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Research Article

Exploiting GWmZd Model by Exploring Knowledge-Based Grey-Holistic Technique for Sustainable Vendor Evaluation

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It is investigated that the thoughts of sustainability gained the momentum among researchers in the present era. The industrial empirical research survey proved that green operations, waste minimization strategies, and zero defect planning are three potential pillars in mapping the sustainability of supplier/vendor units. The authors built and proposed a grey knowledge-based green-waste minimizing and zero defect (GWmZd) sustainability appraisement hierarchical structural evaluation model/framework to production companies for assessing the sustainability ratio of their candidate suppliers/partners. Due to the uncertainty associated with the measures and metrics of the proposed model, the incomplete information is procured from a cluster of professionals' vs GWmZd measures and metrics in the terms of the grey (except fuzzy) set. It is sensed by the prior literature survey that a few grey knowledge-based sustainability model are framed, but they were constrained to the individual first level layer without weight evaluation cum noncomparative analysis-based modern technique, and it is respected as a major research gap and challenge. To compensate the major research gap, the authors elected AHP and enabled AHP (analytic hierarchy process) to materialize and aggregate the assigned rating of each expert for evaluating weights of 2^{nd} level metrics (overcoming the drawback of combined/group ratings). Later, the authors structured and proposed a new mathematical equation, assisted authors to evaluate the global weight of the first layer-three pillars-measures of the proposed model. Eventually, the authors constructed and fruitfully implemented a grey-holistic technique (merger of grey-MOORA-FMF fused with the dominance theory) on the model to compute sustainability index and score of suppliers. A production company is investigated to exhibit the application of the research work practically. The sustainability of supplier A_1 is found the best than the residue of suppliers. The research forum can be explored by production companies to opt the feasible supplier under the proposed model. The conducted research has a value across the global production companies. The research forum can be explored by managers of production companies for benchmarking the performance of global suppliers under GWmZd and future advancing models along with grey-holistic technique fused with the dominance theory.

1. Introduction of Sustainability

The application of technological and performance measurement tools towards attaining the green-lean-economic architectures in vendor units is called as vendor sustainability. The vendor firms can gain the sustainability if firms preserve the cost-effective and best practices/processes, i.e., green, waste minimizing, and zero defects planning across production measures practices, as these practices holistically enable the vendor organizations sustainable at the global platform. It is sensed that numerous vendor organizations attain the sustainability by minimizing miscellaneous wastes, preserving the best green performance, and maintaining economic tradeoffs in their production units in the present era. It is ascertained by the literature survey that advancement in metrics-practices of the green-waste minimizing and zero defect (GW_MZ_D) model advise the production companies to materialize the sustainability of vendor organizations, where the green measure stimulate the vendor companies to preserve the green manufacturing via ramping up the renewable energies utilization, abasing hazard materials byproducts, and recycling of waste water [1–3]. Next, minimization of waste leads to lean manufacturing and eradicate the vendor companies for reducing multiple wastes, i.e., idle time, over processing, unwanted production, and unnecessary movement. Zero defects planning instructs the vendor companies to trim down the defective products, salvaging, and reworks and leads in reducing the cost of the quality. Figure 1 shows the GWmZd model whose base pillars were taken from the manuscript published by [4].

1.1. Green Practice, Waste Minimization, and Zero Defects Concept. Green practice/measure aids the industrialists to eliminate the causes of carbon attacks, minimization of ill-biological particles, fossil fuels, hazard particles, ill-particles, and toxic gasses. Green practice/measure is utilized in the present era as it is considered as a leading competitive strategy to overcome the trust of product consumers. Green practice/measure can be attained by vendor firms by pursuing, such as advanced practices-metrics, i.e., renewable energy process, recycling of waste and hazard materials, and recycling of waste water. A green practice is a procedure to eliminate the amount of many wastes, which are produced during the production. In vendor firms, green practice is used as an effective process for butchery the waste production. Waste can be minimized if vendor firms pursue, such as advanced green metrics-practices, i.e., over processing, most excellent production, and effective movement.

Waste minimization refers to the lean manufacturing strategy, whose objective is the use of economic sources and recycling methods prior to disposal of the wastes. As per the United Nations Green Programme (UNGP), waste minimization refers a strategy that has the aim to prevent waste via upstream interventions. In case of production in vendor firms, these strategies are focusing the on optimizing resource and energy use and lowering toxicity levels during the manufacturing time. Strategies are considered to minimize waste and thus improve resource efficiency before the manufacturing process, i.e., product design, cleaner production, reuse of scrap material, improved quality control, and waste exchanges. Recently, it is observed that minimization of waste does not only eliminate the waste such as idle time, over processing, unwanted production, and unnecessary movement (aids to economic production) but also preserve the healthy green environment, resulting in higher productivity. Minimization of waste helps the vendor firms to achieve sustainability.

Zero defects motivate the vendor firms for abolishing the wastes at first (that leads to cost reduction). Thus, zero defects leads to waste reduction along with cost cutting. All these processes improve the services and therefore, make customer pleasure. Zero defects can be attained by stimulating the vendor firm for pursuing, such as advanced metrics-practices, i.e., elimination of manufacturing of

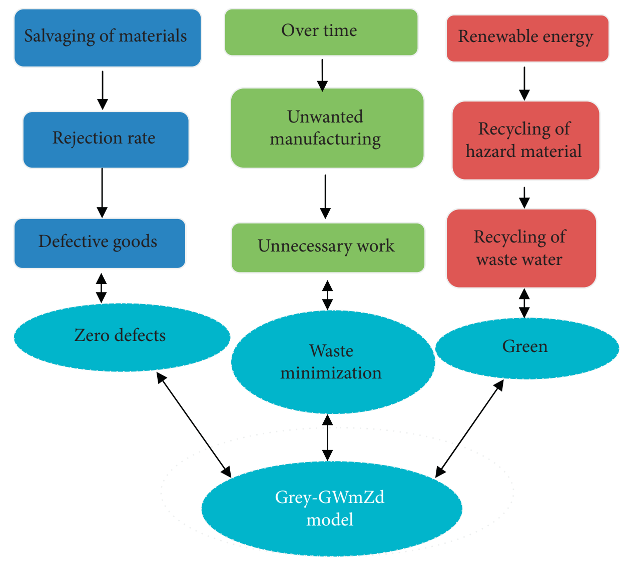

Figure 1: Grey-GWmZd sustainably model.

defective products, meager rejection of goods, and minimization of reworking and salvaging.

2. Literature Survey

Literature survey is conducted into two parts: in the first part, the literature survey is conducted in the context of green manufacturing, waste minimization, and zero defects philosophies for structure and framing the model.

Later, the literature survey is conducted in extant of the multiobjective optimization MOORA methods and grey set theory and their application towards measuring the sustainability of production and vendor firms.

2.1. Part: I

2.1.1. Literature Survey is Conducted in the Context of Green Manufacturing. In [5], the author said that the green stressors may be responsible for protecting the quality and quantity of freshwater resources. Reference [6] articulated an innovative green regulation, which was integrated with licensed Ireland's pharmaceutical manufacturing sector as a part of the case study. In [7], the authors stated that green audit is a management tool, which provides a structure and comprehensive mechanism for ensuring that the goods of an enterprise do not cause unacceptable effects on the atmosphere. Reference [8] proposed a model for appraising the worth of sustainable material providers. The expert's method was applied to distinguish the criterion for assessing the performance of traditional material providers and sustainable material providers. Reference [9] stated that green is a major source of greenhouse gas emissions (55%).

Reference [10] defined that an idea of sustainability can be built by optimizing the link among global society and its natural atmosphere, taking into account society's social, economic, and green chains. In [11], the authors stated that sustainability is an important goal such as promoting economic development, decreasing poverty, and improving quality. The green agenda is a necessary part of holistic, city-led strategies for economic, social, and green sustainability. In [12], the authors stated that green sustainability added the green value in the growing proportion of the world's population, lives in cities. Reference [13] proposed the sustainability tool to aware about the status of sustainability development in organizations by dimensions such as green, social, and economic. In [14], the authors proposed a double layers green supply chain efficient appraisement model for benchmarking the green alternative suppliers. A triangular fuzzy sets theory is used to handle vagueness of the supplier's model and select the most significant supplier. In [15], the authors determined during the case study of coal enterprises of China that various driving mechanisms, i.e., government regulations, enterprise resource capability, and supply chain, aid the global industries to attain the green innovation. Reference [16] developed a multiobjective decision-making hierarchical model, which integrated the forward and reverse logistics in objective to reduce the recycling and manufacturing costs in industries. Reference [17] investigated the united green innovation policy and pricing strategies in a remanufacturing system to attract the huge customers. In [18], the authors investigated the GSC as retailer's strategy. It is ascertained that GSC aids the retailer to improve their retail profit with poor promotional efforts.

2.1.2. Literature Survey is Conducted in the Context of Waste Minimization Manufacturing. Reference [19] explained the principles and conceptions of reuse aspects in case studies of Ecosan in developing countries. Reference [20] outlined the nature of the wastes, waste generating industries, waste characterization, health and green implications of wastes management practices, steps towards planning, design and development of models for effective hazardous waste management, treatment, approaches, and regulations for disposal of hazardous waste. Evaluation of the entire situation with reference to Indian scenario has attempted in order that a better cost-effective strategies for waste management be evolved in future. Reference [21] developed a green vendor selection model, which is solved by application of the artificial neural network (ANN) with two more multiattribute judgment analyses (MAJA) techniques such as data envelopment analysis (DEA) and the analytic network process (ANP) [22]. Industry is a chief consumer of natural resources and a major donor to the overall pollution load. As per organization for economic cooperation and development, it accounts for about one-third of global energy consumption of their member states and for about 10% of the total water withdrawal. The relative contribution to the total pollution load is obviously higher for industry-related pollutants, i.e., organic substances, sulfur dioxide, particulates, and nutrients. In [23], the authors said that lean and agile indicators can be jointed within supply chain. The authors also said that combining agility and leanness in one supply chain via the strategic utility of a decoupling point is called as legality. The legality model can be constructed in future. Reference [24] applied a fuzzy-based quality function deployment (QFD) on lean SC. A case study was conducted out in an Indian electronics switches manufacturing organization. The applied techniques were found so effective in the recognition of lean indicators, lean decision domains, lean attributes, and lean enablers for the business. Reference [25] proposed an agility lean model to evaluate the agility and leanness of an individual firm. The model consisted of a set of agile and lean supply chain practices integrated in an assessment model. Reference [26] estimated the leanness of a manufacturing firm in a fuzzy context. Various leanness indicators have been considered in order to measure the performance of the manufacturing firm by using the concept of the trapezoidal fuzzy number set [27]. Waste minimization is one of the strategies, adopted for minimizing the industrial pollution. The objective of the scheme is to assist the small and medium scale industry in adoption of cleaner production practices.

2.1.3. Literature Survey is Conducted in the Context of Zero Defect (Six Sigma) Philosophy. In [28], zero defects philosophy is a thought that gained its focus from 1960s. It is a programme to take away defects from the industrial production and was primarily intended for automobile production [29]. Zero defects (ZDs) philosophy is a management tool, which has the aim to reduce the defects through preventions. Vendor firm's employees are directed to prevent mistakes by developing a constant, conscious desire to do their job right the first time. In [30], the Six Sigma tools have aims to process the best product quality. Six Sigma tools is the need of organization to build customized products. Reference [31] conducted a systematic review on Lean Six Sigma and found that the environmental (green) is the best method for improving the quality in manufacturing operations. Reference [32] investigated the application of Lean Six Sigma (LSS) tools in food processing industries. It is evaluated that LSS impact on environmental sustainability. Reference [33] proposed an integrated DEA technique with the Six Sigma projects evaluation model for selecting Six Sigma projects. The findings demonstrated that selected projects confirmed expert opinions. Reference [34] evaluated the university leadership performance by using the Lean Six Sigma (LSS) framework. Reference [35] constructed a structural measurement model by creating a link between Lean Six Sigma (LSS) and sustainable manufacturing strategies. Next, structural equation modeling technique is applied to validate the existing links.

2.2. Part: II

2.2.1. Literature Survey is Conducted in Extant of the Multiobjective Optimization MOORA-FMF Methods. Reference [36] explored the multiobjective optimization by ratio analysis (MOORA) technique for project management in a transaction economy. Reference [37] explored the MOORA technique to solve the inner climate problems. Reference [38] proposed the MOORA method to solve many economic, managerial, and construction problems. Reference [39] employed the MOORA method to define the economic policy for balanced regional development in

Lithuania. Reference [40] applied the MOORA method in the construction field to solve the problems related to energy loss in heating buildings. Reference [41] explored the MOORA method to solve different decision-making problems in the real-time manufacturing green. Six decision-making problems are solved. Reference [42] presented the extended MOORA method for solving decision-making problems with interval data to determine the most preferable alternative among possible alternatives. Reference [43] extended the MULTIMOORA method with type-2 grey sets for solving the personnel selection problem under uncertain assessments.

2.2.2. Grey System Application towards Achieving the Sustainability. Reference [44] utilized the grey set and rough set theory towards integrating the sustainability with the vendor selection procedure. Reference [45] compared conventional statistical tools with the grey system theory and declared the three superiorities of the grey system theory, i.e., (a) provides easy calculation, (b) requires few sample size, and (c) has an exact accuracy for prediction. Reference [46] proposed an efficient grey TOPSIS and grey COPRAS methodology with the vendor appraisement platform for vendor evaluation under green concerns. Reference [47] utilized the grey sets theory with integrated MULTIMOORA to benchmark the CNC machine tool under CNC machine tool evaluation criteria. Reference [48] suggested the outline of the grey set so that an upcoming researcher might use the concept for decision-making. Reference [49] extended the application of the grey theory in many decision-making problems. In [50], the authors applied the grey system theory with the expert panel method to set up evaluation index for the material provider. The performance of mass production by Commercial Aircraft Corporation of China Ltd (COMAC) was measured. Reference [51] proposed a fractional reverse accumulative grey Verhulst model to enhance the model stability and improve the prediction accuracy in responding to the characteristics of information on the test. In [52], the authors proposed a fractional order reverse accumulation generation gm model and revealed its applications in solving industrial problems. Reference [53] presented a new ranking method to determine the ranking order of the professionals. The authors built a novel graph model with grey information to solve equilibrium states and decision paths problem. In [27], the authors proposed a QFD network for the early design of a complex product, which demonstrated the top-down decomposition design process. Moreover, an uncertain multilevel programming model and its algorithm are proposed to aid the designers to get an optimal solution. Reference [54] described the way to control and utilize the grey system theory under lack of information or incomplete information. Reference [55] utilized grey concepts and the corresponding theories to develop a multiobjective grey wolf optimizer for handling multiple objectives optimization problems. Reference [56] presented the grey DEMATEL approach to identify and evaluate criterions and alternatives under incomplete information.

3. Motivation to Conduct Research Work, Especially for Sustainability

Sustainability is a thought, which mainly focuses to minimize the industrial wastes by ramping up the quality across processes with green and zero defects planning schemes and concerns. Sustainability can be attained via increasing the renewable energy processes, recycling of waste and hazard materials, recycling of waste water, over processing, most excellent production, effective movement, elimination of manufacturing of defective products, meager rejection of goods, and minimization of reworking. The sustainability assessment of supplier organizations must be carried out by production companies if production companies desire to sustain at global market for a long period of time [6, 9, 12, 22].

(i) Recently, it is virtually investigated that previous authors proposed a single and a few double layers sustainability assessment hierarchical structural model in addressing fuzzy ratings-based simulation techniques such as TOPSIS, PROMATHEE, SAW, VIKOR, and MLMCDM for assessing sustainability of vendor firm alternatives. A few authors attempted for grey ratings evaluation techniques, but they were capable to solve only the single layer sustainability assessment hierarchical structural model. Aforesaid gaps are probed as a first research gap.

(ii) It is also observed and probed by authors, especially focusing over the model structure and framing embedded with measures/metrics that previous researchers introduced ordinary measures practices and its interrelated metrics such as economic and employee retention in framing sustainably-based models (except focusing over the green, minimization of waste, and zero defect measures practices with their interrelated metrics in inducing into the model), and it is noticed as a second research gap.

(iii) Furthermore, the authors observed via the same literature survey that a few proposed sustainability-based hierarchical structural models are facilitated with crisp AHP technique, but AHP was capable to tackle only fused or combined ratings (except individual rating of each member). Next, the crisp AHP weight evaluation method application is observed accompanied with single TOPSIS, PROMATHEE, SAW, VIKOR, and MLMCDM ratings evaluation techniques under only the fuzzy set (except grey set), for assessing sustainability of vendor firm alternatives is found as the third research gap.

(iv) There are no weight evaluation mathematical formulas, which can be used to calculate the weight of measures from metrics data (calculated by the AHP), and it is respected as a forth research gap.

(v) The authors had no research evidence pertaining to grey-based holistic-robust technique that can deliver accurate results as reliability of decision is a big concern, and it is respected as the fifth research gap.

The aforesaid grounds motivated authors to develop the multilevel knowledge-based GWmZd sustainability appraisement hierarchical structural evaluation model, with introducing AHP with new weights, and global weight mathematical formula, with grey set-based holistic technique embedded with the dominance approach to compensate all research gaps.

4. Grey-Holistic Approach with AHP

4.1. Analytic Hierarchy Process (AHP). Analytic hierarchy process (AHP) is one of the multipractices decision-making techniques. In short, it is a technique to derive ratio scales from paired comparisons [57, 58]. The input can be obtained from the actual measurement such as price and weight or from the subjective opinion such as satisfaction feelings and preference. AHP allows some small inconsistency in judgment because human is not always consistent. The ratio scales are derived from the principal eigenvectors, and the consistency index is derived from the principal eigen value.

It is a tool used for solving complex decision problems to evaluate many dilemma in different areas of human requirements, such as political, financial, and various others different interests. The AHP provides a comprehensive and rational framework to help managers set priorities and make the best decision when both qualitative and quantitative aspects of a decision need to be considered. In conventional AHP, the pairwise comparison is established using a scale which converts the human preferences between available alternatives. Even though the discrete scale of AHP has the advantages of simplicity and ease of use, it is not sufficient to take into account the uncertainty associated with mapping of one's perception to a number. However, due to vagueness and uncertainty in the decision maker's judgment, a crisp, pairwise comparison with a conventional AHP may be unable to accurately capture the decision maker's judgment.

Definition 1. Consistency of the pairwise comparison matrix [57].

In the classical AHP, we consider an $n \times n$ a pairwise comparison matrix A with positive elements, such that

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & 1 \end{bmatrix}. \quad (1)$$

This matrix is reciprocal if $a_{ij} = 1/a_{ji}$, for each $1 \le i, j \le n$.We say that A is consistent if

$$a_{ij} * a_{jk} = a_{ik}, \quad \text{for each } 1 \le i, j, k \le n. \quad (2)$$

From the geometrical means, the relative normalized weights of each attributes/criterions can be calculated by normalizing the geometrical means of raw in the comparison matrix. This can be presented in equations (1) and (2); the geometric means method of the AHP is explored to find out the relative normalized weights of the criterion due to its simplicity and easiness to find out the maximum eigen value and to reduce the inconsistency in judgment.

$$A_1 = \left[b_{ij}\right], \quad (3)$$

$$\text{GM} = \left[\prod_{j=1}^{n} b_{ij}\right]^{1/M}, \quad (4)$$

$$A_2 = W_j = \frac{\text{GM}}{\sum_{j=1}^{n} \text{GM}_j}.$$

$$\text{Calculation of matrices } A_3 \text{ and } A_4 \text{ such that } A_3 = A_1 \times A_2 \text{ and } A_4 = \frac{A_3}{A_2}, \quad (5)$$

$$\text{where } A_2 = \left[w_1, w_2, w_3, \dots, w_j\right]^T, \text{and } A_i \text{ is a decision matrix.}$$

Determine the maximum eigen value ($\lambda_{\max}$), i.e., the average of matrix A_4.

Consistency index is evaluated by the following equation:

$$\text{Consistency index (CI)} = \frac{\text{Principle eigen value} - \text{size of the matrix}}{\text{Size of the matrix} - 1} = \frac{\lambda_{\max} - \text{n}}{\text{n} - 1}. \quad (6)$$

For the index of consistency for random judgments, Saaty [57] defined the consistency ratio (CR) as

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}, \tag{7}$$

where RI is chosen by the matrix size using the Saaty [58] (Table 1)

4.2. Global Weights Equation [46].

$$\sum_{i=1}^{n} w_i = 1, \quad w_i = w_1, w_2, w_3, \ldots, j = n. \tag{8}$$

4.3. Theory of Grey Numbers: Mathematical Basis. Grey theory has become a very effective method of solving uncertainty problems under discrete data and incomplete information. Grey theory has now been applied to various areas such as forecasting, system control, and decision-making and computer graphics. Here, we give some basic definitions regarding the relevant mathematical background of the grey system, grey set, and grey number in the grey theory [27, 44, 46, 47, 59, 60].

Definition 2. A grey system is defined as a system containing uncertain information presented by grey numbers and grey variables

Definition 3. Let X be the universal set. Then, a grey set G of X is defined by its two mappings:

$$\begin{cases} \overline{\mu}_G(x)\colon x \longrightarrow [0,1], \\ \underline{\mu}_G(x)\colon x \longrightarrow [0,1]. \end{cases} \tag{9}$$

$\overline{\mu}_G(x) \geq \underline{\mu}_G(x)$, $x \in X$, $X = R$, $\overline{\mu}_G(x)$, and $\underline{\mu}_G(x)$ are the upper and lower membership functions in G, respectively. When $\overline{\mu}_G(x) = \underline{\mu}_G(x)$, the grey number G becomes a grey set. It shows that the grey theory considers the condition of fuzziness and can flexibly deal with the fuzziness situation

Definition 3. Definition 4A grey number is one of which the exact value is unknown, while the upper and/or the lower limits can be estimated. Generally grey number is written as $(\otimes G = G|_{\underline{\mu}}^{\overline{\mu}})$

Definition 5. If only the lower limit of G can be possibly estimated and G is defined as the lower limit grey number,

$$\otimes G = [\underline{G}, \infty]. \tag{10}$$

Definition 6. If only the upper limit of G can be possibly estimated and G is defined as the upper limit grey number,

$$\otimes G = [\infty, \overline{G}]. \tag{11}$$

Definition 7. If the lower and upper limits of G can be estimated and G is defined as the interval grey number,

$$\otimes G = [\underline{G}, \overline{G}]. \tag{12}$$

Definition 8. The basic operations of grey numbers $\otimes x_1 = [\underline{x}_1, \overline{x}_1]$ and $\otimes x_2 = [\underline{x}_2, \overline{x}_2]$ can be expressed as follows:

$$\left.\begin{aligned} &\otimes x_1 + \otimes x_2 = [\underline{x}_1 + \underline{x}_2, \overline{x}_1 + \overline{x}_2] \\ &\otimes x_1 - \otimes x_2 = [\underline{x}_1 - \overline{x}_2, \overline{x}_1 - \underline{x}_2] \\ &\otimes x_1 \times \otimes x_2 = \mathrm{Min}[\underline{x}_1\underline{x}_2, \underline{x}_1\overline{x}_2, \overline{x}_1\underline{x}_2, \overline{x}_1\overline{x}_2], \mathrm{Max}[\underline{x}_1\underline{x}_2\underline{x}_1\overline{x}_2, \overline{x}_1\underline{x}_2, \overline{x}_1\overline{x}_2] \\ &\frac{\otimes x_1}{\otimes x_2} = [\underline{x}_1, \overline{x}_1] \times \left[\frac{1}{\underline{x}_2}, \frac{1}{\overline{x}_2}\right] \end{aligned}\right\}. \tag{13}$$

Whitened value: The whitened value of an interval grey number, $\otimes x$, is a deterministic number with its value lying between the upper and lower bounds of interval $\otimes x$. For a given interval grey number $\otimes x = [\underline{x}, \overline{x}]$, the whitened value $x_{(\lambda)}$ can be determined as follows [44, 46, 47, 50].

$$x_{(\lambda)} = \lambda\,\underline{x} + (1-\lambda)\overline{x}, \tag{14}$$

where λ is the whitening coefficient, and $\lambda \in [0,1]$. Because of its similarity with a popular λ function, formula (15) is often shown in the following form:

$$x_{(\lambda)} = (1-\lambda)\,\underline{x} + \lambda\overline{x}. \tag{15}$$

For $\lambda = 0.5$, formula (16) gets the following form:

Table 1: The value of random consistency index.

M	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

$$x_{(\lambda=0.5)} = \frac{1}{2}\left(\underline{x} + \overline{x}\right). \tag{16}$$

Signed distance: let $\otimes x_1 = [\underline{x}_1, \overline{x}_1]$ and $\otimes x_2 = [\underline{x}_2, \overline{x}_2]$ be two positive interval grey numbers. Then, the distance between $\otimes x_1$ and $\otimes x_2$ can be calculated as a signed difference between its centers as shown in the following equation:

$$\begin{aligned} d(\otimes x_1, \otimes x_2) &= \frac{\underline{x}_1 + \overline{x}_1}{2} - \frac{\underline{x}_2 + \overline{x}_2}{2} \\ &= \frac{1}{2}\left[\left(\underline{x}_1 - \underline{x}_2\right) + \left(\overline{x}_1 - \overline{x}_2\right)\right]. \end{aligned} \tag{17}$$

4.4. Evaluation of Rating from 2nd to 1st Level [46].

$$\mathbf{R} = (\otimes r_i)_{m\times n} = \frac{\otimes r_{ik1} + \otimes r_{ik2} + \otimes r_{ik3} + \otimes r_{ik4} + \otimes r_{ik5} + \otimes r_{ik6}, \ldots, \otimes r_{ikn}}{C_{ikn}}. \tag{18}$$

By using equation (18), denominator $\mathbf{R} = (\otimes r_j)_{m\times n}$, the computed i^{th} rating of 1^{st} level measures vs alternatives j^{th}, can be computed on availing assigned ratings data of 2^{nd} level metrics$(\otimes r_{ik})$. C_{ikn} is the number of metrics that are aligned with its father measure.

4.5. The MOORA Technique. Multiobjective optimization by ratio analysis (MOORA) method is introduced by [37–39, 41, 42] on the basis of previous research studies. The method starts with a matrix of responses of different alternatives on different objectives:

$$X = \left[x_{ij}\right]_{m\times n}, \tag{19}$$

wherex_{ij} is the response of alternative j on objective or attribute$i$; $j = 1, 2, \ldots, m$ is the alternative; and $i = 1, 2, \ldots, n$ is the attribute.

The MOORA method consists of two parts: the ratio system and the reference point approach [38].

4.5.1. The Ratio System Approach of the MOORA Method. Reference [42] proved that the most robust choice for the denominator is the square root of the sum of squares of each alternative per objective, and therefore, the use of the vector normalization method is recommended in order to normalize responses of alternatives. As a result, the following formula is obtained:

$$x_{ij}^* = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x_{ij}^2}}, \tag{20}$$

where x_{ij} is the response of alternative j on objective or attribute i; $j = 1, 2, \ldots, m$ is the number of alternatives; $i = 1, 2, \ldots, n$, where n is the number of objectives; x_{ij}^* is the normalized response of alternative i on objective j; and $x_{ij}^* \in [0, 1]$.

Let $W = (w_1, w_2, \ldots, w_n)$ be the relative weight vector about the practices, evaluated by grey AHP satisfying $\sum_{i=1}^{n} w_i = 1$.

$$\widetilde{R} = \left(\widetilde{r}_{ij}\right)_{m\times n} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccccc} c_1 & c_2 & \cdots & \ldots\ldots & c_n \end{array} \\ \begin{bmatrix} x_{11}^* & x_{12}^* & \cdots & x_{1n}^* \\ x_{21}^* & x_{22}^* & \ldots & x_{2n}^* \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1}^* & x_{m2}^* & \ldots & x_{mn}^* \end{bmatrix} \end{array}. \tag{21}$$

Calculate the weighted normalized decision matrix.

$$v = (v_{ij})_{mn},$$

$$\begin{aligned} \widetilde{R} = \left(\widetilde{r}_{ij}\right)_{m\times n} &= \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{ccccc} c_1 & c_2 & \cdots & \ldots\ldots & c_n \end{array} \\ \begin{bmatrix} x_{11}^* & x_{12}^* & \cdots & x_{1n}^* \\ x_{21}^* & x_{22}^* & \ldots & x_{2n}^* \\ \vdots & \vdots & \vdots & \vdots \\ x_{m1}^* & x_{m2}^* & \cdots & x_{mn}^* \end{bmatrix} \end{array} \times \begin{bmatrix} w_j \\ w_j \\ \cdot \\ w_j \end{bmatrix}, \\ \widetilde{V} = \left(\widetilde{v}_{ij}\right)_{m\times n} &= \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} x_1 & x_2 & \cdots & x_n \end{array} \\ \begin{bmatrix} \widetilde{v}_{11} & \widetilde{v}_{12} & \cdots & \widetilde{v}_{1n} \\ \widetilde{v}_{21} & \widetilde{v}_{22} & \ldots & \widetilde{v}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \widetilde{v}_{m1} & \widetilde{v}_{m2} & \ldots & \widetilde{v}_{mn} \end{bmatrix} \end{array}. \end{aligned} \tag{22}$$

For optimization based on the ratio system approach of the MOORA method, normalized responses are added in case of maximization and subtracted in case of minimization, which can be expressed by the following formula:

$$y_j^* = \sum_{i=1}^{g} x_{ij}^* - \sum_{i=g+1}^{i=n} x_{ij}^*, \tag{23}$$

where x_{ij}^* is the normalized response of alternative j on objectives i; $i = 1, 2, \ldots, g$ is the objective to be maximized; $i = g+1, g+2, \ldots, n$ is the objective to be minimized; $j = 1, 2, \ldots, m$ is the alternatives; and y_j^* is the overall ranking index of alternative$j$. $y_j^* \in [-1, 1]$ provided and proved by [42].

4.5.2. The Importance Given to Objectives. When solving real-world problems using MCDM methods, objectives do not always have the same importance, i.e., some objectives are more important than the others. In order to give more importance to an objective, it could be multiplied with a significance coefficient [42]. Importance given to objectives has influence on the ratio system and reference point approach of the MOORA method. In the ratio system approach, importance given to objectives is included by modifying formula (23), which gets the following form:

$$\ddot{y}_j^* = \sum_{i=1}^{g} s_i x_{ij}^* - \sum_{i=g+1}^{i=n} s_i x_{ij}^*, \tag{24}$$

where s_i is the significance coefficient of objective$i$; $i = 1, 2, \ldots, g$ is the objective to be maximized; $i = g+1, g+2, \ldots, n$ is the objective to be minimized; $j = 1, 2, \ldots, m$ is the alternative; and $\ddot{y}_j^*$ is the overall ranking index of alternative j with respect to all objectives with significance coefficients, $\ddot{y}_j^* \in [-1, 1]$.

After that, formula (24) still remains to determine the most appropriate alternative based on the ratio system approach of the MOORA method.

4.5.3. The Grey-MOORA. The procedure of selecting the most appropriate alternative using the MOORA method involves several important stages that should be considered before an extension of the MOORA method with interval grey numbers, and these are [43]

Stage 1: transforming responses of alternatives into dimensionless values

Stage 2: determining overall ranking indexes for considered alternatives based on the ratio system part of the MOORA method and

Stage 3: determining distances between considered alternatives and the reference point based on the reference point part of the MOORA method

Stage 1: transformation into dimensionless values

For the normalization of responses of alternatives expressed in the form of interval numbers, suggested the use of the following formula:

$$\otimes x_{ij}^* = \frac{\otimes x_{ij}}{\sqrt{\sum_{j=1}^{m}\left(\underline{x}_{ij}^2 + \overline{x}_{ij}^2\right)}}. \tag{25}$$

Formula (25) provides the appropriate form for normalizing responses of alternatives expressed by interval grey numbers. However, in cases of multipractices optimizations, which require simultaneously the use of crisp and interval grey numbers, the previously mentioned formula gives unsatisfactory results.

Stage 2: determining overall ranking index based on the ratio system approach of the MOORA method for optimization based on the ratio system part of the MOORA method, we start from the formula

$$\begin{aligned} y_j^* &= y_j^{\vee} - y_j^{\wedge}, \\ y_j^* &= \sum_{i\in\Omega_G^+} \otimes s_i x_{ij}^* - \sum_{i\in\Omega_G^-} \otimes s_i x_{ij}^*, \\ y_j^{\vee} &= \sum_{i\in\Omega_G^+} \otimes s_i x_{ij}^*, \\ y_j^{\wedge} &= \sum_{i\in\Omega_G^-} \otimes s_i x_{ij}^*, \end{aligned} \tag{26}$$

where y_j^* is the overall ranking index of alternative j; $y_j^{\vee}$ and $y_j^{\wedge}$ are the total sums of maximizing and minimizing responses of alternative j to objectives i, respectively; s_i is the significance coefficient of objective i; x_{ij}^* or $\otimes x_{ij}^*$ as the normalized responses of alternative j on different objectives i, which are expressed in the form on crisp or interval grey numbers; Ω_{G}^{+} are the assets of objectives to be maximized and expressed in the form on crisp or interval grey numbers, and Ω_G^- are the sets of objectives to be minimized and expressed in the form on crisp or interval grey numbers:

(i) When decision makers have the same significance ($\lambda = 0$),

$$\begin{aligned} y_j^* = {} & (1-\lambda)\left(\sum_{i\in\Omega_G^+} \underline{s_i x}_{ij}^* - \sum_{i\in\Omega_G^-} \underline{s_i x}_{ij}^*\right) \\ & + \lambda\left(\sum_{i\in\Omega_G^+} \overline{s_i x}_{ij}^* - \sum_{i\in\Omega_G^-} \overline{s_i x}_{ij}^*\right). \end{aligned} \tag{27}$$

(ii) When the decision maker has no preferences ($\lambda = 0.5$),

$$\begin{aligned} y_j^* = {} & \frac{1}{2}\left(\sum_{i\in\Omega_G^+} \underline{s_i x}_{ij}^* - \sum_{i\in\Omega_G^-} \underline{s_i x}_{ij}^*,\right) \\ & + \frac{1}{2}\left(\sum_{i\in\Omega_G^+} \overline{s_i x}_{ij}^* - \sum_{i\in\Omega_G^-} \overline{s_i x}_{ij}^*\right). \end{aligned} \tag{28}$$

(iii) When the decision maker has no preference and objectives have the same significance ($\lambda = 1$),

$$\begin{aligned} y_j^* = {} & \lambda\left(\sum_{i\in\Omega_G^+} \overline{s_i x}_{ij}^* - \sum_{i\in\Omega_G^-} \overline{s_i x}_{ij}^*,\right) \\ & + (1-\lambda)\left(\sum_{i\in\Omega_G^+} \underline{s_i x}_{ij}^* - \sum_{i\in\Omega_G^-} \underline{s_i x}_{ij}^*\right). \end{aligned} \tag{29}$$

During problem solution, i.e., ranking of alternatives, the attitude of the professionals can lie between pessimistic and optimistic, and the whitening coefficientλ allows the expression of professionals' degree of optimism or pessimism.

In the cases of particularly expressed optimism, the whitening coefficient λ, in accordance with the aforesaid formula, takes

Table 2: Grey knowledge-based GWmZd sustainability appraisement hierarchical structural evaluation model.

Goal (C)	Measures (C_i)	Metrics (C_{ik})
Sustainability measurement	Green (C_1)	Renewable energy ($C_{1,1}$)
		Recycling of hazard material ($C_{1,2}$)
		Recycling of waste water ($C_{1,3}$)
	Waste minimization (C_2)	Over time, ($C_{2,1}$)
		Unwanted manufacturing ($C_{2,2}$)
		Unnecessary work ($C_{2,3}$)
	Zero defect (C_3)	Defective goods ($C_{3,1}$)
		Rejection rate ($C_{3,2}$)
		Salvaging of materials ($C_{3,3}$)

Table 3: Attitude of the measures and their interrelated metrics against supplier organizations A_1, A_2, and A_3.

Goal (C)	Measures (C_i)	Attitudes	Metrics (C_{ik})	Attitudes
Sustainability measurement	Green (C_1)	(+)	Renewable energy ($C_{1,1}$)	(+)
			Recycling of hazard material ($C_{1,2}$)	(+)
			Recycling of waste water ($C_{1,3}$)	(+)
	Waste minimization (C_2)	(−)	Over time ($C_{2,1}$)	(−)
			Unwanted manufacturing ($C_{2,2}$)	(−)
			Unnecessary work ($C_{2,3}$)	(−)
	Zero defect (C_3)	(−)	Defective goods ($C_{3,1}$)	(−)
			Rejection rate ($C_{3,2}$)	(−)
			Salvaging of materials ($C_{3,3}$)	(−)

Table 4: Definition of measures.

C_j	Definition of measures
(C_1)	This focus on maximizing the renewable energy, recycling of waste materials, hazard materials, and recycling of water
(C_2)	The aim is to reduce over processing, unwanted production, and unnecessary movements
(C_3)	The aim is to eliminate the defective product, rejection, and rework

Table 5: The verbal scale of importance by AHP.

Intensity of importance	Verbal scale	Description
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation

higher values ($\lambda \longrightarrow 1$), and the ranking order of alternatives is mainly based on the upper bounds of intervals with which the overall response of each alternative is expressed, $y_{j(\lambda=1)} = y_j^*$. On the other hand, in the cases of particularly expressed pessimistic, the whitening coefficient λ takes lower values ($\lambda \longrightarrow 0$), and the ranking order of alternatives is mainly based on lower bounds of the intervals, $y_{j(\lambda=0)} = y_j^*$. On the other hand, in the cases of particularly expressed moderate, the whitening coefficient λ takes half of lower and upper values ($\lambda \longrightarrow 0.5$), and the ranking order of alternatives is mainly based on lower bounds of the intervals, $y_{j(\lambda=0.5)} = y_j^*$.

4.5.4. The Grey-FMF. Determining overall ranking index is based on multiobjective optimization on the full multification form decision-making evaluation technique; it was the extensive part of MOORA formula [37, 39–41]:

$$y_j^+ = \frac{\prod_{i\in\Omega_G^+} s_i x_{ij}^*}{\prod_{i\in\Omega_G^-} s_i x_{ij}^*}. \tag{30}$$

(i) When objectives have the same significance ($\lambda = 0$),

$$y_j^+ = (1-\lambda)\left(\frac{\prod_{i\in\Omega_G^+} s_i \underline{x}_{ij}^*}{\prod_{i\in\Omega_G^-} s_i \underline{x}_{ij}^*}\right) + \lambda\left(\frac{\prod_{i\in\Omega_G^+} \overline{s_i x_{ij}^*}}{\prod_{i\in\Omega_G^-} \overline{s_i x_{ij}^*}}\right). \tag{31}$$

(ii) When the decision maker has no preferences ($\lambda = 0.5$),

Table 6: Importance against (C_1–C_9), assigned by P_1.

C_i	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1	1/3	1/5	1/3	1/5	1/7	1/5	1/3	1/5
C_2	3	1	1/3	1/5	1/3	1/5	1/7	1/5	1/7
C_3	5	3	1	1/5	1/7	1/5	1/3	1/5	1/3
C_4	3	5	5	1	1/9	1/5	1/5	1/5	1/3
C_5	5	3	7	9	1	1/5	1/9	1/9	1/5
C_6	7	5	5	5	5	1	1/5	1/7	1/5
C_7	5	7	3	5	9	5	1	1/5	1/7
C_8	3	5	5	5	9	7	5	1	1/9
C_9	5	7	3	3	5	5	7	9	1
Crisp representation									
C_1	1.000	0.333	0.200	0.333	0.200	0.143	0.200	0.333	0.200
C_2	3.000	1.000	0.333	0.200	0.333	0.200	0.143	0.200	0.143
C_3	5.000	3.000	1.000	0.200	0.143	0.200	0.333	0.200	0.333
C_4	3.000	5.000	5.000	1.000	0.111	0.200	0.200	0.200	0.333
C_5	5.000	3.000	7.000	9.000	1.000	0.200	0.111	0.111	0.200
C_6	7.000	5.000	5.000	5.000	5.000	1.000	0.200	0.143	0.200
C_7	5.000	7.000	3.000	5.000	9.000	5.000	1.000	0.200	0.143
C_8	3.000	5.000	5.000	5.000	9.000	7.000	5.000	1.000	0.111
C_9	5.000	7.000	3.000	3.000	5.000	5.000	7.000	9.000	1.000

Table 7: Importance against (C_1–C_9), assigned by P_2.

C_i	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1	1/5	1/5	1/5	1/5	1/7	1/9	1/3	1/5
C_2	5	1	1/5	1/5	1/3	1/5	1/7	1/5	1/7
C_3	5	5	1	1/5	1/7	1/5	1/3	1/5	1/3
C_4	5	5	5	1	1/9	1/5	1/5	1/5	1/3
C_5	5	3	7	9	1	1/5	1/9	1/9	1/5
C_6	7	5	5	5	5	1	1/5	1/7	1/5
C_7	9	7	3	5	9	5	1	1/5	1/7
C_8	3	5	5	5	9	7	5	1	1/9
C_9	5	7	3	3	5	5	7	9	1
Crisp representation									
C_1	1.000	0.200	0.200	0.200	0.200	0.143	0.111	0.333	0.200
C_2	5.000	1.000	0.200	0.200	0.333	0.200	0.143	0.200	0.143
C_3	5.000	5.000	1.000	0.200	0.143	0.200	0.333	0.200	0.333
C_4	5.000	5.000	5.000	1.000	0.111	0.200	0.200	0.200	0.333
C_5	5.000	3.000	7.000	9.000	1.000	0.200	0.111	0.111	0.200
C_6	7.000	5.000	5.000	5.000	5.000	1.000	0.200	0.143	0.200
C_7	9.000	7.000	3.000	5.000	9.000	5.000	1.000	0.200	0.143
C_8	3.000	5.000	5.000	5.000	9.000	7.000	5.000	1.000	0.111
C_9	5.000	7.000	3.000	3.000	5.000	5.000	7.000	9.000	1.000

Table 8: Importance against (C_1–C_9), assigned by P_3.

C_i	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1	1/9	1/9	1/9	1/9	1/9	1/9	1/9	1/9
C_2	9	1	1/5	1/5	1/5	1/5	1/5	1/5	1/5
C_3	9	5	1	1/5	1/7	1/5	1/3	1/5	1/3
C_4	9	5	5	1	1/9	1/5	1/5	1/5	1/3
C_5	9	5	7	9	1	1/5	1/9	1/9	1/5
C_6	9	5	5	5	5	1	1/5	1/7	1/5
C_7	9	5	3	5	9	5	1	1/5	1/7
C_8	9	5	5	5	9	7	5	1	1/9
C_9	9	5	3	3	5	5	7	9	1
Crisp representation									
C_1	1.000	0.111	0.111	0.111	0.111	0.111	0.111	0.111	0.111
C_2	9.000	1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200

Table 8: Continued.

C_i	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_3	9.000	5.000	1.000	0.200	0.143	0.200	0.333	0.200	0.333
C_4	9.000	5.000	5.000	1.000	0.111	0.200	0.200	0.200	0.333
C_5	9.000	5.000	7.000	9.000	1.000	0.200	0.111	0.111	0.200
C_6	9.000	5.000	5.000	5.000	5.000	1.000	0.200	0.143	0.200
C_7	9.000	5.000	3.000	5.000	9.000	5.000	1.000	0.200	0.143
C_8	9.000	5.000	5.000	5.000	9.000	7.000	5.000	1.000	0.111
C_9	9.000	5.000	3.000	3.000	5.000	5.000	7.000	9.000	1.000

Table 9: Importance against (C_1–C_9), assigned by P_4.

C_i	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1	1/3	1/3	1/3	1/3	1/3	1/3	1/3	1/3
C_2	3	1	1/7	1/7	1/7	1/7	1/7	1/7	1/7
C_3	3	7	1	1/5	1/7	1/5	1/3	1/5	1/3
C_4	3	7	5	1	1/9	1/5	1/5	1/5	1/3
C_5	3	7	7	9	1	1/5	1/9	1/9	1/5
C_6	3	7	5	5	5	1	1/5	1/7	1/5
C_7	3	7	3	5	9	5	1	1/5	1/7
C_8	3	7	5	5	9	7	5	1	1/9
C_9	3	7	3	3	5	5	7	9	1
Crisp representation									
C_1	1.000	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333
C_2	3.000	1.000	0.143	0.143	0.143	0.143	0.143	0.143	0.143
C_3	3.000	7.000	1.000	0.200	0.143	0.200	0.333	0.200	0.333
C_4	3.000	7.000	5.000	1.000	0.111	0.200	0.200	0.200	0.333
C_5	3.000	7.000	7.000	9.000	1.000	0.200	0.111	0.111	0.200
C_6	3.000	7.000	5.000	5.000	5.000	1.000	0.200	0.143	0.200
C_7	3.000	7.000	3.000	5.000	9.000	5.000	1.000	0.200	0.143
C_8	3.000	7.000	5.000	5.000	9.000	7.000	5.000	1.000	0.111
C_9	3.000	7.000	3.000	3.000	5.000	5.000	7.000	9.000	1.000

Table 10: Importance against (C_1–C_9), assigned by P_5.

C_i	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1	1/5	1/5	1/5	1/5	1/5	1/5	1/5	1/5
C_2	5	1	1/7	1/7	1/7	1/7	1/7	1/7	1/7
C_3	5	7	1	1/5	1/7	1/5	1/3	1/5	1/3
C_4	5	7	5	1	1/9	1/5	1/5	1/5	1/3
C_5	5	7	7	9	1	1/5	1/9	1/9	1/5
C_6	5	7	5	5	5	1	1/5	1/7	1/5
C_7	5	7	3	5	9	5	1	1/5	1/7
C_8	5	7	5	5	9	7	5	1	1/9
C_9	5	7	3	3	5	5	7	9	1
Crisp representation									
C_1	1.000	0.200	0.200	0.200	0.200	0.200	0.200	0.200	0.200
C_2	5.000	1.000	0.143	0.143	0.143	0.143	0.143	0.143	0.143
C_3	5.000	7.000	1.000	0.200	0.143	0.200	0.333	0.200	0.333
C_4	5.000	7.000	5.000	1.000	0.111	0.200	0.200	0.200	0.333
C_5	5.000	7.000	7.000	9.000	1.000	0.200	0.111	0.111	0.200
C_6	5.000	7.000	5.000	5.000	5.000	1.000	0.200	0.143	0.200
C_7	5.000	7.000	3.000	5.000	9.000	5.000	1.000	0.200	0.143
C_8	5.000	7.000	5.000	5.000	9.000	7.000	5.000	1.000	0.111
C_9	5.000	7.000	3.000	3.000	5.000	5.000	7.000	9.000	1.000

Table 11: Aggregated importance against (C_1–C_9), assigned by $P_{1,2,3,4,5}$.

C_i	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
C_1	1.000	0.235	0.209	0.235	0.209	0.186	0.191	0.262	0.209
C_2	5.000	1.000	0.204	0.177	0.230	0.177	0.154	0.177	0.154
C_3	5.400	5.400	1.000	0.200	0.143	0.200	0.333	0.200	0.333
C_4	5.000	5.800	5.000	1.000	0.111	0.200	0.200	0.200	0.333
C_5	5.400	5.000	7.000	9.000	1.000	0.200	0.111	0.111	0.200
C_6	6.200	5.800	5.000	5.000	5.000	1.000	0.200	0.143	0.200
C_7	6.200	6.600	3.000	5.000	9.000	5.000	1.000	0.200	0.143
C_8	4.600	5.800	5.000	5.000	9.000	7.000	5.000	1.000	0.111
C_9	5.400	6.600	3.000	3.000	5.000	5.000	7.000	9.000	1.000

Table 12: Evaluated eigenvector by AHP.

C_i	M^{th} root of products of values	Eigenvectors
C_1	0.256	0.019
C_2	0.316	0.023
C_3	0.537	0.039
C_4	0.705	0.051
C_5	0.981	0.072
C_6	1.434	0.105
C_7	2.099	0.153
C_8	3.057	0.223
C_9	4.302	0.314

Table 13: Evaluated global weights.

Goal (C)	Measures (C_i)	Global weights	Metrics (C_{ik})	Eigenvectors
			Renewable energy ($C_{1,1}$)	0.019
	Green (C_1)	0.081	Recycling of hazard material ($C_{1,2}$)	0.023
			Recycling of waste water ($C_{1,3}$)	0.039
			Over time ($C_{2,1}$)	0.051
Sustainability measurement	Waste minimization (C_2)	0.228	Unwanted manufacturing ($C_{2,2}$)	0.072
			Unnecessary work ($C_{2,3}$)	0.105
			Defective goods ($C_{3,1}$)	0.153
	Zero defect (C_3)	0.691	Rejection rate ($C_{3,2}$)	0.223
			Salvaging of materials ($C_{3,3}$)	0.314

$$y_j^{+} = \lambda\left(\frac{\prod_{i\in\Omega_G^{+}} s_i\underline{x}_{ij}^{*}}{\prod_{i\in\Omega_G^{-}} s_i\underline{x}_{ij}^{*}},\right) + \lambda\left(\frac{\prod_{i\in\Omega_G^{+}} \overline{s_i x}_{ij}^{*}}{\prod_{i\in\Omega_G^{-}} \overline{s_i x}_{ij}^{*}}\right). \quad (32)$$

(iii) When the decision makers have no preference and objectives have the same significance ($\lambda = 1$),

$$y_j^{+} = \lambda\left(\frac{\prod_{i\in\Omega_G^{+}} \overline{s_i x}_{ij}^{*}}{\prod_{i\in\Omega_G^{-}} \overline{s_i x}_{ij}^{*}},\right) + (1-\lambda)\left(\frac{\prod_{i\in\Omega_G^{+}} \underline{s_i x}_{ij}^{*}}{\prod_{i\in\Omega_G^{-}} \underline{s_i x}_{ij}^{*}}\right). \quad (33)$$

During the problem solution, i.e., ranking of alternatives, the attitude of the professionals can lie between pessimistic and optimistic, and the whitening coefficientλ allows the expression of professionals' degree of optimism or pessimism.

In the cases of particularly expressed optimism, the whitening coefficient λ, in accordance with formula (29), takes higher values ($\lambda \longrightarrow 1$), and the ranking order of alternatives is mainly based on the upper bounds of intervals with which the overall response of each alternative is expressed, $y_{j(\lambda=1)} = y_j^{+}$. On the other hand, in the cases of particularly expressed pessimistic, the whitening coefficient λ takes lower values ($\lambda \longrightarrow 0$), and the ranking order of alternatives is mainly based on lower bounds of the intervals, $y_{j(\lambda=0)} = y_j^{+}$. On the other hand, in the cases of particularly expressed moderate, the whitening coefficient λ takes half of lower and upper values ($\lambda \longrightarrow 0.5$), and the ranking order of alternatives is mainly based on lower bounds of the intervals, $y_{j(\lambda=0.5)} = y_j^{+}$.

Table 14: The scale of attribute ratings $\otimes G$.

Scale	$\otimes r$
Very poor (VP)	(0, 1)
Poor (P)	(1, 3)
Medium poor (MP)	(3, 4)
Fair (F)	(4, 5)
Medium good (MG)	(5, 6)
Good (G)	(6, 9)
Very good (VG)	(9, 10)

Table 15: Appropriateness grey rating against metrics for A_1.

Metrics (C_{ik})	P1	P2	P3	P4	P5
Renewable energy ($C_{1,1}$)	VG	G	G	G	VG
Recycling of hazard material ($C_{1,2}$)	VG	VG	VG	VG	MP
Recycling of waste water ($C_{1,3}$)	MG	F	F	MP	MP
Over time ($C_{2,1}$)	G	F	F	MP	VG
Unwanted manufacturing ($C_{2,2}$)	VG	F	F	MP	F
Unnecessary work ($C_{2,3}$)	MG	F	P	MP	F
Defective goods ($C_{3,1}$)	MG	MP	VG	VG	F
Rejection rate ($C_{3,2}$)	MG	MP	F	MG	G
Salvaging of materials ($C_{3,3}$)	F	MP	F	MG	G

Table 16: Appropriateness grey rating against metrics for A_2.

Metrics (C_{ik})	P1	P2	P3	P4	P5
Renewable energy ($C_{1,1}$)	F	G	MG	MG	G
Recycling of hazard material ($C_{1,2}$)	G	MG	MG	G	G
Recycling of waste water ($C_{1,3}$)	MG	MP	MG	G	G
Over time ($C_{2,1}$)	MG	MP	F	G	G
Unwanted manufacturing ($C_{2,2}$)	MG	F	F	G	MG
Unnecessary work ($C_{2,3}$)	VG	F	VG	MG	MG
Defective goods ($C_{3,1}$)	F	VG	F	MG	MG
Rejection rate ($C_{3,2}$)	MG	MP	F	G	F
Salvaging of materials ($C_{3,3}$)	MG	MP	VG	G	MG

Table 17: Appropriateness grey rating against metrics for A_3.

Metrics (C_{ik})	P1	P2	P3	P4	P5
Renewable energy ($C_{1,1}$)	MG	MP	F	G	MG
Recycling of hazard material ($C_{1,2}$)	VG	MP	F	G	MG
Recycling of waste water ($C_{1,3}$)	F	VG	F	G	MG
Over time ($C_{2,1}$)	F	F	G	VG	MG
Unwanted manufacturing ($C_{2,2}$)	MG	F	P	VG	VG
Unnecessary work ($C_{2,3}$)	F	F	VP	MG	G
Defective goods ($C_{3,1}$)	F	VG	VP	MG	G
Rejection rate ($C_{3,2}$)	G	F	G	MG	G
Salvaging of materials ($C_{3,3}$)	MG	VG	G	MG	VG

Table 18: Addition of grey global rating for A_1.

Goal (C)	Measures (C_i)	Global ratings	Attitudes	Metrics (C_{ik})	Metrics ratings	Attitudes
Sustainability measurement	(C_1)	(6.267, 7.667)	(+)	($C_{1,1}$)	(7.2000, 9.4000)	(+)
				($C_{1,2}$)	(7.8000, 8.8000)	(+)
				($C_{1,2}$)	(3.8000, 4.8000)	(+)
	(C_2)	(4.667, 5.800)	(−)	($C_{2,1}$)	(5.2000, 6.6000)	(−)
				($C_{2,2}$)	(4.8000, 5.8000)	(−)
				($C_{2,3}$)	(4.0000, 5.0000)	(−)
	(C_3)	(5.000, 6.267)	(−)	($C_{3,1}$)	(6.0000, 7.0000)	(−)
				($C_{3,2}$)	(4.6000, 6.0000)	(−)
				($C_{3,3}$)	(4.4000, 5.8000)	(−)

5. Empirical Research: Sustainability Evaluation of Alternative Organizations

The grey knowledge-based GWmZd sustainability appraisement hierarchical structural evaluation model is constructed by scrutinizing 3 (three) momentous measures and 9 (nine) interrelated metrics via the literature review of [4–6, 8–16, 18–22, 27, 28, 30, 34, 35, 61, 62]. The model is found valid towards assessing the sustainability of supplier organizations. The model's attitude and measures' definitions are shown in Tables 2–4, respectively. In the presented research work, 3 significant practices/measures, i.e., green, (C_1), waste minimization, (C_2), and zero defect, (C_3), are considered at the 1st level, whilst identified and shortlisted 9

Table 19: Addition of grey global rating for A_2.

Goal (C)	Measures (C_i)	Global ratings	Attitudes	Metrics (C_{ik})	Metrics ratings	Attitudes
				($C_{1,1}$)	(5.2000, 7.0000)	(+)
	(C_1)	(5.267, 7.200)	(+)	($C_{1,2}$)	(5.6000, 7.8000)	(+)
				($C_{1,2}$)	(5.0000, 6.8000)	(+)
				($C_{2,1}$)	(4.8000, 6.6000)	(−)
Sustainability measurement	(C_2)	(5.333, 6.733)	(−)	($C_{2,2}$)	(4.8000, 6.2000)	(−)
				($C_{2,3}$)	(6.4000, 7.4000)	(−)
				($C_{3,1}$)	(5.4000, 6.4000)	(−)
	(C_3)	(5.133, 6.400)	(−)	($C_{3,2}$)	(4.4000, 5.8000)	(−)
				($C_{3,3}$)	(5.6000, 7.0000)	(−)

Table 20: Addition of grey global rating for A_3.

Goal (C)	Measures (C_i)	Global ratings	Attitudes	Metrics (C_{ik})	Metrics ratings	Attitudes
				($C_{1,1}$)	(4.6000, 6.0000)	(+)
	(C_1)	(5.200, 6.600)	(+)	($C_{1,2}$)	(5.4000, 6.8000)	(+)
				($C_{1,2}$)	(5.6000, 7.0000)	(+)
				($C_{2,1}$)	(5.6000, 7.0000)	(−)
Sustainability measurement	(C_2)	(5.000, 6.333)	(−)	($C_{2,2}$)	(5.6000, 6.8000)	(−)
				($C_{2,3}$)	(3.8000, 5.2000)	(−)
				($C_{3,1}$)	(4.8000, 6.2000)	(−)
	(C_3)	(5.667, 7.333)	(−)	($C_{3,2}$)	(5.4000, 7.6000)	(−)
				($C_{3,3}$)	(6.8000, 8.2000)	(−)

Table 21: Grey global rating matrix for sustainability measurement.

Goal (C)	Alternatives A_j	(C_1)	(C_2)	(C_3)
	A_1	(6.267, 7.667)	(4.667, 5.800)	(5.000,6.267)
Sustainability measurement	A_2	(5.267, 7.200)	(5.333, 6.733)	(5.133, 6.400)
	A_3	(5.200, 6.600)	(5.000, 6.333)	(5.667, 7.333)

Table 22: Grey global rating normalized matrix.

Goal (C)	Alternatives A_j	(C_1)	(C_2)	(C_3)
	A_1	(0.362, 0.442)	(0.260, 0.323)	(0.324, 0.406)
Sustainability measurement	A_2	(0.304, 0.415)	(0.297, 0.375)	(0.332, 0.414)
	A_3	(0.300, 0.381)	(0.278, 0.353)	(0.367, 0.475)

Table 23: Weighted normalized matrix.

Goal (C)	Alternatives A_j	(C_1)	(C_2)	(C_3)
	A_1	(0.02929, 0.0358)	(0.0748, 0.093)	(0.2236, 0.2803)
Sustainability measurement	A_2	(0.02462, 0.0337)	(0.0855, 0.108)	(0.2295, 0.2862)
	A_3	(0.0243, 0.0308)	(0.0800, 0.1016)	(0.2534, 0.3258)

metrics (measures' interrelated factors), i.e., renewable energy, ($C_{1,1}$), recycling of hazard material, ($C_{1,2}$), recycling of waste water, ($C_{1,3}$), over time, ($C_{2,1}$), unwanted manufacturing, ($C_{2,2}$), unnecessary work, ($C_{2,3}$), defective goods, ($C_{3,1}$), rejection rate, ($C_{3,2}$), and salvaging of materials, ($C_{3,3}$), are set up over the 2nd level. The model has an objective to evaluate the sustainability scores of supplier organizations in application of dominance comparative analysis. To evaluate results, a committee of five highly experience professionals are formed from units of the case study manufacturing industry and requested to overview and judge the supplier partners/organizations. The procedure steps are following:

Step 1: Verbal information has been collected by a committee of five highly experienced professionals (P), and a team is formed from the cross functional units of the material purchaser (production) industry. Information is collected from each member of a group of professionals (P) via the crisp AHP linguistic scale as shown in Table 5 in relation to 9 metrics. The assigned pairwise weights against 9 metrics are shown in

Table 24: Ranking results obtained using MOORA technique for $\lambda = 0, 0.5, 1$.

λ	$\lambda = 0$		$\lambda = 0.5$		$\lambda = 1$	
Alternatives A_j	y_j^*	Ranking	y_j^*	Ranking	y_j^*	Ranking
A_1	−0.269	1.000	−0.303	1.000	−0.338	1.000
A_2	−0.290	2.000	−0.326	2.000	−0.361	2.000
A_3	−0.309	3.000	−0.353	3.000	−0.397	3.000

Table 25: Ranking results obtained using full multification form technique for $\lambda = 0, 0.5, 1$.

λ	$\lambda = 0$		$\lambda = 0.5$		$\lambda = 1$	
Alternatives, A_j	y_j^+	Ranking	y_j^+	Ranking	y_j^+	Ranking
A_1	1.746	1.000	1.560	1.000	1.373	1.000
A_2	1.254	2.000	1.170	2.000	1.087	2.000
A_3	1.201	3.000	1.066	3.000	0.930	3.000

Table 26: Preferences of supplier organizations at $\lambda = 0, 0.5, 1$.

λ	$\lambda = 0, 0.5, 1$ by MOORA			$\lambda = 0, 0.5, 1$ by FMF			Final rank
Alternatives, A_j	Ranking	Ranking	Ranking	Ranking	Ranking	Ranking	
A_1	1.000	1.000	1.000	1.000	1.000	1.000	Alternative vendor organization A1 sustainability is the best
A_2	2.000	2.000	2.000	2.000	2.000	2.000	
A_3	3.000	3.000	3.000	3.000	3.000	3.000	

Table 27: The conducted research work's applications, limitations, economic values, and commercial values.

Applications	The proposed grey knowledge-based GWmZd sustainability appraisement hierarchical structural evaluation model can be explored for measuring the sustainability of alternative vendor organizations under the proposed grey set-based approach with the dominance theory. Benchmarking and several election problems of industries, i.e., trucks, cranks, and hand trucks, can also be solved by using same research forum.
Limitations	The model is found versatile in nature. It can solve the many decision-making problems, i.e., the evaluation problem of facility locations and routes for new manufacturing firm by replacing the chain of sustainability assessment measures and their interrelated metrics corresponding to defining alternatives. However, single and multivariables linear programming problem under the boundary constraint value cannot be solved.
Economic values	Proposed model neither requires a specific software nor high skill professional. It can be solved by excel sheet.
Commercial values	Proposed model is sharable with other manufacturing firm by e-mail, fax, and other electronic media. The proposed research work is suitable for solving many problems of the manufacturing firm on extension/exchange of the chain of sustainability appraisement measures and their interrelated metrics against defining or facing alternatives.

Tables 6–10 and aggregated by average rule, and data are shown in Table 11. Equations (1)–(5) are applied to compute weights against 9 metrics of the 2nd level as shown in Table 12. The weights are (0.019, 0.023, 0.039, 0.051, 0.072, 0.105, 0.153, 0.223, and 0.314).

In order to check consistency, equation (4) is applied on calculated $\lambda_{\max} = 9.1$ (considered $M = 9$). Then, the consistency (for CI = 1.45) is checked by using equation (7), depicted $0.0862 < 0.1$. The proposing new equation (8) is applied to compute global weights of measures. Table 13 dealt with the global weights.

Step 2: Later, using the concept of the grey set theory, the grey variables, shown in Table 14, are used by the team of same five professionals (P) to assign grey ratings against supplier organizations, i.e., A_1, A_2, and A_3. The assigned grey ratings are aggregated by equation (13) as shown in Tables 15–17 and Tables 18–20 against suppliers, i.e., A_1, A_2, and A_3.

Step 3: Then, to compute grey global rating of the 1st level measures from the 2nd level metrics, equation (18) is utilized to jump from the 2nd level to the 1st level as shown in Tables 18–20. Grey global rating matrix computed for organizations A_1, A_2, and A_3 is depicted in Table 21.

Step 4: Then, normalization is carried out by using equation (25) for bringing grey set values in the interval of 0-1 excluding transforming the nonbeneficial criterion into beneficial measures as shown in Table 22. Then, global weights are multiplied by its measures and constructed the weighted normalized matrix by using equation (22), shown in Table 23.

Step 5: Grey-MOORA is applied on the data available in Table 23. Ranking results are obtained using MOORA technique by equation (26), and ranks computed for $\lambda = 0, 0.5, 1$ by using equations (27)–(29) shown in Table 24. Grey-Full multification form is applied on the data available in Table 23. Ranking results obtained using grey-FMF technique for $\lambda = 0, 0.5, 1$ is calculated by equations (30)–(33), shown in Table 25.

Step 6: The preference's order vs sustainability of supplier organizations under GWmZd measures is obtained by exploring the comparative analysis at $\lambda = 0, 0.5, 1$ as shown in Table 26. It is found that A_1 is the more sustainable supplier than others. It must be the elected material purchasing company for placing orders (Table 27).

6. Applications, Practical Implications, Economic Values, Commercial Values, and Limitations

Applications, practical implications, economic values, commercial values, and limitations are provided in Table 27

7. Conclusions

In the presented research work, the grey knowledge-based GWmZd sustainability appraisement hierarchical structural evaluation model is constructed by the literature survey, consisted of 3 measures, i.e., green, (C_1), waste minimization, (C_2), and zero defect, (C_3) and 9 measures' interrelated metrics. The authors applied the AHP in addressing individual rating of each expert and aggregated all the expert opinion vs 9 metrics as weights. Later, global weights are computed vs 3 measures. Eventually, the grey-holistic approach amalgamated with the dominance theory [37, 39, 41, 42] is applied in order to get consistent results with respect to attitude of experts, i.e., $\lambda = 0, 0.5, 1$. Eventually, it is found that sustainability of 1st vendor candidate alternative is the best. It must be elected by production firm for placing order.

The others conclusions are given in below section:

(i) The presented grey knowledge-based GWmZd model can be powered by Microsoft Windows XP, and manual computation is also possible

(ii) Proposed GWmZd models can be extended with the advance chain of sustainability appraisement measures and their interrelated metrics against defining alternatives with the grey-holistic approach merged with dominance theory to compute robust results

(iii) Proposed work does not require a special support of the software. It could be solved by excel sheet.

(iv) The authors developed and proposed new mathematical equations, assisted authors to evaluate the global weight of first layer-three pillars from second level metrics

The future scope of the presented research work is that the novel GWmZd model can be constructed with advanced sustainability measures and their interrelated metrics in future. The decision can be simulated by using the same grey-holistic approach fused with the dominance theory.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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