective weights of experts based on deviation

Group decision making is a process of joint negotiation among multiple experts, and the greater the deviation from the group decision, the further the expert deviates from the common will of the group, and should be assigned a smaller weight. Using the distance formula and the comprehensive objective weights of the attributes, the deviation degree f_k between the expert k evaluation results and the group is calculated:

$$f_k = \sum_{h=1,h\neq k}^{z} \sum_{j=1}^{n} \sum_{i=1}^{m} d\left(z_{ij}^k, z_{ij}^h\right) w_j \tag{11}$$

Then the weight of expert k based on the deviation is:

$$\lambda_k^2 = \frac{1}{f_k} \Big/ \sum_{k=1}^{z} \frac{1}{f_k} \tag{12}$$

3.3.3. Comprehensive objective weights of experts

In order to obtain more comprehensive information about the expert weights, the two types of weights can be set by the decision maker according to the specific decision problem with parameters $\beta(0 \leq \beta \leq 1)$. Then, the comprehensive objective weights of the experts can be obtained as:

$$\lambda_k = \beta\lambda_k^1 + (1-\beta)\lambda_k^2 \tag{13}$$

3.4. Rough number-grey correlation TOPSIS green supplier evaluation model for high energy-consuming enterprises

3.4.1. Process of qualitative indicators

Assume that there are m alternative green suppliers i = 1, 2, …, m, corresponding to n green suppliers with qualitative evaluation indexes j = 1, 2, …, n. The experts use the traditional method of determining values (1–5 for "very dissatisfied", "dissatisfied", "average", "satisfied" and "very satisfied" respectively). Assume that there are z experts involved in the decision making k = 1, 2, …, z, (i = 1, …, m; j = 1, 2, …, n) is the judgment score of the k-th decision maker for the i-th supplier relative to the j-th evaluation index. All the decision makers' evaluation matrices form the group solution decision matrix $\widetilde{D}$.

Step 1. Rough number transformation. The supplier evaluation value x_{ij}^k in matrix $\widetilde{D}$ is transformed into the initial evaluation matrix into a rough number matrix by the index-assigned partial rough number transformation method.

Step 2. Weighted normalization of the rough decision matrix. In order to include the evaluation indicators corresponding to different indicators into a comparable range, they need to be normalized to obtain the weighted normalized rough matrix:

$$x_{ij}^{'L} = \frac{x_{ij}^L}{\max_{i=1}^m \left\{\max\left[x_{ij}^L, x_{ij}^U\right]\right\}}$$
$$x_{ij}^{'U} = \frac{x_{ij}^U}{\max_{i=1}^m \left\{\max\left[x_{ij}^L, x_{ij}^U\right]\right\}} \tag{14}$$

$$v_{ij}^L = w \times x_{ij}^{'L} \quad i = 1,2,...,m, j = 1,2,...,n$$
$$v_{ij}^U = w \times x_{ij}^{'U} \quad i = 1,2,...,m, j = 1,2,...,n \tag{15}$$

w denotes the evaluation index weights. At this point, the following positive ideal solutions (PIS) and negative ideal solutions (NIS) can be determined.

Step 3. Based on TOPSIS, the Rough Deviation Distance of the ideal solution is calculated using the n-dimensional Euclidean distance to measure the deviation distance d^+ , d^- of each service scheme relative to the positive and negative ideal solutions:

$$d_i^+ = \left\{ \sum_{j\in B} \left(v_{ij}^L - v^+(j)\right)^2 + \sum_{j\in C} \left(v_{ij}^U - v^-(j)\right)^2 \right\}^{1/2} \quad i=1,2,...,m; j=1,2,...,n$$
$$d_i^- = \left\{ \sum_{j\in B} \left(v_{ij}^L - v^-(j)\right)^2 + \sum_{j\in C} \left(v_{ij}^U - v^+(j)\right)^2 \right\}^{1/2} \quad i=1,2,...,m; j=1,2,...,n \tag{16}$$

Step 4: Rough grey incidence coefficient based on grey correlation. For any rating index of a green supplier, the ideal reference value of the relationship is the relationship value that can best meet the requirements of the index. Based on this, the grey incidence coefficient γ_{ij} corresponding to each candidate green supplier can be obtained. The grey incidence coefficient is obtained from the following formula:

$$\gamma_{ij}^+ = \frac{\min_{i=1}^m \min_{j=1}^n r_{ij}^+ + \xi \max_{i=1}^m \max_{j=1}^n r_{ij}^+}{r_{ij}^+ + \xi \max_{i=1}^m \max_{j=1}^n r_{ij}^+} \tag{17}$$

$$\gamma_{ij}^- = \frac{\min_{i=1}^m \min_{j=1}^n r_{ij}^- + \xi \max_{i=1}^m \max_{j=1}^n r_{ij}^-}{r_{ij}^- + \xi \max_{i=1}^m \max_{j=1}^n r_{ij}^-} \tag{18}$$

$$r_{ij}^+ = v^0(j) - v_{ij}^L(j) \quad j \in B \quad i=1,2,...,m$$
$$r_{ij}^- = v_{ij}^U(j) - v^0(j) \quad j \in C \quad j=1,2,...,n \tag{19}$$

$v^0(j)$ is the maximum upper bound of the benefit class and minimum lower bound of the cost class, which evaluates the rough relation value of candidate suppliers that meet the j-th green supplier evaluation criterion. In general, the resolution coefficient $\xi(0 \le \xi \le 1)$ is set to 0.5 to ensure a moderate resolution effect and better result stability.

Step 5. Compute the grey relational degree of each candidate green supplier. The grey relational degrees R^+ and R^- for the i-th candidate green supplier can be obtained by the following formula:

$$R_i^+ = \frac{\sum_{j=1}^n \gamma_{ij}^+}{n} \quad i=1,2,...,m \tag{20}$$

$$R_i^- = \frac{\sum_{j=1}^n \gamma_{ij}^-}{n} \quad i=1,2,...,m \tag{21}$$

The larger the grey relational degree Γ, the closer the relationship value of the green supplier is to the ideal relationship value, and the higher its priority. The priority of the green supplier can help scientifically choose the most suitable supplier.

Step 6: Candidate supplier qualitative indicators of relative closeness. Firstly, the Euclidean distance is merged with the closeness of association. If d_i^- and r_i^+ are larger, the better. Thus, the following combined equation can be derived:

$$S_i^+ = \alpha_1 d_i^- + \alpha_2 R_i^+, (i=1,2,...,m) \tag{22}$$

$$S_i^- = \alpha_1 d_i^+ + \alpha_2 R_i^-, (i=1,2,...,m) \tag{23}$$

Relative closeness of qualitative indicators $C_i^{'}$.

$$C_i^{'} = \frac{S_i^+}{S_i^+ + S_i^-}, (i=1,2,...,m) \tag{24}$$

3.4.2. Quantitative index processing process

Min-Max is used to normalize the quantitative index values, and combined with grey correlation method and TOPSIS method to calculate the relative closeness of quantitative indexes of candidate suppliers. The larger the d_i^- and R_i, the closer the candidate green supplier is to the positive ideal solution, and the better it is, The following combined formula can be derived:

$$C_i^{''} = \beta d_i^- + (1-\beta)R_i, (i=1,2,...,m) \tag{25}$$

3.4.3. Determining the final ranking of candidates

The final ranking of candidate solutions relies on the combined relative closeness C_i of the solutions to determine the final ranking.

$$C_i = C_i^{'} + C_i^{''} \tag{26}$$

All the candidates are ranked according to the calculation result of C_i. When the value of C_i is calculated to be larger, it means that the candidate supplier is better. Therefore the supplier with the highest value of C_i should be selected for the supply of subsequent cooperation.

4. Results

4.1. Determination of index system

Up to now, a total of 226 journal articles and 134 doctoral dissertations were searched in the CNKI database with "green supplier" and "evaluation" as the subject terms. In order to select the candidate evaluation indexes for green suppliers, based on the results of the existing literature search, the articles with weak relevance to high energy-consuming enterprises and those without specific evaluation indexes were excluded. Then, by organizing the evaluation indexes of green suppliers of high energy-consuming enterprises in the literature, we obtained 45 high-frequency indexes that were used more than 10 times, such as delivery [34], quality [35], and environmental certification [36]. Table 3 summarizes the green supplier evaluation indicators. Existing studies show that in the present time of increasing green development requirements, enterprises need to consider not only the price, quality, and delivery time of their products in the selection of suppliers, but also the environmental impact of their products should be fully considered.

Since the indicators screened through the literature lack the analysis and generalization of the overall characteristics of high energy-consuming enterprises, further screening and integration of the indicators should also be conducted with reference to the opinions of experts from relevant industries. In this study, 16 procurement and technical experts in the heat, power, metallurgy and chemical industries, which are representative of high energy-consuming industries, as well as 4 experts and scholars in the field of supply chain were selected for interviews, and to ensure that the interviewees have granular differentiation in terms of industry, position and other statistical characteristics. The basic characteristics of the interviewees are shown in Table 4 below.

According to the opinions of experts and scholars, this paper eliminates the indicators that more than half of them say are "unimportant". At the same time, it also adopts the experts' suggestion to include "delivery mode", which affects the organization's procurement cost, into the evaluation index system; and in the context of the rapid development of digital production, service and visualization management of enterprises, this study incorporates "information service and traceability capability" into the evaluation index system, taking into account the specific supplier selection needs. Furthermore, the study incorporates "information service and traceability" into the evaluation index system. In addition, the "government preferential policies" that affect the procurement cost are regarded as price discounts and merged with the "price cost" index. The final green supplier evaluation index system contains 32 indicators (Table 5 below), which include both the common evaluation of suppliers' supply ability, such as quality and cost, and the evaluation of suppliers' green supply ability. The index system meets the demand for all-round and multi-faceted evaluation of green suppliers of high energy-consuming enterprises.

Table 3
Green supplier evaluation index of common high energy-consuming enterprises.

Indicators	Indicators
Total assets/size	Order demand fulfillment rate
Corporate Social Responsibility/Corporate Image	Government incentives
Assets and liabilities ratio	Replenishment Rate
Cooperation History	Green Design Capability
Quality Management and Risk Control	R&D Rate
Supplier Type	Problem Solving Capability
Quality/Certification Qualification	Continuous Improvement Capability
New Product Development Capability	Effectiveness of Environmental Management System
After-sales service support	Continuous monitoring and regulatory compliance commitment and practice
Timely Response Capability	Robust internal control procedures
Information Provision Capability/Information Level	Green packaging/transportation of products
Product Qualification Rate	Internal member support recognition
Production flexibility	Social recognition of the company's green image
Production cycle time	Green credentials/certifications
Degree of product demand satisfaction	Environmental Purification Facilities
New product line change capability	Recycling facilities
Continuous compliance with product requirements/continuous supply capacity	Selection of suppliers according to environmental standards
Product price cost	Procurement of environmentally friendly raw materials
Transaction Costs	Influence upstream and downstream supply chain members to green production
Shipping Costs	Reduce material/energy consumption
Disposal Costs	Increase reuse and recycling rates
On-time delivery rate/delivery capacity	Avoid or reduce hazardous substances
Order lead time/speed of delivery	Order demand fulfillment rate

Table 4
Results of descriptive statistics of interviewees.

Dimension	Classification Indicators	Number of people	Percentage
Gender	Male	13	65 %
	Female	7	35 %
Age	25–30 years old	2	10 %
	31–40 years old	9	45 %
	41–50 years old	7	35 %
	51 years old and above	2	10 %
Industry	Mining	5	25 %
	Chemical	3	15 %
	Metallurgy	8	40 %
	Academic	4	20 %
Education	Junior high school and below	1	5 %
	High School or College	3	15 %
	Undergraduate	10	50 %
	Graduate and above	6	30 %
Rank/position	Intermediate	14	70 %
	Senior	6	30 %

4.2. Sample selection and data source

Company L as a company is a steel production enterprise with an annual crude steel production capacity of more than 8 million tons, which needs to consume a large amount of coal for blast furnace production. The quality and greenness of iron ore powder used for blast furnace production (e.g., iron content, sulfur content, etc.) affect the consumption of energy resources and the ability of clean production in Company L. Moreover, the daily demand of iron ore powder used for blast furnace production in Company L is huge, and the supplier evaluation needs are frequent. Therefore, a comprehensive green supplier evaluation should be conducted on the raw material suppliers of iron ore powder in L company.

This study verifies the validity of the green supplier evaluation model for high energy-consuming enterprises constructed in this paper by distributing questionnaires to the iron ore powder procurement-related personnel of Company L and evaluating the candidate iron ore powder suppliers of Company L - Company D (Brazil), Company B (Australia) and Company T (UK).

4.3. Determination of index weights

In the context of risk neutrality ($\alpha = 0.5$) the weights of the green supplier evaluation indicators of iron ore fines of enterprise L are calculated by applying the rough number method (Table 6 below).

4.4. Expert weighting results

The objective expert assignment method is based on the analysis of the results of the experts' evaluation of the candidate solutions to derive the expert weights. In this paper, the analysis of the evaluation experts' supplier evaluation values, the uncertainty of each expert's evaluation of the same supplier, and the deviation of individual evaluation results from the evaluation results of the decision-making group are calculated, and thus the decision maker weights are derived (Table 7 below).

4.5. Reliability test of index system

In order to verify the reliability of the green supplier evaluation index system of high energy-consuming enterprises constructed in this paper, this paper uses the index system to evaluate the candidate suppliers of iron ore powder of L enterprises, and the reliability test of this questionnaire was conducted according to the results of the questionnaire. The questionnaire used LIKERT five-point scale, where 1 = least important, 5 = most important, and SPSS software was used to test the reliability of the index screening results. The results of the test are shown in Table 8.

4.6. Rough number-grey correlation TOPSIS ranking

The relative closeness of subjective evaluation results is calculated. In this paper, the same preference for the role of TOPSIS method and grey correlation method in the final evaluation results (Table 9 below), $\alpha_1 = \alpha_2 = 0.5$, yields the relative closeness of each candidate program subjective evaluation index $C_i^{'}$.

The relative closeness of objective evaluation indexes is calculated. The evaluation results of objective evaluation indexes are directly obtained from public data to obtain accurate data, which are not interfered by subjective preferences and perceptions of evaluation subjects, so there is no need for rough number transformation. According to the calculation formula of grey correlation-TOPSIS, the relative closeness of the objective tube evaluation results of each candidate supplier $C_i^{''}$ is obtained (Table 10 below):

Table 5
Indicators, properties and scoring sources.

Criteria Level	Secondary Indicators	Indicator Meaning	Properties of indicators	Scoring Source
Comprehensive evaluation	Z1Total capital/size	The number of total assets of the supplier or the size of the enterprise	Quantitative	Corporate Annual Reports
	Z2 Supplier Type	Evaluate the initiative of our company in this transaction	Qualitative	Expert Scoring
	Z3 Financial status	Measure supplier strength, stability and sustainability of cooperation through gearing ratio, gearing ratio = total liabilities/total assets	Quantitative	Corporate Annual Reports
	Z4 Degree of Demand Satisfaction	The extent to which the supplier meets multiple demands simultaneously. Degree of satisfaction = number of demands met/total number of demands	Quantitative	Expert Scoring/ Formula calculation
	Z5 Timely response capability	Judging the speed and ability of the supplier to respond to customer needs in a timely manner	Qualitative	Expert Scoring
	Z6 Cooperation History	Comprehensive judgment of whether the previous cooperation experience will bring advantages in terms of price and procedure for this transaction	Qualitative	Expert Scoring
	Z7 After-sales service support	After-sales service capability, attitude and scope	Qualitative	Expert Scoring
	Z8 Corporate image	Measure the supplier's legal compliance and social image, whether it will bring good/bad influence to the enterprise	Qualitative	Expert Scoring
	Z9 Digital service and traceability	Supplier digital production, service level, visualization, traceable production, service capability	Qualitative	Expert Scoring
	C1 Transaction Costs	The time, money, manpower and material cost of negotiation and communication, travel and supervision to reach a deal with the supplier	Qualitative	Expert Scoring
	C2 Price cost	The extent to which the supplier's product/service pricing meets our expectations or is advantageous compared to other suppliers	Quantitative	Corporate Purchase Orders
	C3 Transportation cost	The cost of transporting the supplier's products to the company	Quantitative	Corporate Purchase Orders
	C4 Delivery Model	Judgment of the supplier's delivery mode. For example, in-stock delivery; offshore delivery, deferred payment, etc.	Qualitative	Expert Scoring
	Q1 Quality Qualification	The number of different quality certifications the company has for its products. For example, ISO9001 quality certification, EU quality standard certification, etc.	Qualitative	Expert Scoring
	Q2 Product/Service Qualification Rate	Qualification rate of products or services received by the enterprise from suppliers or judged by quality inspection pass rate	Quantitative	Formula calculation
	Q3 Quality and Risk Control Capability	The department and system of supplier product quality supervision or product quality risk control	Qualitative	Expert Scoring
	Q4 New Product Development Capability	The speed of development of new products/services or the length of update cycle of suppliers, which is used to judge the ability of suppliers to continuously meet the needs of our company	Qualitative	Expert Scoring
	G1 On-time delivery capability	Evaluation or judgment of the supplier's ability, commitment, and on-time delivery guarantee mechanism (overdue compensation) to deliver on time	Qualitative	Expert Scoring
	G2 Delivery cycle	The time required by the supplier to complete a single order, to determine whether the order delivery time meets the requirements of the enterprise	Qualitative	Expert Scoring
	G3 Production flexibility	The supplier's ability to accept temporary adjustments to increase or decrease the number of products or services required	Qualitative	Expert Scoring
	G4 Stable supply capability	Judging the willingness and possibility of long-term cooperation with the supplier from the supplier's R&D capability, business status and cooperation experience	Qualitative	Expert Scoring
Green Indicators	L1 Green product certification	The quantity of the supplier's products that have passed ISO14001 environmental management system certification and other environmental quality control certifications at home and abroad	Qualitative	Expert Scoring
	L2 Purification facilities	The number of investment in environmental purification facilities and the degree of equipment completeness of the supplier (the degree of completeness covering the entire production process)	Qualitative	Expert Scoring
	L3 Recycling facilities	The amount of capital invested and the degree of equipment completeness of the recycling facilities of this supplier (the degree of completeness covering the whole production process)	Qualitative	Expert Scoring

(*continued on next page*)

Table 5 (*continued*)

Criteria Level	Secondary Indicators	Indicator Meaning	Properties of indicators	Scoring Source
	L4 Reduction of material/energy consumption	The degree of savings in raw materials, energy and other aspects of the supplier's products compared to other suppliers' products of the same quality	Qualitative	Expert Scoring
	L5 Reduction of harmful substances use	The extent to which the supplier reduces and replaces harmful substances required in the production of products	Qualitative	Expert Scoring
	L6 Green design capability	The supplier's measures and ability to research, develop and design products to save energy and prevent pollution	Qualitative	Expert Scoring
	L7 Procurement of environmentally friendly materials	The supplier's behavior and extent of purchasing and selecting environmentally friendly raw materials	Qualitative	Expert Scoring
	L8 Green packaging/ transportation level	Whether the packaging of the products is recyclable and whether the transportation process meets the standards of environmental protection supervision (including packaging and transportation during the production process and after delivery)	Qualitative	Expert Scoring
	L9 Green image	The degree of public recognition of the supplier's social responsibility for environmental protection	Qualitative	Expert Scoring
	L10 Compliance with environmental regulations commitment/practice	Whether the supplier has the commitment and practice to comply with environmental protection laws and regulations, and whether it has been punished for environmental protection	Qualitative	Expert Scoring
	L11 Green R&D investment	How much resources and attention are invested in green production and service technology research and development	Qualitative	Expert Scoring

Table 6
Evaluation index weights.

Indicator name	$\underline{\omega_i}$	$\overline{\omega_i}$	s_i
Z1Total capital/size	0.9175	1.0000	0.0328
Z2 Supplier Type	0.9037	0.9037	0.0309
Z3 Financial status	0.8052	0.9946	0.0308
Z4 Degree of Demand Satisfaction	0.9037	0.9037	0.0309
Z5 Timely response capability	0.9175	1.0000	0.0328
Z6 Cooperation History	0.9175	1.0000	0.0328
Z7 After-sales service support	0.9175	1.0000	0.0328
Z8 Corporate image	0.8052	0.9946	0.0308
Z9 Digital service and traceability	0.8013	0.8892	0.0289
C1 Transaction Costs	0.9175	1.0000	0.0328
C2 Price cost	0.9175	1.0000	0.0328
C3 Transportation cost	0.6875	0.8740	0.0267
C4 Delivery Model	0.8013	0.8892	0.0289
Q1 Quality Qualification	0.9175	1.0000	0.0328
Q2 Product/Service Qualification Rate	0.9175	1.0000	0.0328
Q3 Quality and Risk Control Capability	0.9037	0.9037	0.0309
Q4 New Product Development Capability	0.8052	0.9946	0.0308
G1 On-time delivery capability	0.9037	0.9037	0.0309
G2 Delivery cycle	0.8052	0.9946	0.0308
G3 Production flexibility	0.6826	0.9786	0.0284
G4 Stable supply capability	0.8052	0.9946	0.0308
L1Green product certification	0.9037	0.9037	0.0309
L2 Purification facilities	0.9175	1.0000	0.0328
L3 Recycling facilities	0.9037	0.9037	0.0309
L4 Reduction of material/energy consumption	0.9175	1.0000	0.0328
L5 Reduction of harmful substances use	0.9037	0.9037	0.0309
L6 Green design capability	0.9175	1.0000	0.0328
L7 Procurement of environmentally friendly materials	0.9037	0.9037	0.0309
L8 Green packaging/transportation level	0.9175	1.0000	0.0328
L9 Green image	0.9037	0.9037	0.0309
L10 Compliance with environmental regulations commitment/practice	0.8013	0.8892	0.0289
L11 Green R&D investment	0.9175	1.0000	0.0328

By combining the results of subjective and objective evaluations, the final degree of closeness for each candidate solution can be determined. The results are show in Table 11.

According to the final proximity data, A3 (Company D) has the greatest final proximity and is the best supplier for Company L. A1

Table 7
Expert weighting table.

Combined expert weights	z_1	z_2	z_3	z_4
Uncertainty	0.2381	0.2381	0.2857	0.2381
Deviation	0.2019	0.3043	0.2165	0.2773
Expert weight	0.2200	0.2712	0.2511	0.2577

Table 8
Reliability statistics.

Variable Name	Cronbach's α	Number of items
Supply capacity	0.847	21
Green supply capacity	0.916	11

The internal consistency coefficient Cronbach's a of each level index is greater than greater than 0.7, so the content of the constructed evaluation index system has high reliability and passed the reliability test.

Table 9
Relative closeness of subjective evaluation results.

Relative closeness	A1	A2	A3
$C_i^{'}$	0.4914	0.4936	0.4936

Table 10
Relative closeness of objective evaluation results.

Relative closeness	A1	A2	A3
$C_i^{''}$	0.4017	0.3985	0.4074

Table 11
Relative closeness of candidate suppliers.

Relative closeness	A1	A2	A3
$C_i^{'}$	0.4914	0.4936	0.4936
$C_i^{''}$	0.4017	0.3985	0.4074
C_i	0.8931	0.8921	0.9009

(Company B) is the next best supplier, and A2 (Company T) is the least suitable supplier for cooperation among the three candidate suppliers for Company L. Furthermore, Company D was also the supplier of iron ore powder used for blast furnace in the quarter of the survey and study by Company L, which illustrates the effectiveness of the evaluation model.

4.7. Sensitivity analysis

Since this paper uses rough number indicator weights for assignment, when risk preference α is changed, the results of indicator weights of evaluation index system will be changed in an orderly manner. Therefore, this paper obtains the indicator weights under different risk preferences by changing the size of α, where the closer α is to 1, the higher the degree of decision risk preference.

Table 12
Results of sensitivity analysis.

α	A1	A2	A3
0.1	0.8941	0.8918	0.9034
0.2	0.8938	0.8919	0.9025
0.3	0.8934	0.8920	0.9017
0.4	0.8931	0.8921	0.9009
0.5	0.8931	0.8921	0.9009
0.6	0.8931	0.8921	0.9009
0.7	0.8931	0.8921	0.9009
0.8	0.8931	0.8921	0.9009
0.9	0.8931	0.8922	0.9009

Then, when α varies, the rate of change of the relative closeness of each candidate is depicted in Fig. 1 below.

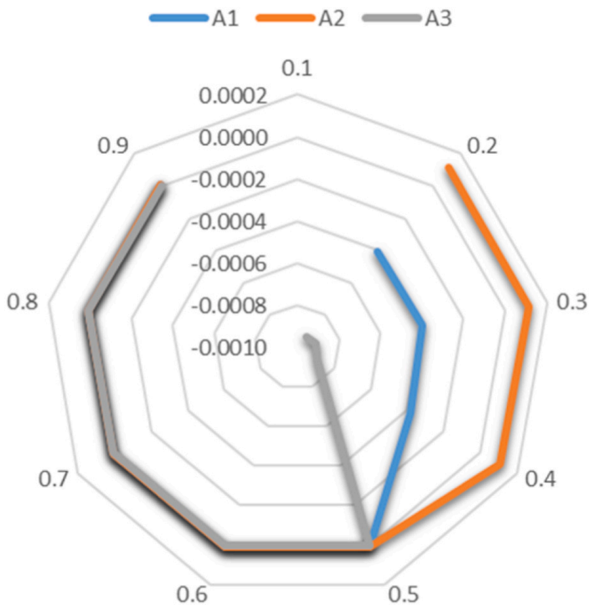

Fig. 1. Rate of change of relative closeness.

The sensitivity analysis of the model is performed by using Matlabe to test the stability of the evaluation results of each candidate solution under the change of indicator weights in the rough number-grey correlation TOPSIS model. The results of the sensitivity analysis are shown in Table 12:.

As can be seen from Table 11, the relative progress of Company D is the largest in all nine experiments, and the relative posting results are most significantly affected by the change in indicator weights when the risk appetite level is less than 0.5, but do not affect the overall ranking of the programs; the relative posting progress of Company B ranks second in all nine experiments; and the relative posting progress of Company T is the smallest in all nine experiments.

Meanwhile, when the level of risk appetite is greater than 0.5, the relative fit level of each scheme tends to be stable. In summary, the candidate green supplier evaluation ranking results did not change in the nine experiments, so the rough number-grey correlation TOPSIS evaluation model constructed in this paper is relatively insensitive to the change of evaluation index weights, which verifies the stability of the green supplier evaluation model constructed in this paper.

5. Discussion

With China's determination to achieve the "30–60″ target of carbon neutrality, the importance of green development in economic growth has been increasing, and higher requirements have been put forward for the operation and development of enterprises. As the unit production is accompanied by more energy consumption, the risks and possibilities of environmental pollution caused by the operations of high-energy-consuming enterprises increase. Therefore, it is crucial to promote the green development of high-energy-consuming enterprises in their production and operation. This study focuses on the evaluation of green suppliers for high-energy-consuming enterprises, which can helps to reduce or control the degree of environmental pollution caused by the production and operation of high-energy-consuming enterprises at the source of the supply chain, and contributes to achieving China's goals of "zero carbon" and "carbon neutrality".

From the existing research results, the current research on supplier evaluation lacks a focus on high-energy-consuming enterprise suppliers; in terms of research methods, there is little attention to the handling of uncertain information, and the existing methods for handling uncertain information are mainly based on fuzzy theory. They focus on the interference of uncertain information on weighting and evaluation results in multi-criteria decision-making processes and use fuzzy theory to improve the weighting or evaluation process, such as fuzzy TOPSIS evaluation [37], SWARA-TOPSIS [38], and intuitionistic fuzzy TOPSIS [39]. However, the application of fuzzy theory in evaluation research has drawbacks such as subjectivity, difficulty in operation, and weak interpretability. On the other hand, rough set theory can address these limitations in evaluation research.

In this study, a green supplier evaluation index system focused on the needs of suppliers in the high-energy-consuming industry was constructed by integrating literature analysis, statistical analysis, and expert interviews. Additionally, rough set theory was introduced into the green supplier evaluation selection process to improve the handling of uncertain semantic information in the indicator weights and evaluation process. The evaluation model constructed using rough number-grey correlation TOPSIS is effective and stable for evaluating green suppliers for high-energy-consuming enterprises.

6. Conclusion

In terms of constructing the evaluation index system, this study comprehensively considered the needs of supplier evaluation and the characteristics of high-energy-consuming enterprises. By using literature research, statistical analysis, and expert interviews, a total of 32 evaluation indicators were selected to construct a green supplier evaluation index system for high-energy-consuming enterprises. In addition, this study used the supplier evaluation data of L company for reliability testing. The results showed that by incorporating 11 green supply capacity evaluation indicators such as "green product certification" and "purification facilities" into the supplier evaluation index system, a reliable green supplier evaluation index system for high-energy-consuming enterprises can be constructed, providing a basis for green supplier evaluation and selection.

Moreover, empirical research results have demonstrated that by using rough set-weighting methods and weighting indicators based on the scores assigned by decision-makers for the importance of evaluation indicators, the evaluation purpose and intention of the decision-makers can be effectively preserved. This method also considers the intrinsic relationship among different evaluators' importance evaluations of indicators, reduces the influence of individual evaluator's subjective bias on the weight results, and ensures the accuracy and completeness of the weight results. Furthermore, by combining rough set theory with the grey correlation-TOPSIS method, it is possible to improve the scientificity and practicality of the evaluation model, by enhancing the way uncertain information during the evaluation process is handled. Empirical research results have shown that the rough set-grey correlation-TOPSIS evaluation model maintains stability in the evaluation results under the conditions of adjusting risk preferences and changing indicator weights.

This paper has improved the evaluation process of green suppliers for high-energy-consuming enterprises; however, there are still some shortcomings that need to be further improved. Future research on green suppliers in high-energy-consuming industries can be combined with the type and characteristics of the products to be purchased (such as raw materials and equipment) to further supplement and improve the evaluation index system. On the other hand, this paper's evaluation model only focuses on improving the way uncertain semantic information is processed, but not on other types of uncertain information processing in the evaluation. Moreover, the information aggregation method for group decision-making needs to be further optimized in future research.

Data availability statement

All data are included in the article and its supplementary information files.

CRediT authorship contribution statement

Xiaoxi Wang: Conceptualization, Methodology, Validation, Visualization, Writing – original draft. **Zhangfan Liu:** Formal analysis, Methodology, Writing – original draft, Writing – review & editing. **Haining Kong:** Project administration, Writing – original draft, Writing – review & editing. **Geng Peng:** Data curation.

Declaration of competing interest

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

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e21700.

References

[1] F. Li, L. Deng, L.X. Li, Z.Z. Cheng, H. Yu, A two-stage model for monitoring the green supplier performance considering dual-role and undesirable factors, Asia Pac, J. Mark. Logist. 32 (2020) 253–280.
[2] H.T. Wu, Y.W. Li, Y. Hao, S.Y. Ren, P.F. Zhang, Environmental decentralization, local government competition, and regional green development: evidence from China, Sci. Total Environ. 708 (2020).
[3] J.W. Xu, Y.B. Yu, Y. Wu, J.Z. Zhang, Y.L. Liu, Y.H. Cao, P. Eachempati, Green supply chain management for operational performance: anteceding impact of corporate social responsibility and moderating effects of relational capital, J. Enterp. Inf. Manag. 35 (2022) 1613–1638.
[4] K. Wang, H. Liu, L. Liu, J. Huang, Green supplier evaluation and selection using Cloud model theory and the QUALIFLEX method, Sustainability 9 (2017) 688.
[5] X. Li, D. Liu, Z. Zhang, T. Cheng, L. Liu, J. Yuan, The impact of internal and external green supply chain management activities on performance improvement: evidence from the automobile industry, Heliyon 8 (2022), e11486.
[6] N. Yusof, A. Tabassi, M. Esa, Going beyond environmental regulations-The influence of firm size on the effect of green practices on corporate financial performance, Corp. Soc. Responsib. Environ. Manag. 27 (2020) 32–42.
[7] G. Noci, Designing 'green' vendor rating systems for the assessment of a supplier's environmental performance, Eur. J. Purch. Supply Manag. 3 (1997) 103–114.
[8] C. Garg, A. Sharma, G. Goyal, A hybrid decision model to evaluate critical factors for successful adoption of GSCM practices under fuzzy environment, Uncertain, Supply Chain Manag. 5 (2017) 59–70.
[9] R. Vanalle, G. Ganga, M. Godinho Filho, W. Lucato, Green supply chain management: an investigation of pressures, practices, and performance within the Brazilian automotive supply chain, J. Clean. Prod. 151 (2017) 250–259.

[10] A. Çalık, A novel Pythagorean fuzzy AHP and fuzzy TOPSIS methodology for green supplier selection in the Industry 4.0 era, Soft Comput. 25 (2021) 2253–2265.
[11] S. Haeri, J. Rezaei, A grey-based green supplier selection model for uncertain environments, J. Clean. Prod. 221 (2019) 768–784.
[12] A. Fallahpour, E. Olugu, S. Musa, D. Khezrimotlagh, K. Wong, An integrated model for green supplier selection under fuzzy environment: application of data envelopment analysis and genetic programming approach, Neural Comput. Appl. 27 (2016) 707–725.
[13] S. Harridan, A. Cheaitou, Supplier selection and order allocation with green criteria: an MCDM and multi-objective optimization approach, Comput. Oper. Res. 81 (2017) 282–304.
[14] G. Vorosmarty Dobos, Green supplier selection and evaluation using DEA-type composite indicators, Int. J. Prod. Econ. 157 (2014) 273–278.
[15] S. Gupta, U. Soni, G. Kumar, Green supplier selection using multi-criterion decision making under fuzzy environment: a case study in automotive industry, Compu. Ind. Eng. 136 (2019) 663–680.
[16] J. Liou, Y. Chuang, E. Zavadskas, G. Tzeng, Data-driven hybrid multiple attribute decision-making model for green supplier evaluation and performance improvement, J. Clean. Prod. 241 (2019).
[17] A. Afful-Dadzie, E. Afful-Dadzie, C. Turkson, A TOPSIS extension framework for re-conceptualizing sustainability measurement, Kybernetes 45 (2016) 70–86.
[18] S. Tsai, Y. Wei, K. Chen, L. Xu, P. Du, H. Lee, Evaluating green suppliers from a green environmental perspective, Environ. Plann. B Plann. Des. 43 (2016) 941–959.
[19] S. Zakeri, M. Keramati, Systematic combination of fuzzy and grey numbers for supplier selection problem, Grey Syst. Theory Appl. 5 (2015) 313–343.
[20] P. Humphreys, Y. Wong, F. Chan, Integrating environmental criteria into the supplier selection process, J. Mater. Process. Technol. 138 (2003) 349–356.
[21] G. Buyukozkan, G. Cifci, A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers, Expert Syst. Appl. 39 (2012) 3000–3011.
[22] L. Shen, L. Olfat, K. Govindan, R. Khodaverdi, A. Diabat, A fuzzy multi criteria approach for evaluating green supplier's performance in green supply chain with linguistic preferences, Resour. Conserv. Recycl. 74 (2013) 170–179.
[23] A. Sanayei, S.F. Mousavi, A. Yazdankhah, Group decision making process for supplier selection with VIKOR under fuzzy environment, Expert Syst. Appl. 37 (2010) 24–30.
[24] A.K. Kar, A hybrid group decision support system for supplier selection using analytic hierarchy process, fuzzy set theory and neural network, J. Comput. Sci. 6 (2015) 23–33.
[25] C.W. Hsu, T.C. Kuo, S.H. Chen, A.H. Hu, Using DEMATEL to develop a carbon management model of supplier selection in green supply chain management, J. Clean. Prod. 56 (2013) 164–172.
[26] X.Y. You, J.X. You, H.C. Liu, L. Zhen, Group multi-criteria supplier selection using an extended VIKOR method with interval 2-tuple linguistic information, Expert Syst 42 (2015) 1906–1916.
[27] C.Y. Wang, S.M. Chen, Multiple attribute decision making based on interval-valued intuitionistic fuzzy sets, linear programming methodology, and the extended TOPSIS method, Inf. Sci. 397 (2017) 155–167.
[28] K. Shaw, R. Shankar, S.S. Yadav, L.S. Thakur, Supplier selection using fuzzy AHP and fuzzy multi-objective linear programming for developing low carbon supply chain, Expert Syst. Appl. 39 (2012) 8182–8192.
[29] H. Shi, M.Y. Quan, H.C. Liu, C.Y. Duan, A novel integrated approach for green supplier selection with interval-valued intuitionistic uncertain linguistic information: a case study in the Agri-Food industry, Sustainability 10 (2018).
[30] M. Yazdani, P. Chatterjee, E.K. Zavadskas, S. Hashemkhani Zolfani, Integrated QFD-MCDM framework for green supplier selection, J. Clean. Prod. 142 (2017) 3728–3740.
[31] C. Bai, J. Sarkis, Green supplier development: analytical evaluation using rough set theory, J. Clean. Prod. 18 (2010) 1200–1210.
[32] Z. Chen, P.S. Zhong, M. Liu, Q. Ma, G.Y. Si, An integrated expert weight determination method for design concept evaluation, Sci. Rep. 12 (2022) 6358.
[33] G. Odu, Weighting methods for multi-criteria decision making technique, J. Appl. Sci. Environ. Manage. 23 (2019) 1449–1457.
[34] F. Pulansari, A. Putri, Green Supply Chain Operation Reference (Green SCOR) performance evaluation (case study: steel company), J. Physics: Conf. Ser. 1569 (2020), 032006.
[35] Q. Zhang, H. Shen, Y. Huo, An evaluation model of green coal supplier for thermal power supply chain based on PCA-SVM, Math. Probl Eng. (2021) 1–8.
[36] F.S. Garzon, M. Enjolras, M. Camargo, L. Morel, A green procurement methodology based on Kraljic matrix for suppliers evaluation and selection: a case study from the chemical sector, Supply Chain Forum Int. J. 20 (2019) 185–201.
[37] B.M. Dos Santos, L.P. Godoy, L.M. Campos, Performance evaluation of green suppliers using entropy-TOPSIS-F, J. Clean. Prod. 207 (2019) 498–509.
[38] S. Akcan, M.A. Taş, Green supplier evaluation with SWARA-TOPSIS integrated method to reduce ecological risk factors, Environ. Monit. Assess. 191 (2019) 1–22.
[39] B.D. Rouyendegh, A. Yildizbasi, P. Üstünyer, Intuitionistic fuzzy TOPSIS method for green supplier selection problem, Soft Comput. 24 (2020) 2215–2228.