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A Composited Regret-Theory-Based Spherical Fuzzy Prioritization Approach for Moving High-Tech Manufacturing in Southeast Asia

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Abstract: After the pandemic, global supply chains will be in the process of restructuring. The relocation of production lines among countries is being considered for the purpose of sustainable development. The problem of determining the most suitable destination for manufacturers' investments will become important, especially in the field of manufacturing high-tech products, which involves many complicated factors such as technological maturity, support policies, political issues, and technology security. In that context, Southeast Asia is seen as one of the regions attracting multinational manufacturers. To address this problem, a novel composited regret-theory-based spherical fuzzy prioritization approach is proposed. On the one hand, the super-efficiency slack-based model (super-SBM) of data envelopment analysis (DEA) is applied to evaluate efficiency, based on indicators. On the other hand, the novel spherical fuzzy regret-theory-based decision-making approach (SfRDMA) is developed and introduced to determine effectiveness, based on criteria. Then, the efficiency and the effectiveness of countries are combined by a composite-score function that is based on a geometric mean and an arithmetic mean. The findings imply that government policy, political stability, and human resources availability are the three most important criteria. Moreover, India, Thailand, Vietnam, Malaysia, and Indonesia are identified as promising destinations for the world's high-tech production lines.

Keywords: multiple criteria decision making; fuzzy theory; regret theory; spherical fuzzy; high-tech manufacturing; production line moving

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1. Introduction

Scientific revolutions and changes in industry have posed new challenges for countries around the world. However, such changes also provide an opportunity for countries to improve their competitiveness [1]. Over the past two decades, many growth feats in countries have been the result of high-tech-based international trade activities. High-tech products drive the performance of countries and lead to positive externalities and dynamism in their economies [2]. Furthermore, many endogenous economic growth theories emphasize that innovative products representing high-tech play an important role in technological progress, creating comparative advantages in trade [3]. Beyond the theoretical framework, many empirical studies have concluded that technological progress promotes international trade, leading to higher economic growth [4]. Therefore, the development of multinational high-tech companies is the means to achieve the above goals. On the contrary, from the perspective of high-tech manufacturers, a right decision on investment destination has a great impact on a company's sustainable development, as well as limiting risks and saving costs for investors. Therefore, this study aims to prioritize investment destinations in the East Asia and South Asia regions for high-tech production lines. This prioritization process determines both the efficiency and the effectiveness of developing countries based on quantitative indicators and qualitative criteria, respectively.

To address this prioritization problem, a novel composited regret-theory-based spherical fuzzy prioritization approach is proposed. On the one hand, the super-efficiency slack-based model (super-SBM) of data envelopment analysis (DEA) is applied to evaluate the efficiency of thirteen countries in Southeast Asia, based on indicators such as inflation, gross domestic products (GDPs), costs to export, high-technology exports records, and ease-of-doing-business scores. On the other hand, the novel spherical fuzzy regret-theory-based decision-making approach (SfRDMA) is developed and introduced to determine the effectiveness of the thirteen countries, based on ten evaluation criteria. Then, the efficiency and the effectiveness of the countries are combined by a composite-score function that is based on a geometric mean and an arithmetic mean. The novel composited regret-theory-based spherical fuzzy prioritization approach is the primary theoretical contribution of this research to the field of decision science. Meanwhile, the results of destination preferences for high-tech manufacturing moving to Southeast Asia provide the secondary practical contribution of this study.

The remainder of this paper is set out as follows. A summary of relevant studies is provided in Section 2; A detailed profile of the paper is presented in Section 3. Section 4 provides a discussion, as well as a description of the results of the study. Section 5 provides the paper's conclusions.

2. Related Works

Multiple-criteria decision making (MCDM) encompasses a variety of methods that support decision makers in evaluating and choosing the most suitable decision from a set of alternatives, based on multiple criteria. Over the years, many approaches have been developed and proposed for MCDM problems, as presented in Table 1. A closer look at the overview reveals that primitive methods tend to be used in an integrated manner [5]. Most combinations of MCDM methods aim to individually perform the two tasks of determining the importance of the criteria and prioritizing alternatives [6]. For example, Ilyas et al. combined two MCDM methods—the Best-Worst method (BWM) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)—for the purpose of supplier selection [7]. In that study, the criterion weight was calculated using the BWM method; then, the ranking of risks affecting the supplier were calculated through the TOPSIS method. Taddese et al. combined two MCDM methods as a combined AHP–VIKOR method for the purpose of evaluating the sustainable performance of face-shield frame production [8]. A new era in MCDM began when Zadeh introduced the concept of fuzzy sets [9]. Fuzzy set theory has been proven to be powerful in dealing with various MCDM problems to overcome uncertainty, inaccurate data, and unclear information. Fuzzy MCDM has been used in a wide range of practical applications. For example, Yao analyzed environmental regulation and green economic efficiency in China by applying the fuzzy analytical hierarchy process (AHP) andthe fuzzy VIeKriterijumska Optimizacija I Kompromisno Resenje (VIKOR, a Serbian term for "multi-criteria optimization and compromise solution") [10]. Mahmut Bakır et al. evaluated the quality of electronic services in the airline industry from the consumer's point of view, using an integrated fuzzy analytical hierarchy process (F-AHP) and fuzzy Measurement of Alternatives and Ranking according to COmpromise Solution (F-MARCOS) approach [11]. Liu et al. introduced an integrated approach—TODIM (an acronym in Portuguese for interactive and multiple-attribute decision making)-ELECTER II (elimination and choice translating reality II)—to solve technology selection problems [12]. In addition, extensions with fuzzy sets of the MCDM method are being introduced with increasing popularity. Therefore, the development of fuzzy set types nearly parallels the development of MCDM methods. The most recent fuzzy development is the introduction of spherical fuzzy extensions of MCDM methods [13–15].

Recent studies show that evaluation based on distance from average solution (EDAS) is emerging as one of the most effective assessment methods. This distance-based method was introduced by Ghorabaee et al. in 2015 [16]. The EDAS method is a multi-criteria distance-based decision-making methods similar to TOPSIS and VIKOR. However, the

EDAS method simplifies the distance calculation to speed up the decision-making process [17]. EDAS also outperforms TOPSIS and VIKOR in terms of complexity, due to the elimination of unpromising candidates. In addition, this method is very convenient when there is information about the preferred mean of the attribute evaluation [18].

Another popular MCDM method to identify potential relationships between factors and weighting factors for the evaluation process is the decision-making trial and evaluation laboratory (DEMATEL) method. This matrix-based method was first introduced in 1974 to solve complex and interdependent problems in various fields, such as manufacturing, supply chain technology, and services [19–21]. As discussed above, fuzzy theory is continuously developed and applied to MCDM methods to deal with ambiguities in human perspective. Among these applications, spherical fuzzy is one of the recently developed and introduced fuzzy sets. The spherical fuzzy set is capable of expressing membership, non-membership and hesitation in decision makers' opinions. Therefore, spherical fuzzy extensions of MCDM methods are introduced more and more in many fields [22–24]. In addition, decision makers' psychological behaviors, such as expectation, risk aversion, and regret aversion, are also believed to have a significant impact on decisions. Therefore, theories that describe the psychological behavior of decision makers, such as prospect theory and regret theory, are increasingly applied in bounded rationality decision-making processes [25–27]. For quantitative indicators, DEA models are considered as one of the most powerful tools for assessing the efficiency of alternatives [6,28]. In some studies, DEA has also been applied as a filter of alternatives in decision making [29]. For integrating the results of many different methods, the geometric mean and the arithmetic mean are common candidates for the task of aggregation operators [30].

The inspiration behind this article's proposed approach came from those previous studies. For the qualitative assessment of effectiveness, this study develops a matrix-based and distance-based MCDM method in the spherical fuzzy environment that integrates the principles of regret theory. For the quantitative assessment of efficiency, DEA's super-SBM model is applied. Finally, the effectiveness and efficiency scores of the alternatives are combined to finalize prioritization by a composite-score function.

Table 1. Previous relevant studies.

No.	Author	Year	Method	Fuzzy Sets
1	S. Yao [10]	2021	AHP and VIKOR	Triangular fuzzy
2	Bakir and Atalik [11]	2021	AHP and MARCOS	Triangular fuzzy
3	Ilyas et al. [7]	2021	BWM and TOPSIS	-
4	G. Taddese et al. [8]	2021	AHP and VIKOR	-
5	Liu et al. [12]	2021	TODIM and ELECTRE II	Hesitant fuzzy
6	Wanget al. [31]	2021	AHP and TOPSIS	Triangular fuzzy
7	Valmohammadi et al. [32]	2021	AHP and TOPSIS	Triangular fuzzy
8	Seker and Aydin [33]	2022	SWARA and WASPAS	Intuitionistic fuzzy
9	Le et al. [34]	2022	DEA, AHP and CoCoSo	Spherical fuzzy
10	Salimian et al. [35]	2022	VIKOR and MARCOS	Intuitionistic fuzzy
11	Rezvani et al. [36]	2022	GIS and OWA	-
This study	Wang et al.	2022	SfRDMA and DEA	Spherical fuzzy

Notations: SWARA—stepwise weight assessment ratio analysis; WASPAS—weighted aggregated sum product assessment; CoCoSo—combined compromise solution; GIS—geographic information system; OWA—ordered weighted averaging.

3. Methodology

As shown in Figure 1, at the pre-processing stage, experts and related documents are assembled. Then, the super-efficiency of the alternatives is determined by the DEA model based on the quantitative indicators. Simultaneously, the effectiveness of the alternatives is calculated by the novel spherical fuzzy regret-theory-based decision-making approach, based on qualitative criteria. Finally, the composite scoring function is used to aggregate the efficiency and effectiveness scores of alternatives. The higher the ultimate score, the higher the alternative's rank.

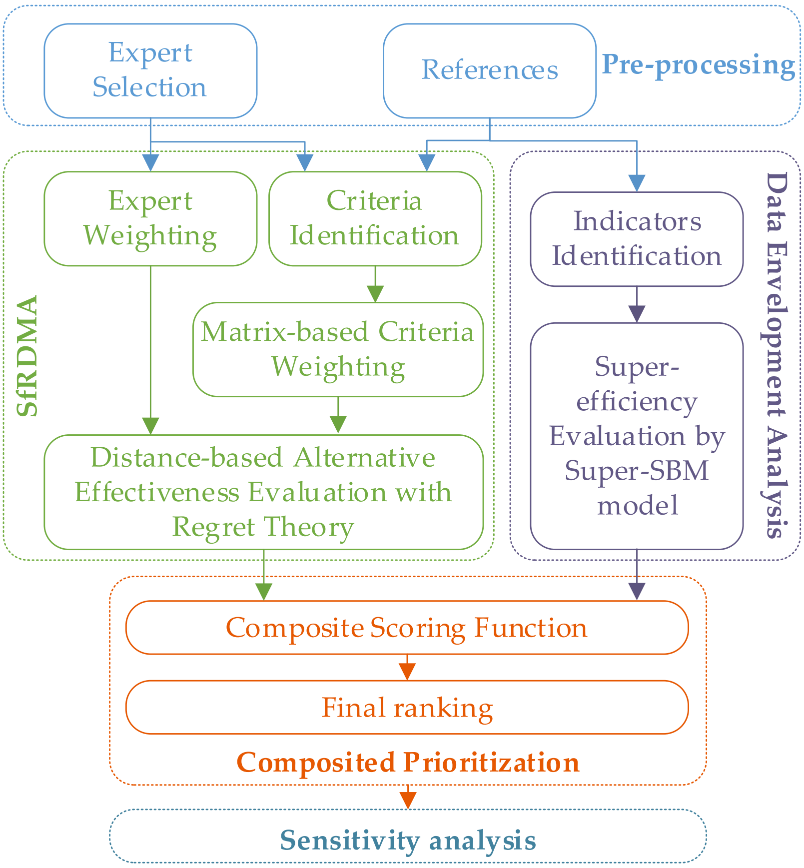

Figure 1. The proposed approach.

3.1. Preliminaries

3.1.1. Spherical Fuzzy Sets

Spherical fuzzy sets (SFS), an extension of fuzzy sets, have recently been introduced by Gundogdu et al. [23]. The decision-uncertain maker's judgment is stated in each level of membership, non-membership, and hesitance, as defined below.

Definition 1. *The SFS $\widetilde{A}$ of the universe of L is described in Equation (1) [23]:*

$$\widetilde{\mathrm{A}} = \left\{ \mathrm{l}, \vartheta_{\widetilde{\mathrm{A}}}(\mathrm{l}), \mu_{\widetilde{\mathrm{A}}}(\mathrm{l}), \pi_{\widetilde{\mathrm{A}}}(\mathrm{l}) \middle| \mathrm{l} \in \mathrm{L} \right\} \tag{1}$$

where $\vartheta_{\widetilde{A}}, \mu_{\widetilde{A}}, \pi_{\widetilde{A}}(l) : L \to [0,1]$ *and* $0 \leq \vartheta^2_{\widetilde{A}}(l) + \mu^2_{\widetilde{A}}(l) + \pi^2_{\widetilde{A}}(l) \leq 1, \forall l \in L$

The numbers $\vartheta_{\widetilde{A}}(l)$, $\mu_{\widetilde{A}}(l)$, $\pi_{\widetilde{A}}(l)$ are the levels of membership, non-membership, and hesitance of l to $\widetilde{A}$.

Definition 2. *The SFS of two values $\widetilde{A} = \left(\vartheta_{\widetilde{A}}, \mu_{\widetilde{A}}, \pi_{\widetilde{A}}\right)$ and $\widetilde{B} = \left(\vartheta_{\widetilde{B}}, \mu_{\widetilde{B}}, \pi_{\widetilde{B}}\right)$ of the universe of L_1 and L_2 are illustrated based on some calculations demonstrated by the following Equations (2)–(5) [23]:*

Addition

$$\widetilde{A} \oplus \widetilde{B} = \left(\sqrt{\vartheta^2_{\widetilde{A}} + \vartheta^2_{\widetilde{B}} - \vartheta^2_{\widetilde{A}}\vartheta^2_{\widetilde{B}}}, \mu_{\widetilde{A}}\mu_{\widetilde{B}}, \sqrt{\left(1 - \vartheta^2_{\widetilde{B}}\right)\pi^2_{\widetilde{A}} + \left(1 - \vartheta^2_{\widetilde{A}}\right)\pi^2_{\widetilde{B}} - \pi^2_{\widetilde{A}}\pi^2_{\widetilde{B}}} \right) \tag{2}$$

Multiplication

$$\widetilde{A} \otimes \widetilde{B} = \left(\vartheta_{\widetilde{A}} \vartheta_{\widetilde{B}}, \sqrt{\mu_{\widetilde{A}}^2 + \mu_{\widetilde{B}}^2 - \mu_{\widetilde{A}}^2 \mu_{\widetilde{B}}^2}, \sqrt{\left(1 - \mu_{\widetilde{B}}^2\right) \pi_{\widetilde{A}}^2 + \left(1 - \mu_{\widetilde{A}}^2\right) \pi_{\widetilde{B}}^2 - \pi_{\widetilde{A}}^2 \pi_{\widetilde{B}}^2} \right) \tag{3}$$

Multiplication by a scalar $(\lambda > 0)$

$$\lambda \widetilde{A} = \left(\sqrt{1 - (1 - \vartheta_{\widetilde{A}}^2)^{\lambda}}, \mu_{\widetilde{A}}^{\lambda}, \sqrt{(1 - \vartheta_{\widetilde{A}}^2)^{\lambda} - (1 - \vartheta_{\widetilde{A}}^2 - \pi_{\widetilde{A}}^2)^{\lambda}} \right) \tag{4}$$

Power of $\widetilde{A}$ *(*$\lambda > 0$*)*

$$\widetilde{A}^{\lambda} = \left(\vartheta_{\widetilde{A}}^{\lambda}, \sqrt{1 - (1 - \mu_{\widetilde{A}}^2)^{\lambda}}, \sqrt{\left(1 - \mu_{\widetilde{A}}^2\right)^{\lambda} - (1 - \mu_{\widetilde{A}}^2 - \pi_{\widetilde{A}}^2)^{\lambda}} \right) \tag{5}$$

Definition 3. *Spherical weighted geometric mean (SWG) and spherical weighted arithmetic mean (SWA) are described through the weight vector* $\omega = (\omega_1, \omega_2, \ldots, \omega_n)$*, where* $0 \leq \omega_i \leq 1$ *and* $\sum_{i=1}^{n} \omega_i = 1$ *by the following Equations (6) and (7) [23]:*

$$\begin{gathered} \mathrm{SWG}_{\omega}\left(\widetilde{A}_1, \widetilde{A}_2, \ldots, \widetilde{A}_n\right) = \widetilde{A}_1{}^{\omega_1} + \widetilde{A}_2{}^{\omega_2} + \ldots + \widetilde{A}_k{}^{\omega_k} \\ = \left(\prod_{i=1}^{k} \vartheta_{\widetilde{A}_i}^{\omega_i}, \sqrt{1 - \prod_{i=1}^{k} \left(1 - \mu_{\widetilde{A}_i}^2\right)^{\omega_i}}, \sqrt{\prod_{i=1}^{k} \left(1 - \mu_{\widetilde{A}_i}^2\right)^{\omega_i} - \prod_{i=1}^{k} (1 - \mu_{\widetilde{A}_i}^2 - \pi_{\widetilde{A}_i}^2)^{\omega_i}} \right) \end{gathered} \tag{6}$$

$$\begin{gathered} SWA_{\omega}\left(\widetilde{A}_1, \widetilde{A}_2, \ldots, \widetilde{A}_n\right) = \omega_1 \widetilde{A}_1 + \omega_2 \widetilde{A}_2 + \ldots + \omega_k \widetilde{A}_k \\ = \left(\sqrt{1 - \prod_{i=1}^{k} \left(1 - \vartheta_{\widetilde{A}_i}^2\right)^{\omega_i}}, \prod_{i=1}^{k} \mu_{\widetilde{A}_i}^{\omega_i}, \sqrt{\prod_{i=1}^{k} \left(1 - \vartheta_{\widetilde{A}_i}^2\right)^{\omega_i} - \prod_{i=1}^{k} (1 - \vartheta_{\widetilde{A}_i}^2 - \pi_{\widetilde{A}_i}^2)^{\omega_i}} \right) \end{gathered} \tag{7}$$

Definition 4. *The SFS of two values* $\widetilde{A} = \left(\vartheta_{\widetilde{A}}, \mu_{\widetilde{A}}, \pi_{\widetilde{A}}\right)$ *and* $\widetilde{B} = \left(\vartheta_{\widetilde{B}}, \mu_{\widetilde{B}}, \pi_{\widetilde{B}}\right)$ *of the expanse of* L_1 *and* L_2 *under the condition* λ, λ_1, $\lambda_2 > 0$, *are represented in Equations (8)–(13) [23]:*

$$\widetilde{A} \oplus \widetilde{B} = \widetilde{B} \oplus \widetilde{A} \tag{8}$$

$$\widetilde{A} \otimes \widetilde{B} = \widetilde{B} \otimes \widetilde{A} \tag{9}$$

$$\lambda\left(\widetilde{A} \oplus \widetilde{B}\right) = \lambda\widetilde{A} \oplus \lambda\widetilde{B} \tag{10}$$

$$\lambda_1\widetilde{A} \oplus \lambda_2\widetilde{A} = (\lambda_1 + \lambda_2)\widetilde{A} \tag{11}$$

$$(\widetilde{A} \otimes \widetilde{B})^{\lambda} = \widetilde{A}^{\lambda} \otimes \widetilde{B}^{\lambda} \tag{12}$$

$$\widetilde{A}^{\lambda_1} \oplus \widetilde{A}^{\lambda_2} = \widetilde{A}^{\lambda_1 + \lambda_2} \tag{13}$$

Definition 5. *The defuzzied value of SFN* $\widetilde{A} = \left(\vartheta_{\widetilde{A}}, \mu_{\widetilde{A}}, \pi_{\widetilde{A}}\right)$ *is represented by the following Equation (14):*

$$\mathrm{A} = (\vartheta_{\widetilde{A}} - \pi_{\widetilde{A}})^2 + (\mu_{\widetilde{A}} - \pi_{\widetilde{A}})^2 \tag{14}$$

3.1.2. Regret Theory

Regret theory is a well-known behavioral decision theory in which humans' bounded rationality is considered. Accordingly, the decision maker will feel regretful when choosing an alternative that is worse than others. Conversely, the decision maker will rejoice in the choice. The findings of regret theory can be presented as the following definitions.

Definition 6. *Let x be a consequence of choosing alternative X, the utility value is obtained by alternative X can be determined as follows:*

$$u(x) = x^{\varphi},\ \ 0 < \varphi < 1 \tag{15}$$

where φ represents the decision maker's risk-aversion coefficient. The larger the value of the risk-aversion coefficient, the smaller the degree of the decision maker's risk aversion. Based on experiments, the value of φ is suggested to be 0.88.

Definition 7. *Let x_1 and x_2 be consequences of choosing alternative X_1 and X_2. The regret–rejoice value of choosing alternative X_1 rather than X_2 is determined as follows:*

$$r(x_1, x_2) = 1 - e^{-\lambda(u(x_1) - u(x_2))},\ \ \lambda > 0 \tag{16}$$

where λ represents the decision maker's regret-aversion coefficient. The smaller the value of the regret-aversion coefficient, the smaller the degree of decision maker's regret aversion. The value of $r(x_1, x_2)$ represents the regret value when $u(x_1) \le u(x_2)$. Otherwise, it represents the rejoice value. Based on experiments, the value of λ is suggested to be 0.3.

Definition 8. *Let $x_i(i = 1 \ldots n)$ be a consequence of choosing alternative $X_i(i = 1 \ldots n)$. The overall utility value is obtained by alternative X_i and can be defined as:*

$$v(x_i) = u(x_i) + r(x_i, x^*) \tag{17}$$

where

$$x^* = \max_{1 \le i \le n} x_i \text{ and } r(x_i, x^*) \le 0 \tag{18}$$

3.2. Composited Group Decision-Making Approach

3.2.1. Super-Efficiency Slack-Based Model (Super-SBM)

In 1978, DEA was first introduced as a method to measure the relative efficiency of decision-making units (DMUs) [37]. DMUs can be companies, organizations, etc., that can take multiple inputs and convert them to different outputs. Over the years, the development of different models in DEA has evolved and is widely adopted by researchers in many fields around the world [38]. The first model is the CCR model (Charnes, Cooper and Rhodes), followed by the BBC model (Banker, Charnes and Cooper) [39]. In 2001, Tone developed a slack-based performance measure (SBM) to evaluate the efficiency (ρ_1) of DMU_k in n DMUs with s output and m inputs, according to Equation (19) [40]:

$$\begin{gathered} min\ \rho_1 = \frac{1 - \frac{1}{m}\sum_{i=1}^{m}\frac{s_i^-}{x_{ik}}}{1 + \frac{1}{s}\sum_{r=1}^{s}\frac{s_r^+}{y_{rk}}} \\ Subject\ to \\ x_{ik} = \sum_{j=1}^{n} x_{ik}\lambda_j + s_i^-, i = 1,\ \ldots,\ m \\ y_{rk} = \sum_{j=1}^{n} y_{rj}\lambda_j - s_i^+, r = 1,\ \ldots,\ s \\ \lambda_j \ge 0,\ i = 1,\ \ldots,\ n \\ s_i^- \ge 0,\ i = 1,\ \ldots,\ m \\ s_r^+ \ge 0,\ i = 1,\ \ldots,\ s \end{gathered} \tag{19}$$

where x_{ij} and y_{rj} denote the ith input and the rth output of the DMU_j, respectively. The λ_j is a nonnegative vector with $\sum_{j=1}^{n}\lambda_j = 1$. Let $x_i^1 = x_{ik} - s_i^-$ and $y_r^1 = y_{rk} - s_r^+$. The SBM model can be rewritten by Equation (20):

$$\begin{gathered} min\ \rho_1 = \frac{\frac{1}{m}\sum_{i=1}^{m}\frac{x_i^1}{x_{ik}}}{\frac{1}{s}\sum_{r=1}^{s}\frac{y_r^1}{y_{rk}}} \\ Subject\ to \\ x_i^1 \geq \sum_{j=1}^{n} x_{ik}\lambda_j, i = 1, \ldots, m \\ y_r^1 \leq \sum_{j=1}^{n} y_{rj}\lambda_j, r = 1, \ldots, s \\ \lambda_j \geq 0,\ i = 1, \ldots, n \\ x_{ik} \geq x_i^1 \geq 0,\ i = 1, \ldots, m \\ y_r^1 \geq y_{rk},\ r = 1, \ldots, s \end{gathered} \tag{20}$$

However, demonstrating the efficiency of the DMUs, the SBM model uses a benchmark of "1". Due to this limitation, Tone developed a super-SBM model with unlimited scores to evaluate the efficiency of a DMU [41]. The super-SBM DEA model is used to evaluate the super-efficiency of $DMU_k\ (\rho_2)$, according to Equation (21):

$$\begin{gathered} min\ \rho_2 = \frac{\frac{1}{m}\sum_{i=1}^{m}\frac{x_i^2}{x_{ik}}}{\frac{1}{s}\sum_{r=1}^{s}\frac{y_r^2}{y_{rk}}} \\ Subject\ to \\ x_i^2 \geq \sum_{j=1,\ j\neq k}^{n} x_{ik}\lambda_j, i = 1, \ldots, m \\ y_r^2 \leq \sum_{j=1, j\neq k}^{n} y_{rj}\lambda_j, r = 1, \ldots, s \\ \lambda_j \geq 0,\ \mathrm{j} = 1, \ldots, \mathrm{n}\ ,\ j \neq k \\ x_{ik} \leq x_i^2,\ i = 1, \ldots, m \\ 0 \leq y_r^2 \leq y_{rk},\ r = 1, \ldots, s \end{gathered} \tag{21}$$

If the DMU_k is determined as efficient by model (20), then model (21) is used to calculate super-efficiency with any feasible solution $\left(x_i^2, y_r^2\right)$. The super-efficiency of DMUs is denoted as efficiency score (AS_i^α) in this approach.

3.2.2. Spherical Fuzzy Regret-Theory-Based Decision-Making Approach (SfRDMA)

The growing trend of MCDM approaches is to combine different methods in roles such as weighting criteria, prioritizing alternatives, and aggregating results [5]. For criterion weighting, the robustness of the DEMATEL method, which is based on matrix calculations, has been proven in many studies [13,14,21]. For the prioritization of alternatives, distance-based methods such as TOPSIS and EDAS are widely applied [42,43]. On the other hand, for integrating the results of many different methods, the geometric mean and the arithmetic mean are common candidates for the task of aggregation operators [30,44]. Accordingly, this study proposes novel approaches that combine the principles of matrix computation and distance-based solution analysis in a spherical fuzzy environment. Moreover, the proposed approach is reinforced by regret theory to evaluate the influence of behavior on decision making. The proposed approach includes the following steps:

Step 1. A group of decision makers $(k = 1 \ldots K)$ is identified to contribute assessments. Then, the weight of the kth decision maker (Ψ_k) is determined by Equation (22) based on his/her expertise, which is presented as the given SFN $\widetilde{Q}^k = \left(\vartheta_{\widetilde{Q}^k}, \mu_{\widetilde{Q}^k}, \pi_{\widetilde{Q}^k}\right)$ [45]. The expertise of decision makers is defined by higher-level decision makers in linguistics terms, as shown in Table 2.

$$\Psi_k = \frac{1 - \sqrt{\left(\left(1 - \vartheta^2_{\widetilde{Q}^k}\right) + \mu^2_{\widetilde{Q}^k} + \pi^2_{\widetilde{Q}^k}\right)/3\right)}}{\sum_{l=1}^{K}\left(1 - \sqrt{\left(\left(1 - \vartheta^2_{\widetilde{Q}^l}\right) + \mu^2_{Q^l} + \pi^2_{\widetilde{Q}^l}\right)/3\right)}\right)} \tag{22}$$

$$\text{where} \sum_{k=1}^{K} \Psi_k = 1 \text{ and } 0 \leq \vartheta^2_{\widetilde{Q}^k} + \mu^2_{\widetilde{Q}^k} + \pi^2_{\widetilde{Q}^k} \leq 1$$

Table 2. Linguistic terms for expertise's decision makers.

Linguistic Term	Spherical Fuzzy Number (ϑ,μ,π)
Very high	(0.85, 0.15, 0.45)
High	(0.60, 0.20, 0.35)
Moderate	(0.35, 0.25, 0.25)

Step 2. Decision makers define evaluation criteria $(j = 1 \ldots J)$ based on expertise, experience, and references. Then, decision makers provide pairwise comparisons in the form of linguistic terms about the influence among criteria. As shown in the scale presented in Table 3, pairwise comparisons are converted to SFNs.

Table 3. Linguistic terms for criteria influence [22].

Linguistic Term	Spherical Fuzzy Number (ϑ,μ,π)
No influence	(0.00, 0.30, 0.15)
Weak influence	(0.35, 0.25, 0.25)
Moderate influence	(0.60, 0.20, 0.35)
Strong influence	(0.85, 0.15, 0.45)

As a result, the individual SF direct-influence matrices are established. The individual SF direct-influence matrix of kth decision maker $(\widetilde{A}^k)$ is represented as Equation (23).

$$\widetilde{A}^k = \begin{bmatrix} \widetilde{a}^k_{11} & \widetilde{a}^k_{12} & \cdots & \widetilde{a}^k_{1J} \\ \widetilde{a}^k_{21} & \widetilde{a}^k_{22} & \cdots & \widetilde{a}^k_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{a}^k_{J1} & \widetilde{a}^k_{J2} & \cdots & \widetilde{a}^k_{JJ} \end{bmatrix} with\ \widetilde{a}^k_{jp} = \left(\vartheta_{\widetilde{x}^k_{jp}}, \mu_{\widetilde{x}^k_{jp}}, \pi_{\widetilde{x}^k_{jp}}\right); j = 1 \ldots J, p = 1 \ldots J \quad (23)$$

Step 3. To aggregate individual matrices, the spherical weight arithmetic mean is used with decision makers' weights (Ψ_k), as described in Equation (7). Hence, the SF direct-influence matrix $\left(\widetilde{A}\right)$ is established, as represented in Equation (24).

$$\widetilde{A} = \begin{bmatrix} \widetilde{a}_{11} & \widetilde{a}_{12} & \cdots & \widetilde{a}_{1J} \\ \widetilde{a}_{21} & \widetilde{a}_{22} & \cdots & \widetilde{a}_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{a}_{J1} & \widetilde{a}_{J2} & \cdots & \widetilde{a}_{JJ} \end{bmatrix} with\ \widetilde{a}_{jp} = \left(\vartheta_{\widetilde{a}_{jp}}, \mu_{\widetilde{a}_{jp}}, \pi_{\widetilde{a}_{jp}}\right); j = 1 \ldots J, p = 1 \ldots J \quad (24)$$

Step 4. To construct the SF initial direct-influence submatrices, the SF direct influence matrix is separated into three submatrices corresponding to the three parameters of spherical fuzzy, as represented in Equation (25). Then, the submatrices are normalized according to Equations (26)–(28).

$$A^\vartheta = \begin{bmatrix} \vartheta_{\widetilde{a}_{11}} & \vartheta_{\widetilde{a}_{12}} & \cdots & \vartheta_{\widetilde{a}_{1J}} \\ \vartheta_{\widetilde{a}_{21}} & \vartheta_{\widetilde{a}_{22}} & \cdots & \vartheta_{\widetilde{a}_{2J}} \\ \vdots & \vdots & \ddots & \vdots \\ \vartheta_{\widetilde{a}_{J1}} & \vartheta_{\widetilde{a}_{J2}} & \cdots & \vartheta_{\widetilde{a}_{JJ}} \end{bmatrix}, A^\mu = \begin{bmatrix} \mu_{\widetilde{a}_{11}} & \mu_{\widetilde{a}_{12}} & \cdots & \mu_{\widetilde{a}_{1J}} \\ \mu_{\widetilde{a}_{21}} & \mu_{\widetilde{a}_{22}} & \cdots & \mu_{\widetilde{a}_{2J}} \\ \vdots & \vdots & \ddots & \vdots \\ \mu_{\widetilde{a}_{J1}} & \mu_{\widetilde{a}_{J2}} & \cdots & \mu_{\widetilde{a}_{JJ}} \end{bmatrix}, A^\pi = \begin{bmatrix} \pi_{\widetilde{a}_{11}} & \pi_{\widetilde{a}_{12}} & \cdots & \pi_{\widetilde{a}_{1J}} \\ \pi_{\widetilde{a}_{21}} & \pi_{\widetilde{a}_{22}} & \cdots & \pi_{\widetilde{a}_{2J}} \\ \vdots & \vdots & \ddots & \vdots \\ \pi_{\widetilde{a}_{J1}} & \pi_{\widetilde{a}_{J2}} & \cdots & \pi_{\widetilde{a}_{JJ}} \end{bmatrix} \quad (25)$$

$$B^{\vartheta} = \begin{bmatrix} \vartheta_{\widetilde{b}_{11}} & \vartheta_{\widetilde{b}_{12}} & \cdots & \vartheta_{\widetilde{b}_{1J}} \\ \vartheta_{\widetilde{b}_{21}} & \vartheta_{\widetilde{b}_{22}} & \cdots & \vartheta_{\widetilde{b}_{2J}} \\ \vdots & \vdots & \ddots & \vdots \\ \vartheta_{\widetilde{b}_{J1}} & \vartheta_{\widetilde{b}_{J2}} & \cdots & \vartheta_{\widetilde{b}_{JJ}} \end{bmatrix} \text{ where } \vartheta_{\widetilde{b}_{jp}} = \vartheta_{\widetilde{a}_{jp}} \times min\left(\frac{1}{\max\limits_{1 \le j \le J} \sum_{p=1}^{J} \vartheta_{\widetilde{a}_{jp}}}, \frac{1}{\max\limits_{p1 \le p \le J} \sum_{j=1}^{J} \vartheta_{\widetilde{a}_{jp}}} \right); j = 1 \ldots J, p = 1 \ldots J \tag{26}$$

$$B^{\mu} = \begin{bmatrix} \mu_{\widetilde{b}_{11}} & \mu_{\widetilde{b}_{12}} & \cdots & \mu_{\widetilde{b}_{1J}} \\ \mu_{\widetilde{b}_{21}} & \mu_{\widetilde{b}_{22}} & \cdots & \mu_{\widetilde{b}_{2J}} \\ \vdots & \vdots & \ddots & \vdots \\ \mu_{\widetilde{b}_{J1}} & \mu_{\widetilde{b}_{J2}} & \cdots & \mu_{\widetilde{b}_{JJ}} \end{bmatrix} \text{ where } \mu_{\widetilde{b}_{jp}} = \mu_{\widetilde{a}_{jp}} \times min\left(\frac{1}{\max\limits_{1 \le j \le J} \sum_{p=1}^{J} \mu_{\widetilde{a}_{jp}}}, \frac{1}{\max\limits_{1 \le p \le J} \sum_{j=1}^{J} \mu_{\widetilde{a}_{jp}}} \right); j = 1 \ldots J, p = 1 \ldots J \tag{27}$$

$$B^{\pi} = \begin{bmatrix} \pi_{\widetilde{b}_{11}} & \pi_{\widetilde{b}_{12}} & \cdots & \pi_{\widetilde{b}_{1J}} \\ \pi_{\widetilde{b}_{21}} & \pi_{\widetilde{b}_{22}} & \cdots & \pi_{\widetilde{b}_{2J}} \\ \vdots & \vdots & \ddots & \vdots \\ \pi_{\widetilde{b}_{J1}} & \pi_{\widetilde{b}_{J2}} & \cdots & \pi_{\widetilde{b}_{JJ}} \end{bmatrix} \text{ where } \pi_{\widetilde{b}_{jp}} = \pi_{\widetilde{a}_{jp}} \times min\left(\frac{1}{\max\limits_{1 \le j \le J} \sum_{p=1}^{J} \pi_{\widetilde{a}_{jp}}}, \frac{1}{\max\limits_{1 \le p \le J} \sum_{j=1}^{J} \pi_{\widetilde{a}_{jp}}} \right); j = 1 \ldots J, p = 1 \ldots J \tag{28}$$

Step 5. The SF total-influence submatrices are calculated based on the SF initial direct-influence submatrices, according to Equations (29)–(31) [21]. However, in some cases, results that are inconsistent with the nature of the SFN appear by the conversation process. To remedy this situation, the conversation results that are not consistent with the SFN should be adjusted by Euclidean normalization. By concatenating submatrices, the SF total influence matrix $\left(\widetilde{C}\right)$ is formed, as shown in Equation (32).

$$C^{\vartheta} = B^{\vartheta} + B^{\vartheta'} = B^{\vartheta}\left(I - B^{\vartheta}\right)^{-1} = \begin{bmatrix} \vartheta_{\widetilde{c}_{11}} & \vartheta_{\widetilde{c}_{12}} & \cdots & \vartheta_{\widetilde{c}_{1J}} \\ \vartheta_{\widetilde{c}_{21}} & \vartheta_{\widetilde{c}_{22}} & \cdots & \vartheta_{\widetilde{c}_{2J}} \\ \vdots & \vdots & \ddots & \vdots \\ \vartheta_{\widetilde{c}_{J1}} & \vartheta_{\widetilde{c}_{J2}} & \cdots & \vartheta_{\widetilde{c}_{JJ}} \end{bmatrix} \tag{29}$$

$$C^{\mu} = B^{\mu} + B^{\mu'} = B^{\mu}(I - B^{\mu})^{-1} = \begin{bmatrix} \mu_{\widetilde{c}_{11}} & \mu_{\widetilde{c}_{12}} & \cdots & \mu_{\widetilde{c}_{1J}} \\ \mu_{\widetilde{c}_{21}} & \mu_{\widetilde{c}_{22}} & \cdots & \mu_{\widetilde{c}_{2J}} \\ \vdots & \vdots & \ddots & \vdots \\ \mu_{\widetilde{c}_{J1}} & \mu_{\widetilde{c}_{J2}} & \cdots & \mu_{\widetilde{c}_{JJ}} \end{bmatrix} \tag{30}$$

$$C^{\pi} = B^{\pi} + B^{\pi'} = B^{\pi}(I - B^{\pi})^{-1} = \begin{bmatrix} \pi_{\widetilde{c}_{11}} & \pi_{\widetilde{c}_{12}} & \cdots & \pi_{\widetilde{c}_{1J}} \\ \pi_{\widetilde{c}_{21}} & \pi_{\widetilde{c}_{22}} & \cdots & \pi_{\widetilde{c}_{2J}} \\ \vdots & \vdots & \ddots & \vdots \\ \pi_{\widetilde{c}_{J1}} & \pi_{\widetilde{c}_{J2}} & \cdots & \pi_{\widetilde{c}_{JJ}} \end{bmatrix} \tag{31}$$

$$\widetilde{C} = \begin{bmatrix} \widetilde{c}_{11} & \widetilde{c}_{12} & \cdots & \widetilde{c}_{1J} \\ \widetilde{c}_{21} & \widetilde{c}_{22} & \cdots & \widetilde{c}_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{c}_{J1} & \widetilde{c}_{J2} & \cdots & \widetilde{c}_{JJ} \end{bmatrix} \text{ with } \widetilde{c}_{jp} = \left(\vartheta_{\widetilde{c}_{jp}}, \mu_{\widetilde{c}_{jp}}, \pi_{\widetilde{c}_{jp}}\right); j = 1 \ldots J, p = 1 \ldots J \tag{32}$$

Step 6. For criteria weighting, the SF total-influence matrix is defuzzied, according to Equation (14) and represented as Equation (33). Then, the weights of the criteria are determined according to Equations (34) and (35).

$$C = \begin{bmatrix} c_{11} & c_{12} & \cdots & c_{1J} \\ c_{21} & c_{22} & \cdots & c_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ c_{J1} & c_{J2} & \cdots & c_{JJ} \end{bmatrix} \tag{33}$$

$$c_j^{row} = \sum_{p=1}^{J} c_{jp};\ c_j^{column} = \sum_{p=1}^{J} c_{pj} \tag{34}$$

$$w_j = \frac{c_j^{row} + c_j^{column}}{\sum_{j=1}^{J}\left(c_j^{row} + c_j^{column}\right)} \tag{35}$$

Step 7. Decision makers provide linguistic evaluations of alternatives $(i = 1 \ldots I)$ for each criterion. As shown in Table 4, linguistic evaluations are converted into corresponding SFNs. As a result, the individual SF decision matrices $\left(\widetilde{S}^k\right)$ are constructed, as shown in Equation (36). Based on the decision makers' weights (Ψ_k), the SF decision matrix $\left(\widetilde{S}\right)$ is aggregated using the spherical weight arithmetic mean, as shown in Equation (37).

$$\widetilde{S}^k = \begin{bmatrix} \widetilde{s}_{11}^k & \widetilde{s}_{12}^k & \cdots & \widetilde{s}_{1J}^k \\ \widetilde{s}_{21}^k & \widetilde{s}_{22}^k & \cdots & \widetilde{s}_{2J}^k \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{s}_{I1}^k & \widetilde{s}_{I2}^k & \cdots & \widetilde{s}_{IJ}^k \end{bmatrix} \ with\ \widetilde{s}_{ij}^k = \left(\vartheta_{\widetilde{s}_{ij}^k}, \mu_{\widetilde{s}_{ij}^k},\ \pi_{\widetilde{s}_{ij}^k}\right); i = 1 \ldots I, j = 1 \ldots J \tag{36}$$

$$\widetilde{S} = \begin{bmatrix} \widetilde{s}_{11} & \widetilde{s}_{12} & \cdots & \widetilde{s}_{1J} \\ \widetilde{s}_{21} & \widetilde{s}_{22} & \cdots & \widetilde{s}_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ \widetilde{s}_{I1} & \widetilde{s}_{I2} & \cdots & \widetilde{s}_{IJ} \end{bmatrix} \ with\ \widetilde{s}_{ij} = \left(\vartheta_{\widetilde{s}_{ij}}, \mu_{\widetilde{s}_{ij}},\ \pi_{\widetilde{s}_{ij}}\right); i = 1 \ldots I, j = 1 \ldots J \tag{37}$$

Table 4. Linguistic terms for decision matrix [42].

Linguistic Term	Spherical Fuzzy Number (ϑ,μ,π)	Linguistic Term	Spherical Fuzzy Number (ϑ,μ,π)
Absolutely Low	(0.1, 0.9, 0.1)	Slightly High	(0.6, 0.4, 0.4)
Very Low	(0.2, 0.8, 0.2)	High	(0.7, 0.3, 0.3)
Low	(0.3, 0.7, 0.3)	Very High	(0.8, 0.2, 0.2)
Slightly Low	(0.4, 0.6, 0.4)	Absolutely High	(0.9, 0.1, 0.1)
Neutral	(0.5, 0.5, 0.5)		

Step 8. The SF decision matrix (S) is then defuzzied, as represented in Equation (38). Applying regret theory, the utility matrix (U) is constructed with the risk-aversion coefficient (φ) as Equation (39).

$$S = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1J} \\ s_{21} & s_{22} & \cdots & s_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ s_{I1} & s_{I2} & \cdots & s_{IJ} \end{bmatrix} \tag{38}$$

$$U = \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1J} \\ u_{21} & u_{22} & \cdots & u_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ u_{I1} & u_{I2} & \cdots & u_{IJ} \end{bmatrix} \; with \; u_{ij} = \left(s_{ij}\right)^{\varphi}; i = 1 \ldots I, j = 1 \ldots J, 0 < \varphi < 1 \quad (39)$$

Step 9. Based on the utility matrix, the vector of ideal points (U^*) is defined as Equations (40) and (41). Hence, the regret matrix (T) is determined with the regret-aversion coefficient (λ), according to Equation (42).

$$U^* = \begin{bmatrix} u_1^* & u_2^* & \cdots & u_J^* \end{bmatrix} \quad (40)$$

where

$$u_j^* = \max_{1 \le i \le I}\left(u_{ij}\right);\; j = 1 \ldots J \quad (41)$$

$$T = \begin{bmatrix} t_{11} & t_{12} & \cdots & t_{1J} \\ t_{21} & t_{22} & \cdots & t_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ t_{I1} & t_{I2} & \cdots & t_{IJ} \end{bmatrix} \; with \; t_{ij} = 1 - e^{-\lambda\left(u_{ij} - u_j^*\right)}; i = 1 \ldots I, j = 1 \ldots J, \lambda > 0 \quad (42)$$

Step 10. The overall utility matrix (V) is defined according to Equation (43).

$$V = \begin{bmatrix} v_{11} & v_{12} & \cdots & v_{1J} \\ v_{21} & v_{22} & \cdots & v_{2J} \\ \vdots & \vdots & \ddots & \vdots \\ v_{I1} & v_{I2} & \cdots & v_{IJ} \end{bmatrix} \; with \; v_{ij} = u_{ij} + t_{ij};\; i = 1 \ldots I, j = 1 \ldots J \quad (43)$$

Step 11. The vector of average solution $\left(\overline{V}\right)$ is defined as Equations (44) and (45).

$$\overline{V} = \begin{bmatrix} \overline{v}_1 & \overline{v}_2 & \cdots & \overline{v}_J \end{bmatrix} \quad (44)$$

where

$$\overline{v}_j = \frac{1}{I} \sum\nolimits_{i=1}^{I} v_{ij} \quad (45)$$

Step 12. The positive (V^+) and negative distance (V^-) from average solution matrices are determined according to Equations (46) and (47).

$$V^+ = \begin{bmatrix} v_{11}^+ & v_{12}^+ & \cdots & v_{1J}^+ \\ v_{21}^+ & v_{22}^+ & \cdots & v_{2J}^+ \\ \vdots & \vdots & \ddots & \vdots \\ v_{I1}^+ & v_{I2}^+ & \cdots & v_{IJ}^+ \end{bmatrix} with v_{ij}^+ = \max\left(0, \left(v_{ij} - \overline{v}_j\right)\right); i = 1 \ldots I, j = 1 \ldots J \quad (46)$$

$$V^- = \begin{bmatrix} v_{11}^- & v_{12}^- & \cdots & v_{1J}^- \\ v_{21}^- & v_{22}^- & \cdots & v_{2J}^- \\ \vdots & \vdots & \ddots & \vdots \\ v_{I1}^- & v_{I2}^- & \cdots & v_{IJ}^- \end{bmatrix} with v_{ij}^- = \max\left(0, \left(\overline{v}_j - v_{ij}\right)\right); i = 1 \ldots I, j = 1 \ldots J \quad (47)$$

Step 13. The effectiveness appraisal scores $\left(AS_i^{\beta}\right)$ of alternatives are determined according to Equation (48). The alternative with a higher appraisal score is better.

$$AS_i^{\beta} = \frac{1}{2}\left(\left(\frac{\sum_{j=1}^{J} w_j v_{ij}^+}{\max\limits_{1 \le i \le I}\left(\sum_{j=1}^{J} w_j v_{ij}^+\right)}\right) + \left(1 - \frac{\sum_{j=1}^{J} w_j v_{ij}^-}{\max\limits_{1 \le i \le I}\left(\sum_{j=1}^{J} w_j v_{ij}^-\right)}\right)\right) \quad (48)$$

3.2.3. Composite-Scoring Function

The efficiency and effectiveness appraisal scores are normalized as Equations (49) and (50). Finally, the ultimate score of an alternative (US_i) is defined as Equation (51). The alternatives are ranked in descending order, according to the values of the ultimate scores. In other words, the greater the value of the ultimate score, the better the alternative.

$$NAS_i^{\alpha} = \frac{AS_i^{\alpha} - \min_{1 \le i \le I}\left(AS_i^{\alpha}\right)}{\max_{1 \le i \le I}\left(AS_i^{\alpha}\right) - \min_{1 \le i \le I}\left(AS_i^{\alpha}\right)} \quad (49)$$

$$NAS_i^{\beta} = \frac{AS_i^{\beta} - \min_{1 \le i \le I}\left(AS_i^{\beta}\right)}{\max_{1 \le i \le I}\left(AS_i^{\beta}\right) - \min_{1 \le i \le I}\left(AS_i^{\beta}\right)} \quad (50)$$

$$US_i = \left(\frac{NAS_i^{\alpha} + NAS_i^{\beta}}{2}\right) + \sqrt{NAS_i^{\alpha} + NAS_i^{\beta}} \quad (51)$$

4. Numerical Results

As discussed, the objective of this study is to prioritize countries in Southeast Asia as destinations for high-tech production line displacement. Accordingly, thirteen countries with great potential in Southeast Asia were considered as alternatives in the problem of prioritization. This list included Brunei Darussalam, Vietnam, Lao PDR, Malaysia, India, Indonesia, Philippines, Thailand, Myanmar, Singapore, Cambodia, Bangladesh, and Sri Lanka. Then, the efficiency and effectiveness of these countries were determined, as shown in Sections 4.1 and 4.2.

4.1. Efficiency Determination by Super-SBM

For efficiency, there are five proposed indicators to assess the efficiency of countries according to expert's suggestions. These indicators include inflation, export costs, GDPs, high-tech export records, and ease-of-doing-business scores. These metrics are categorized as the inputs and outputs of the super-SBM model. Accordingly, the outputs are indicators for which the larger the value, the better. Conversely, indicators with as low a value as possible are considered inputs. The data for these indicators were collected from the open database of the World Bank and are presented in Table A1 in Appendix A [46].

By solving the super-SBM model, the efficiency of the countries is determined as described in Table A2 and illustrated in Figure 2. Based on the efficiency scores, countries can be divided into three groups. The first group—the countries with efficiency scores greater than 1—included five countries: India, Thailand, Malaysia, Cambodia, and Singapore. They were be considered to be countries on the way to fast economic development and convenient transportation. They are most suitable for developing high-tech manufacturing projects, in terms of efficiency. The second group—Vietnam, Philippines, and Indonesia—can also attract attention because of the insignificant difference in assessment scores. In contrast, the remaining countries, with scores close to zero, can be considered as inefficient for high-tech production lines in the near future.

4.2. Effectiveness Determination by SfRDMA

For effectiveness, first, a group of ten experts was established with qualifications as shown in Table A3. In step 1, because of differences in expertise, the weights of experts (Ψ_k) were determined according to Equation (22), as illustrated in Figure 3. As suggested by experts and references, ten criteria were identified to evaluate the effectiveness of countries, including construction, installation costs (EFC-1) [47,48], diversity of transportation services (EFC-2) [47,49,50], labor costs (EFC-3) [47,49,50], human resources availability (EFC-4) [47,49,50], political stability (EFC-5) [47], environmental management systems (EFC-6) [47,48], logistics costs (EFC-7) [47,49], land costs (EFC-8) [47,50], government policies (EFC-9) [47], and climate (EFC-10) [48].

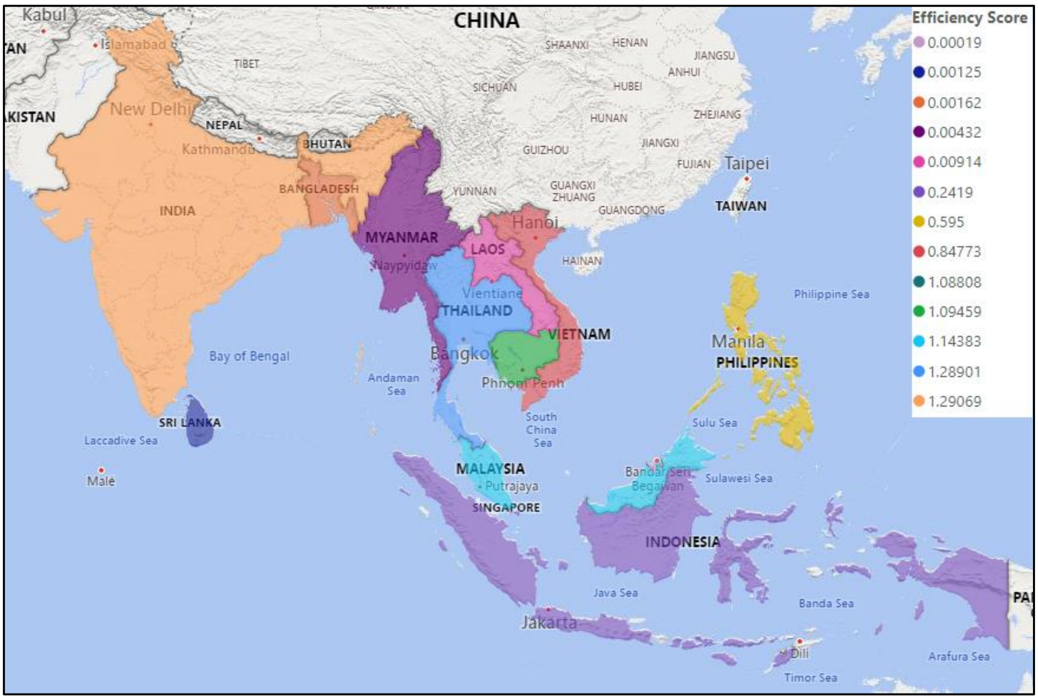

Figure 2. Super-SBM efficiency map.

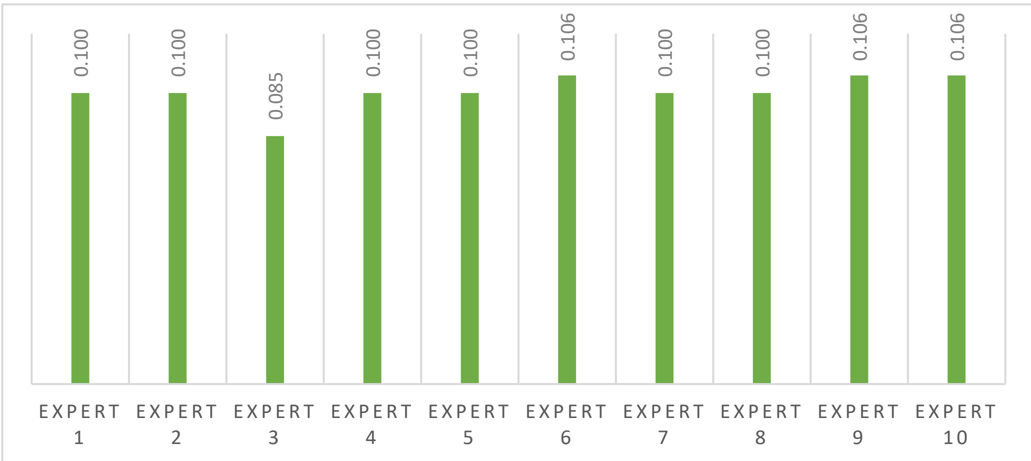

Figure 3. Experts' weights.

In step 2, linguistic pairwise comparisons of influence across criteria were provided by each expert. Then, the linguistic terms were converted into the scale SFNs, as shown in Table 3. As a result, the individual SF direct-influence matrices were established. Based on expert weights, the SF direct influence matrix was aggregated using the spherical weight arithmetic mean as Equation (7) in step 3. The SF direct-influence matrix is shown in Table A4. Based on that matrix, in step 4 and step 5, the SF total-influence matrix was determined according to Equations (25)–(32), as shown in Table A5. In step 6, as shown in Table 5, the defuzzied total influence matrix was formed according to Equation (14). According to Equations (34) and (35), the criteria weights were determined and are illustrated in Figure 4. From the results, government policy (EFC-9), political stability (EFC-5), and human resources availability (EFC-4) were the three most important criteria, with weights of 0.128, 0.120, and 0.109, respectively. The weight of the environmental management system criterion (EFC-6) had the lowest importance, with a weight of 0.073. Meanwhile, the remaining criteria had no significant difference in weight.

Table 5. The defuzzied total influence matrix construction.

Criteria	EFC-1	EFC-2	EFC-3	EFC-4	EFC-5	EFC-6	EFC-7	EFC-8	EFC-9	EFC-10
EFC-1	0.018	0.030	0.027	0.036	0.028	0.028	0.024	0.023	0.026	0.024
EFC-2	0.020	0.035	0.025	0.023	0.021	0.016	0.022	0.023	0.028	0.019
EFC-3	0.024	0.024	0.025	0.023	0.023	0.019	0.024	0.022	0.034	0.018
EFC-4	0.028	0.030	0.028	0.026	0.030	0.028	0.028	0.038	0.037	0.028
EFC-5	0.027	0.037	0.032	0.038	0.035	0.034	0.047	0.039	0.048	0.034
EFC-6	0.013	0.014	0.019	0.017	0.020	0.017	0.019	0.016	0.022	0.009
EFC-7	0.025	0.023	0.024	0.022	0.023	0.017	0.028	0.024	0.029	0.020
EFC-8	0.018	0.032	0.022	0.023	0.024	0.016	0.019	0.028	0.033	0.017
EFC-9	0.040	0.038	0.043	0.039	0.035	0.030	0.034	0.040	0.032	0.034
EFC-10	0.019	0.030	0.026	0.029	0.028	0.016	0.027	0.022	0.025	0.028

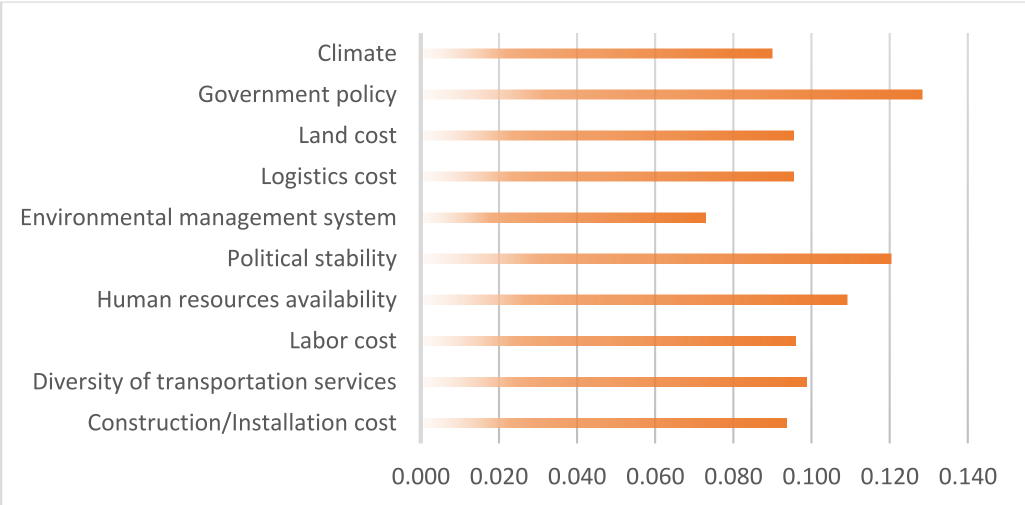

Figure 4. Criteria weighting results.

In step 7, experts provided linguistic assessments of the alternatives corresponding to the criteria. These linguistic assessments were converted into the individual SF decision matrices, as shown in Table 3. Once again, the spherical weight arithmetic mean was used for the aggregation of individual matrices. As a result, the SF decision matrix was constructed as shown in Table A6. In steps 8–10, the SF decision matrix was then defuzzied, according to Equation (14). The defuzzied results are shown in Table A7. According to Equations (39) and (43), with the suggested risk-aversion coefficient $(\varphi = 0.88)$ and regret-aversion coefficient $(\lambda = 0.3)$ [51], the utility matrix, the regret matrix, and the overall utility matrix were established, as shown in Tables 6–8. Based on the overall utility matrix, as shown in Table 8, the average solution vector was determined according to Equations (44) and (45) in step 11. In step 12, the positive and negative distance from average solution matrices was calculated as Equations (46) and (47). Finally, according to Equation (48) in step 13, the effectiveness score was determined, as shown in Table A8 and illustrated in Figure 5.

Table 6. Utility matrix.

Country	EFC-1	EFC-2	EFC-3	EFC-4	EFC-5	EFC-6	EFC-7	EFC-8	EFC-9	EFC-10
Brunei Darussalam	0.074	0.190	0.315	0.167	0.171	0.211	0.135	0.139	0.180	0.266
Viet Nam	0.108	0.132	0.188	0.183	0.176	0.368	0.202	0.230	0.265	0.107
Lao PDR	0.185	0.092	0.291	0.168	0.151	0.141	0.187	0.193	0.123	0.241
Malaysia	0.219	0.146	0.133	0.046	0.329	0.157	0.275	0.243	0.149	0.089
India	0.079	0.247	0.068	0.423	0.149	0.482	0.135	0.120	0.187	0.164
Indonesia	0.211	0.210	0.235	0.178	0.266	0.203	0.165	0.023	0.318	0.258
Philippines	0.157	0.129	0.132	0.132	0.292	0.150	0.197	0.144	0.121	0.136
Thailand	0.211	0.199	0.065	0.208	0.272	0.111	0.182	0.230	0.218	0.265
Myanmar	0.100	0.125	0.221	0.152	0.062	0.281	0.154	0.269	0.238	0.083
Singapore	0.152	0.099	0.150	0.277	0.098	0.203	0.088	0.235	0.261	0.136
Cambodia	0.194	0.181	0.072	0.154	0.289	0.187	0.030	0.143	0.246	0.186
Bangladesh	0.107	0.128	0.120	0.208	0.328	0.123	0.240	0.092	0.161	0.303
Sri Lanka	0.168	0.195	0.293	0.219	0.065	0.185	0.353	0.174	0.176	0.126

Table 7. Regret matrix.

Country	EFC-1	EFC-2	EFC-3	EFC-4	EFC-5	EFC-6	EFC-7	EFC-8	EFC-9	EFC-10
Brunei Darussalam	−0.045	−0.017	0.000	−0.080	−0.049	−0.085	−0.068	−0.040	−0.042	−0.011
Viet Nam	−0.034	−0.035	−0.039	−0.075	−0.047	−0.035	−0.046	−0.012	−0.016	−0.061
Lao PDR	−0.010	−0.048	−0.007	−0.080	−0.055	−0.108	−0.051	−0.023	−0.060	−0.019
Malaysia	0.000	−0.031	−0.056	−0.120	0.000	−0.102	−0.024	−0.008	−0.052	−0.066
India	−0.043	0.000	−0.077	0.000	−0.055	0.000	−0.068	−0.046	−0.040	−0.043
Indonesia	−0.003	−0.011	−0.024	−0.076	−0.019	−0.087	−0.058	−0.077	0.000	−0.014
Philippines	−0.019	−0.036	−0.056	−0.091	−0.011	−0.104	−0.048	−0.038	−0.061	−0.051
Thailand	−0.002	−0.014	−0.078	−0.067	−0.017	−0.118	−0.053	−0.012	−0.031	−0.011
Myanmar	−0.037	−0.037	−0.029	−0.085	−0.083	−0.062	−0.061	0.000	−0.025	−0.068
Singapore	−0.021	−0.045	−0.051	−0.045	−0.072	−0.087	−0.083	−0.010	−0.017	−0.051
Cambodia	−0.008	−0.020	−0.076	−0.084	−0.012	−0.093	−0.102	−0.039	−0.022	−0.036
Bangladesh	−0.034	−0.036	−0.060	−0.067	−0.001	−0.114	−0.034	−0.055	−0.048	0.000
Sri Lanka	−0.016	−0.016	−0.007	−0.063	−0.082	−0.093	0.000	−0.029	−0.044	−0.055

Table 8. Overall utility matrix.

Country	EFC-1	EFC-2	EFC-3	EFC-4	EFC-5	EFC-6	EFC-7	EFC-8	EFC-9	EFC-10
Brunei Darussalam	0.029	0.172	0.315	0.087	0.122	0.126	0.067	0.099	0.138	0.255
Viet Nam	0.074	0.097	0.149	0.109	0.129	0.334	0.155	0.218	0.248	0.047
Lao PDR	0.175	0.044	0.283	0.088	0.097	0.033	0.135	0.170	0.063	0.222
Malaysia	0.219	0.115	0.077	−0.073	0.329	0.055	0.251	0.235	0.097	0.023
India	0.036	0.247	−0.009	0.423	0.094	0.482	0.068	0.074	0.147	0.121
Indonesia	0.208	0.199	0.211	0.102	0.247	0.116	0.107	−0.053	0.318	0.244
Philippines	0.138	0.093	0.076	0.040	0.281	0.046	0.149	0.105	0.060	0.084
Thailand	0.209	0.185	−0.012	0.141	0.255	−0.006	0.130	0.218	0.188	0.254
Myanmar	0.063	0.088	0.192	0.067	−0.021	0.219	0.093	0.269	0.213	0.015
Singapore	0.131	0.053	0.100	0.232	0.026	0.115	0.005	0.225	0.244	0.084
Cambodia	0.186	0.161	−0.003	0.070	0.277	0.094	−0.072	0.104	0.224	0.151
Bangladesh	0.072	0.092	0.059	0.141	0.327	0.009	0.206	0.037	0.113	0.303
Sri Lanka	0.153	0.180	0.287	0.156	−0.017	0.091	0.353	0.145	0.133	0.071
Average solution	0.130	0.133	0.133	0.122	0.165	0.132	0.127	0.142	0.168	0.144

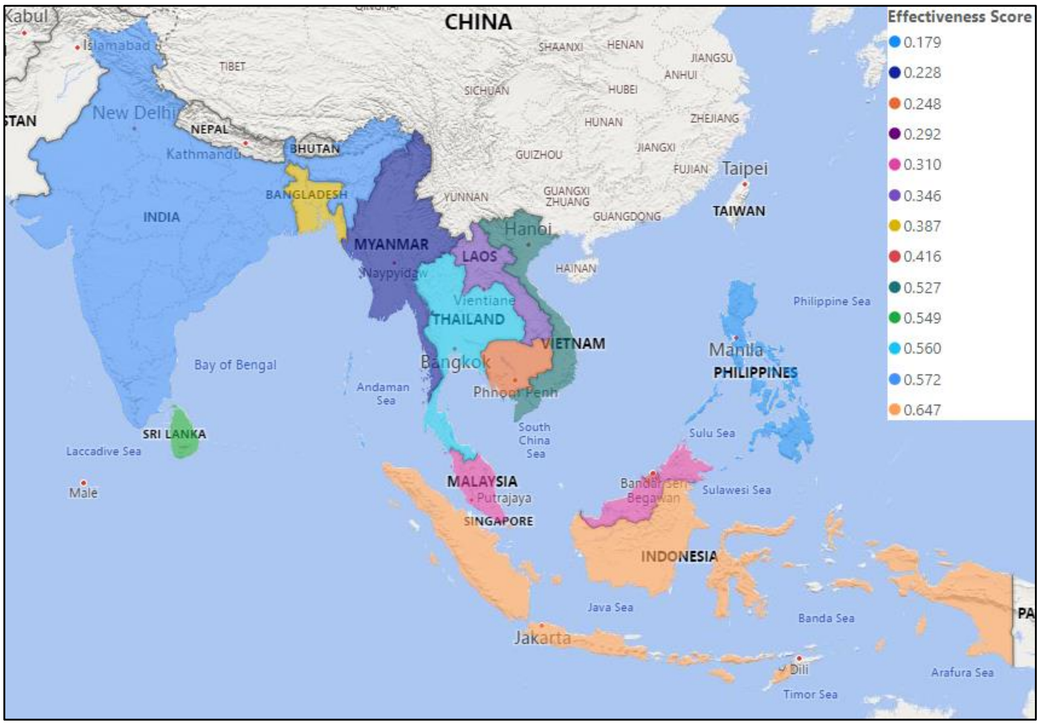

Figure 5. SfRDMA effectiveness map.

4.3. Final Prioritization by Composite Scoring Function

In this section, the efficiency and effectiveness score are aggregated by Equations (49)–(51). As seen in Figure 6, the value amplitude of the ultimate score is relatively large. In other words, the results of assessing the ability for moving high-tech production lines to Southeast Asia show the differences in the suitability of countries. With high maturity in technology, India is at the top of the list. Meanwhile, the rapidly growing economy, supportive policies, and the young population structure are significant advantages for Thailand, Vietnam, Malaysia, and Indonesia.

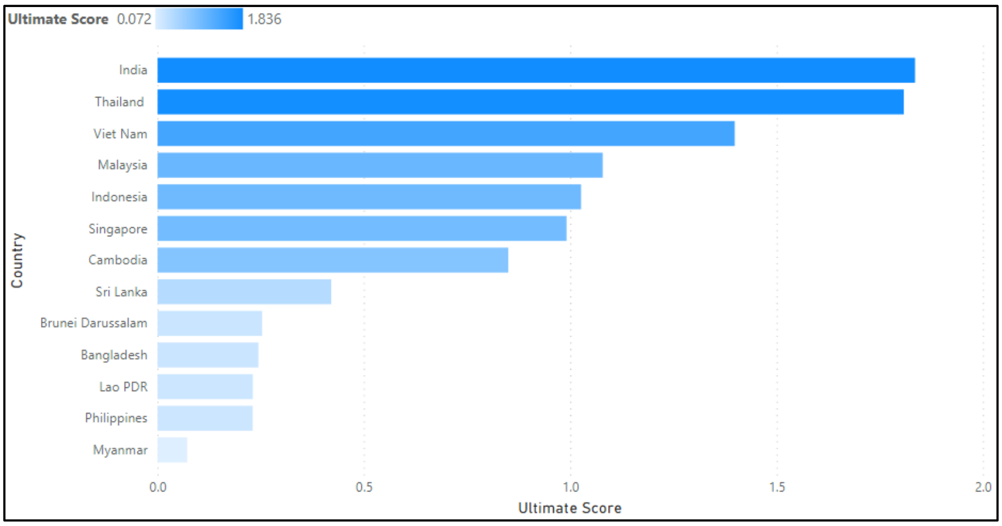

Figure 6. The ultimate score for moving high-tech manufacturing.

4.4. Sensitivity Analysis

4.4.1. Criteria Weights

To analyze the sensitivity of the criteria weights to prioritization, first, the criteria are classified into three groups—a cost-related group, a policy-related group, and a production-condition-related group. For these groups, four different criteria weight allocation scenarios were constructed, as shown in Table 9. In scenario 1, the criteria were weighted equally. Meanwhile, scenario 2 focused on cost-related criteria. Scenario 3 was concerned with policy criteria, while scenario 4 was concerned with production conditions. As shown in Figure 7, the sensitivity analysis results showed that the weight of the criteria had a significant influence on the evaluation results of the proposed method. The ranking of countries did not show a big difference between the base scenario, where the weights of the criteria were determined by the proposed method, and scenario 1. Another finding was that the rankings of India, Thailand, and Vietnam were always at the top, regardless of differences in the allocation of weights. As the weight of the cost-related criteria decreased, Malaysia's ranking dropped significantly from 3rd to 7th place. In contrast, Singapore rose in rank as decision makers became more concerned about the criteria for production conditions.

Table 9. Weighting scenarios.

Criteria	Group	Scenarios				
		Base	1	2	3	4
Construction, installation cost	Cost-related	0.094	0.1	+30%	−10%	−20%
Diversity of transportation services	Production-condition-related	0.099	0.1	−20%	−10%	+30%
Labor cost	Cost-related	0.096	0.1	+30%	−10%	−20%
Human resources availability	Production-condition-related	0.109	0.1	−20%	−10%	+30%
Political stability	Policy-related	0.120	0.1	−15%	+30%	−15%
Environmental management system	Production-condition-related	0.073	0.1	−20%	−10%	+30%
Logistics cost	Cost-related	0.095	0.1	+30%	−10%	−20%
Land cost	Cost-related	0.095	0.1	+30%	−10%	−20%
Government policy	Policy-related	0.128	0.1	−15%	+30%	−15%
Climate	Production-condition-related	0.090	0.1	−20%	−10%	+30%

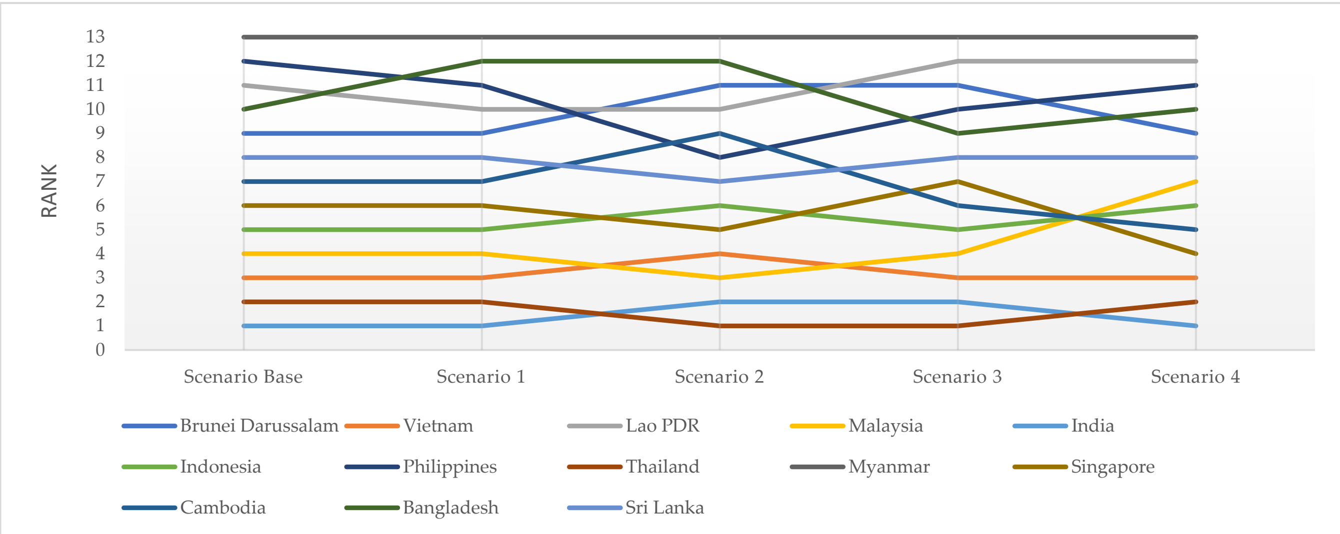

Figure 7. Weighting scenario analysis.

4.4.2. Psychological Behavior Coefficients

The advantage of the proposed method is the reinforcement of regret theory in the prioritization process. Therefore, the coefficients reflecting the psychological behavior of decision makers should also be analyzed for sensitivity. As shown in Figure 8, the risk aversion coefficient is believed to have an influence on the prioritization outcome. However, the effect of this coefficient mainly swaps the rank of adjacent alternatives. For example, when the risk-aversion coefficient is greater than or equal to 0.88, the rankings for India and Thailand are interchangeable. Similarly, the rankings of Indonesia and Singapore swap with very low or very high values of the risk-aversion coefficient.

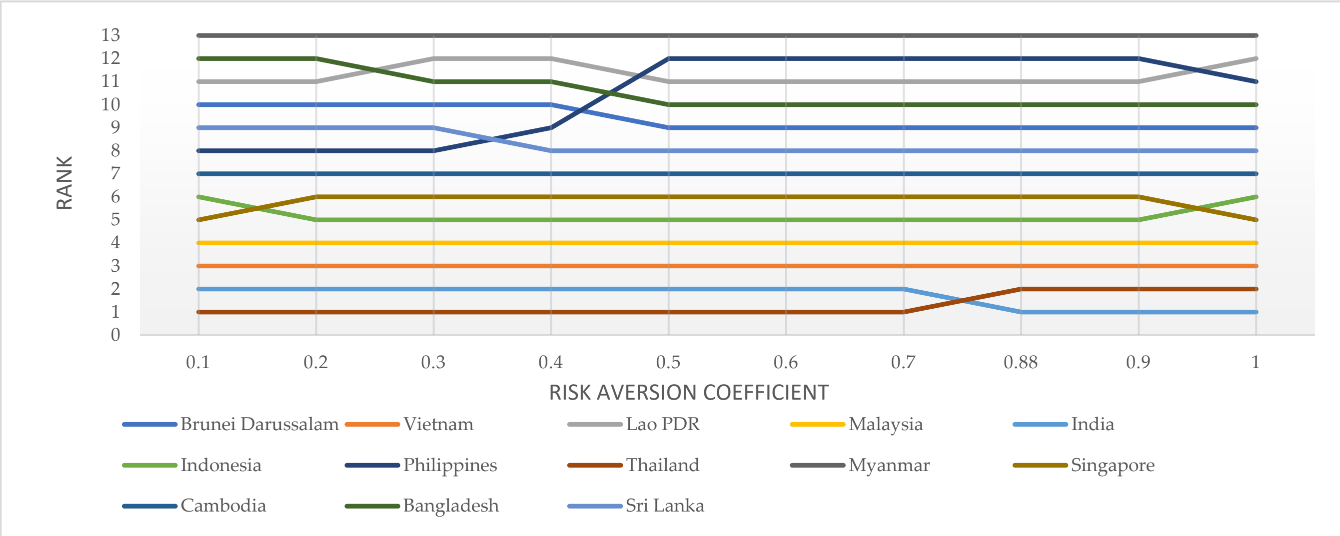

Figure 8. Risk-aversion coefficient sensitivity analysis.

For the regret-aversion coefficient, the sensitivity analysis shows that this coefficient can create a large disturbance in the results of the proposed method. As shown in Figure 9, the ranking disturbance becomes larger with a larger regret-aversion coefficient, especially from the threshold of 0.7. Accordingly, it can be concluded that the proposed method can effectively reflect the psychological behavior of the decision maker in the evaluation process. As a result, it is possible to determine the solution that best suits the context. In other words, while the efficient-evaluation process, based on objective data, is optimized by the DEA model, the effectiveness of subjective judgments is maximally tailored to the decision maker.

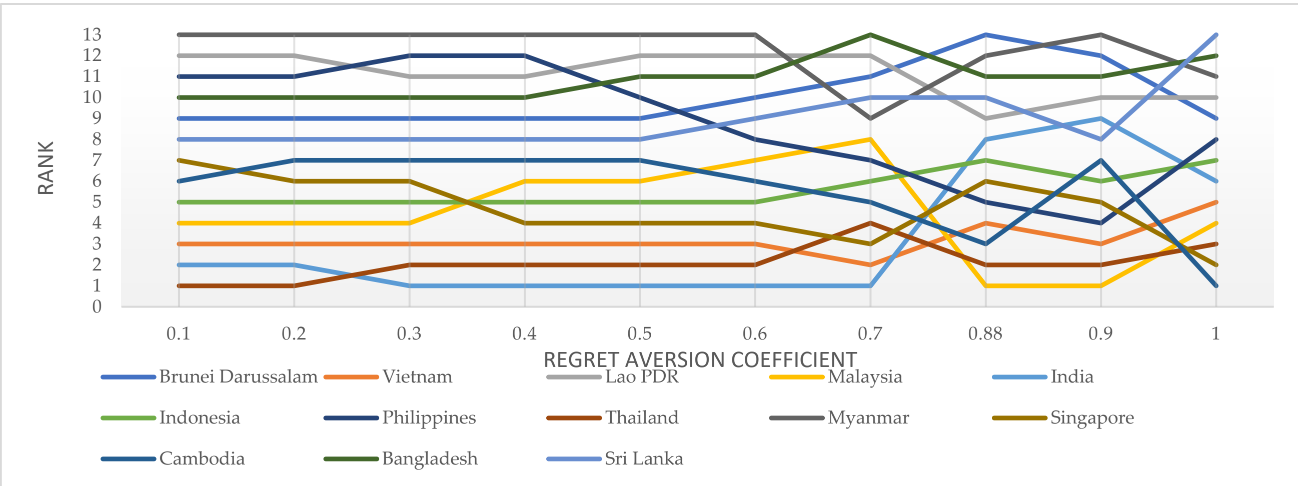

Figure 9. Regret-aversion coefficient sensitivity analysis.

4.5. Methodology Comparison

The most significant advantage of the proposed approach is the integration of both objective data and subjective opinions in the evaluation process. Furthermore, for subjective opinions, the prioritization considers the psychological behavior of the decision makers through the risk-aversion coefficient and the regret-aversion coefficient. This advantage makes decisions more consistent with the worldview of the decision maker.

To verify the quality of the solution, the proposed method was compared with the proven powerful spherical fuzzy TOPSIS method, which is another distance-based method. In order for the results to be comparable, the risk-aversion coefficient and the regret-aversion coefficient in the proposed method were disabled $(\varphi = 1,\ \lambda = 0)$. As shown in Figure 10, the ranking results were not significantly different. The difference mainly appeared in the adjacent ranks. In other words, if the psycho-behavioral consideration feature is omitted, the results of the proposed method are remarkably consistent with that of the proven similar method.

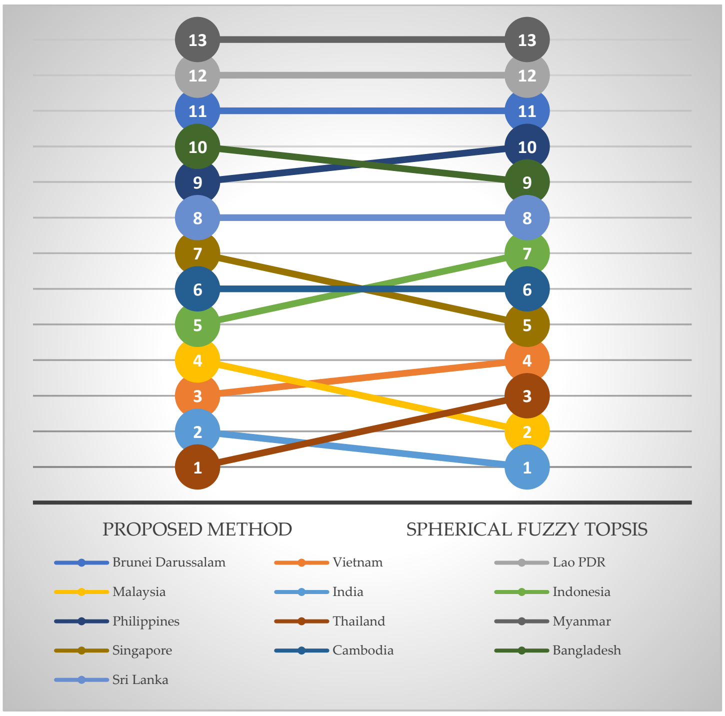

Figure 10. Comparison analysis with another distance-based MCDM method.

5. Conclusions

The development of high-tech companies is a powerful means of creating job growth, revitalizing a region's economy, and enhancing national technological innovation rates and cross-border competitiveness [52]. Selecting suitable destinations for overseas production lines of multinational high-tech companies has a great impact on their sustainable development, as well as limiting risks and saving costs. This study aimed to prioritize the destinations, which are in the East Asia and South Asia regions, for high-tech production lines. This prioritization process determined both the efficiency and the effectiveness of developing countries, based on quantitative indicators and qualitative criteria, respectively. Using a novel bounded rationality MCDM approach, thirteen countries in Southeast Asia were prioritized according to different indicators and criteria. In the proposed approach, for efficiency assessment, the super-SBM model was applied to evaluate the super-efficiency countries for high-tech manufacturing. On the other hand, for assessing effectiveness, a novel SfRDMA approach was developed and introduced for the first time to determine effectiveness based on ten criteria. Finally, the efficiency and effectiveness were composited for the prioritized countries. From these results, it was clear that India, Thailand, Vietnam, Malaysia, and Indonesia are priority destinations for high-tech production lines.

In addition to making a practical contribution through our findings, the novel composited regret-theory-based spherical fuzzy prioritization approach was the primary theoretical contribution of this research to the field of decision science. Furthermore, the findings of this study could be valuable for researchers or investors in promoting the development of high-tech. In future research, the performance of tests for the risk-aversion coefficient and the regret-aversion coefficient is proposed.

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Appendix A

Table A1. Super-SBM Model's Data.

Country	Inputs			Outputs	
	Inflation (%)	Cost to Export (US$)	High-Technology Exports (US$)	GDP (US$)	Ease of Doing Business Score (0 = Lowest Performance to 100 = Best Performance)
Brunei Darussalam	15	340	15,965	14,007	70
Viet Nam	3	290	101,534,393	362,638	70
Lao PDR	4	140	235,751	18,827	51
Malaysia	6	213	108,683,180	372,701	81
India	10	212	27,446,654	3,173,398	71
Indonesia	6	211	7,492,073	1,186,093	70
Philippines	2	456	38,194,373	394,086	63
Thailand	2	223	45,837,990	505,982	80
Myanmar	5	432	296,936	65,068	47
Singapore	4	335	159,927,958	396,987	86
Cambodia	1	375	308,424	26,961	54
Bangladesh	4	408	93,608	416,265	45
Sri Lanka	8	366	94,326	84,519	62

Table A2. Super-SBM model results.

Country	Efficiency Score	Country	Efficiency Score
Brunei Darussalam	0.00019	Philippines	0.59500
Viet Nam	0.84773	Thailand	1.28901
Lao PDR	0.00914	Myanmar	0.00432
Malaysia	1.14383	Singapore	1.08808
India	1.29069	Cambodia	1.09459
Indonesia	0.24190	Bangladesh	0.00162
Sri Lanka	0.00125		

Table A3. Expert's qualification and linguistic evaluation.

Expert	Qualification	Year of Experience	Expertise Linguistic Evaluation	Spherical Fuzzy Value
Expert 1	Master of Science	8	High	(0.6, 0.2, 0.35)
Expert 2	Doctor of Philosophy	6	High	(0.6, 0.2, 0.35)
Expert 3	Master of Science	5	Moderate	(0.35, 0.25, 0.25)
Expert 4	Doctor of Philosophy	5	High	(0.6, 0.2, 0.35)
Expert 5	Master of Engineering	8	High	(0.6, 0.2, 0.35)
Expert 6	Doctor of Philosophy	7	Very high	(0.85, 0.15, 0.45)
Expert 7	Master of Science	8	High	(0.6, 0.2, 0.35)
Expert 8	Doctor of Philosophy	6	High	(0.6, 0.2, 0.35)
Expert 9	Master of Science	10	Very high	(0.85, 0.15, 0.45)
Expert 10	Doctor of Philosophy	7	Very high	(0.85, 0.15, 0.45)

Table A4. The SF direct-influence matrix.

Criteria	EFC-1	EFC-2	EFC-3	EFC-4	EFC-5
EFC-1	(0, 0.3, 0.2)	(0.49, 0.24, 0.39)	(0.52, 0.23, 0.38)	(0.4, 0.25, 0.28)	(0.5, 0.24, 0.39)
EFC-2	(0.57, 0.22, 0.44)	(0, 0.3, 0.2)	(0.59, 0.22, 0.44)	(0.62, 0.22, 0.47)	(0.68, 0.2, 0.49)
EFC-3	(0.47, 0.24, 0.38)	(0.68, 0.2, 0.48)	(0, 0.3, 0.2)	(0.69, 0.2, 0.49)	(0.67, 0.2, 0.47)
EFC-4	(0.5, 0.24, 0.38)	(0.7, 0.19, 0.48)	(0.44, 0.26, 0.37)	(0, 0.3, 0.2)	(0.6, 0.21, 0.44)
EFC-5	(0.63, 0.22, 0.47)	(0.73, 0.19, 0.49)	(0.64, 0.21, 0.47)	(0.62, 0.21, 0.44)	(0, 0.3, 0.2)
EFC-6	(0.56, 0.23, 0.45)	(0.68, 0.2, 0.49)	(0.49, 0.24, 0.39)	(0.58, 0.23, 0.44)	(0.49, 0.24, 0.38)
EFC-7	(0.52, 0.24, 0.39)	(0.69, 0.2, 0.48)	(0.57, 0.23, 0.44)	(0.62, 0.22, 0.47)	(0.77, 0.18, 0.48)
EFC-8	(0.64, 0.21, 0.47)	(0.59, 0.21, 0.4)	(0.66, 0.21, 0.47)	(0.63, 0.21, 0.47)	(0.58, 0.22, 0.44)
EFC-9	(0.51, 0.23, 0.32)	(0.56, 0.23, 0.44)	(0.5, 0.23, 0.32)	(0.51, 0.23, 0.39)	(0.56, 0.23, 0.44)
EFC-10	(0.54, 0.24, 0.44)	(0.51, 0.24, 0.39)	(0.51, 0.23, 0.39)	(0.58, 0.22, 0.4)	(0.53, 0.23, 0.39)

Criteria	EFC-6	EFC-7	EFC-8	EFC-9	EFC-10
EFC-1	(0.57, 0.22, 0.39)	(0.57, 0.22, 0.44)	(0.61, 0.22, 0.47)	(0.57, 0.23, 0.44)	(0.58, 0.22, 0.44)
EFC-2	(0.64, 0.21, 0.47)	(0.65, 0.21, 0.47)	(0.76, 0.18, 0.49)	(0.65, 0.21, 0.47)	(0.73, 0.19, 0.49)
EFC-3	(0.67, 0.2, 0.46)	(0.61, 0.22, 0.45)	(0.61, 0.22, 0.47)	(0.59, 0.21, 0.4)	(0.62, 0.22, 0.48)
EFC-4	(0.62, 0.21, 0.44)	(0.57, 0.23, 0.44)	(0.39, 0.26, 0.28)	(0.38, 0.25, 0.27)	(0.66, 0.2, 0.47)
EFC-5	(0.59, 0.22, 0.44)	(0.47, 0.24, 0.31)	(0.52, 0.23, 0.39)	(0.46, 0.23, 0.3)	(0.69, 0.2, 0.49)
EFC-6	(0, 0.3, 0.2)	(0.48, 0.24, 0.38)	(0.53, 0.24, 0.44)	(0.47, 0.25, 0.39)	(0.63, 0.22, 0.48)
EFC-7	(0.65, 0.21, 0.47)	(0, 0.3, 0.2)	(0.59, 0.22, 0.44)	(0.59, 0.22, 0.44)	(0.65, 0.21, 0.47)
EFC-8	(0.65, 0.21, 0.47)	(0.66, 0.21, 0.49)	(0, 0.3, 0.2)	(0.5, 0.24, 0.38)	(0.72, 0.2, 0.49)
EFC-9	(0.63, 0.22, 0.48)	(0.71, 0.19, 0.48)	(0.57, 0.22, 0.4)	(0, 0.3, 0.2)	(0.74, 0.19, 0.5)
EFC-10	(0.61, 0.23, 0.48)	(0.5, 0.23, 0.38)	(0.65, 0.2, 0.47)	(0.7, 0.2, 0.5)	(0, 0.3, 0.2)

Table A5. The SF total-influence matrix.

Criteria	EFC-1	EFC-2	EFC-3	EFC-4	EFC-5
EFC-1	(0.57, 0.41, 0.44)	(0.72, 0.37, 0.5)	(0.65, 0.39, 0.46)	(0.66, 0.38, 0.46)	(0.69, 0.38, 0.49)
EFC-2	(0.77, 0.36, 0.54)	(0.77, 0.37, 0.52)	(0.77, 0.36, 0.53)	(0.82, 0.35, 0.56)	(0.84, 0.34, 0.57)
EFC-3	(0.73, 0.37, 0.52)	(0.84, 0.34, 0.56)	(0.65, 0.39, 0.47)	(0.79, 0.35, 0.55)	(0.8, 0.34, 0.55)
EFC-4	(0.65, 0.39, 0.47)	(0.75, 0.35, 0.51)	(0.64, 0.39, 0.46)	(0.61, 0.4, 0.44)	(0.71, 0.37, 0.49)
EFC-5	(0.72, 0.36, 0.51)	(0.81, 0.34, 0.54)	(0.72, 0.36, 0.5)	(0.76, 0.35, 0.51)	(0.68, 0.38, 0.47)
EFC-6	(0.66, 0.39, 0.5)	(0.75, 0.36, 0.54)	(0.65, 0.4, 0.48)	(0.7, 0.38, 0.51)	(0.7, 0.38, 0.51)
EFC-7	(0.74, 0.37, 0.52)	(0.84, 0.34, 0.57)	(0.74, 0.36, 0.52)	(0.79, 0.35, 0.54)	(0.82, 0.33, 0.55)
EFC-8	(0.75, 0.36, 0.53)	(0.82, 0.34, 0.55)	(0.75, 0.36, 0.52)	(0.79, 0.35, 0.54)	(0.79, 0.35, 0.54)
EFC-9	(0.7, 0.37, 0.47)	(0.78, 0.35, 0.52)	(0.69, 0.37, 0.47)	(0.73, 0.36, 0.5)	(0.75, 0.36, 0.51)
EFC-10	(0.69, 0.38, 0.5)	(0.75, 0.36, 0.52)	(0.68, 0.38, 0.49)	(0.72, 0.36, 0.5)	(0.73, 0.37, 0.51)

Criteria	EFC-6	EFC-7	EFC-8	EFC-9	EFC-10
EFC-1	(0.73, 0.36, 0.51)	(0.68, 0.37, 0.49)	(0.69, 0.38, 0.5)	(0.65, 0.38, 0.47)	(0.77, 0.35, 0.53)
EFC-2	(0.86, 0.33, 0.58)	(0.81, 0.34, 0.56)	(0.83, 0.33, 0.56)	(0.78, 0.35, 0.53)	(0.93, 0.32, 0.61)
EFC-3	(0.83, 0.34, 0.57)	(0.78, 0.35, 0.54)	(0.78, 0.35, 0.54)	(0.74, 0.36, 0.5)	(0.88, 0.34, 0.59)
EFC-4	(0.74, 0.36, 0.51)	(0.69, 0.37, 0.49)	(0.67, 0.38, 0.46)	(0.63, 0.39, 0.43)	(0.79, 0.34, 0.53)
EFC-5	(0.8, 0.35, 0.53)	(0.73, 0.36, 0.48)	(0.74, 0.36, 0.5)	(0.7, 0.37, 0.46)	(0.86, 0.33, 0.56)
EFC-6	(0.65, 0.4, 0.49)	(0.68, 0.39, 0.5)	(0.69, 0.39, 0.51)	(0.65, 0.4, 0.48)	(0.78, 0.36, 0.56)
EFC-7	(0.84, 0.34, 0.57)	(0.69, 0.38, 0.49)	(0.78, 0.35, 0.54)	(0.74, 0.36, 0.51)	(0.88, 0.33, 0.59)
EFC-8	(0.83, 0.34, 0.57)	(0.78, 0.35, 0.54)	(0.69, 0.38, 0.49)	(0.73, 0.37, 0.5)	(0.89, 0.33, 0.59)
EFC-9	(0.79, 0.35, 0.54)	(0.76, 0.35, 0.51)	(0.74, 0.36, 0.5)	(0.62, 0.4, 0.43)	(0.85, 0.33, 0.56)
EFC-10	(0.77, 0.36, 0.54)	(0.71, 0.37, 0.5)	(0.73, 0.36, 0.52)	(0.7, 0.37, 0.5)	(0.72, 0.38, 0.51)

Table A6. The SF decision matrix.

Criteria	EFC-1	EFC-2	EFC-3	EFC-4	EFC-5
Brunei Darussalam	(0.59, 0.44, 0.37)	(0.65, 0.38, 0.28)	(0.78, 0.23, 0.26)	(0.69, 0.33, 0.33)	(0.68, 0.33, 0.32)
Viet Nam	(0.65, 0.37, 0.37)	(0.67, 0.34, 0.35)	(0.68, 0.34, 0.29)	(0.71, 0.3, 0.33)	(0.67, 0.36, 0.3)
Lao PDR	(0.69, 0.32, 0.31)	(0.59, 0.42, 0.35)	(0.74, 0.29, 0.24)	(0.64, 0.39, 0.29)	(0.63, 0.39, 0.3)
Malaysia	(0.7, 0.31, 0.28)	(0.59, 0.44, 0.29)	(0.65, 0.36, 0.33)	(0.55, 0.46, 0.39)	(0.77, 0.24, 0.24)
India	(0.58, 0.44, 0.36)	(0.71, 0.32, 0.26)	(0.56, 0.46, 0.37)	(0.81, 0.2, 0.2)	(0.63, 0.39, 0.3)

Table A6. *Cont.*

Criteria	EFC-1	EFC-2	EFC-3	EFC-4	EFC-5
Indonesia	(0.72, 0.3, 0.3)	(0.69, 0.33, 0.28)	(0.71, 0.31, 0.27)	(0.68, 0.34, 0.3)	(0.74, 0.27, 0.27)
Philippines	(0.69, 0.33, 0.34)	(0.63, 0.39, 0.32)	(0.64, 0.38, 0.32)	(0.67, 0.35, 0.35)	(0.76, 0.26, 0.26)
Thailand	(0.71, 0.29, 0.3)	(0.68, 0.36, 0.28)	(0.57, 0.46, 0.37)	(0.71, 0.31, 0.3)	(0.75, 0.27, 0.27)
Myanmar	(0.59, 0.42, 0.34)	(0.63, 0.39, 0.33)	(0.72, 0.29, 0.3)	(0.66, 0.36, 0.32)	(0.57, 0.44, 0.38)
Singapore	(0.68, 0.34, 0.33)	(0.63, 0.39, 0.36)	(0.68, 0.33, 0.34)	(0.76, 0.25, 0.28)	(0.52, 0.51, 0.33)
Cambodia	(0.7, 0.32, 0.3)	(0.67, 0.35, 0.3)	(0.58, 0.44, 0.37)	(0.66, 0.35, 0.32)	(0.75, 0.26, 0.25)
Bangladesh	(0.59, 0.43, 0.33)	(0.66, 0.36, 0.35)	(0.65, 0.37, 0.35)	(0.7, 0.31, 0.29)	(0.76, 0.25, 0.23)
Sri Lanka	(0.68, 0.33, 0.31)	(0.69, 0.34, 0.29)	(0.76, 0.24, 0.26)	(0.69, 0.34, 0.27)	(0.58, 0.43, 0.38)
Country	**EFC-6**	**EFC-7**	**EFC-8**	**EFC-9**	**EFC-10**
Brunei Darussalam	(0.72, 0.29, 0.31)	(0.67, 0.35, 0.35)	(0.65, 0.36, 0.33)	(0.68, 0.33, 0.31)	(0.74, 0.27, 0.27)
Viet Nam	(0.79, 0.21, 0.23)	(0.71, 0.31, 0.3)	(0.72, 0.3, 0.28)	(0.75, 0.27, 0.28)	(0.62, 0.4, 0.34)
Lao PDR	(0.62, 0.41, 0.31)	(0.69, 0.33, 0.3)	(0.68, 0.34, 0.29)	(0.61, 0.41, 0.32)	(0.74, 0.28, 0.3)
Malaysia	(0.67, 0.35, 0.32)	(0.74, 0.28, 0.26)	(0.73, 0.29, 0.28)	(0.65, 0.37, 0.32)	(0.61, 0.41, 0.36)
India	(0.83, 0.17, 0.17)	(0.66, 0.36, 0.34)	(0.63, 0.39, 0.34)	(0.68, 0.34, 0.3)	(0.66, 0.35, 0.3)
Indonesia	(0.69, 0.33, 0.29)	(0.66, 0.36, 0.3)	(0.53, 0.47, 0.42)	(0.74, 0.28, 0.22)	(0.73, 0.29, 0.27)
Philippines	(0.67, 0.34, 0.33)	(0.65, 0.38, 0.27)	(0.64, 0.38, 0.32)	(0.64, 0.38, 0.34)	(0.68, 0.33, 0.36)
Thailand	(0.59, 0.44, 0.33)	(0.67, 0.35, 0.3)	(0.74, 0.28, 0.3)	(0.72, 0.3, 0.3)	(0.73, 0.29, 0.26)
Myanmar	(0.76, 0.25, 0.28)	(0.65, 0.37, 0.31)	(0.74, 0.27, 0.27)	(0.74, 0.28, 0.29)	(0.62, 0.39, 0.38)
Singapore	(0.69, 0.33, 0.29)	(0.57, 0.45, 0.35)	(0.71, 0.31, 0.27)	(0.73, 0.28, 0.27)	(0.64, 0.38, 0.33)
Cambodia	(0.66, 0.36, 0.28)	(0.52, 0.49, 0.41)	(0.63, 0.4, 0.31)	(0.73, 0.28, 0.28)	(0.68, 0.34, 0.3)
Bangladesh	(0.65, 0.36, 0.35)	(0.71, 0.31, 0.27)	(0.61, 0.41, 0.36)	(0.68, 0.32, 0.33)	(0.76, 0.25, 0.26)
Sri Lanka	(0.68, 0.35, 0.3)	(0.79, 0.22, 0.23)	(0.69, 0.33, 0.32)	(0.67, 0.35, 0.3)	(0.65, 0.37, 0.34)

Table A7. The defuzzied SF decision matrix.

Country	EFC-1	EFC-2	EFC-3	EFC-4	EFC-5	EFC-6	EFC-7	EFC-8	EFC-9	EFC-10
Brunei Darussalam	0.052	0.151	0.269	0.131	0.134	0.170	0.103	0.106	0.143	0.222
Viet Nam	0.079	0.100	0.149	0.146	0.139	0.321	0.162	0.188	0.221	0.079
Lao PDR	0.147	0.066	0.246	0.131	0.117	0.108	0.148	0.154	0.093	0.199
Malaysia	0.178	0.112	0.101	0.031	0.283	0.122	0.230	0.200	0.115	0.064
India	0.056	0.204	0.047	0.376	0.115	0.436	0.103	0.090	0.149	0.128
Indonesia	0.171	0.170	0.193	0.141	0.222	0.163	0.129	0.014	0.272	0.214
Philippines	0.122	0.098	0.101	0.100	0.247	0.116	0.158	0.110	0.091	0.103
Thailand	0.171	0.160	0.045	0.168	0.228	0.083	0.145	0.188	0.177	0.221
Myanmar	0.073	0.094	0.180	0.117	0.043	0.237	0.120	0.225	0.195	0.059
Singapore	0.117	0.072	0.116	0.233	0.071	0.163	0.063	0.193	0.217	0.103
Cambodia	0.155	0.143	0.050	0.119	0.244	0.149	0.019	0.110	0.203	0.148
Bangladesh	0.079	0.097	0.090	0.168	0.281	0.092	0.198	0.066	0.126	0.257
Sri Lanka	0.132	0.156	0.248	0.178	0.045	0.147	0.307	0.137	0.139	0.095

Table A8. SfRDMA results.

Country	Effectiveness Score	Country	Effectiveness Score
Brunei Darussalam	0.416	Philippines	0.179
Viet Nam	0.527	Thailand	0.560
Lao PDR	0.346	Myanmar	0.228
Malaysia	0.310	Singapore	0.292
India	0.572	Cambodia	0.248
Indonesia	0.647	Bangladesh	0.387
Sri Lanka	0.549		

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