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A Fuzzy Simultaneous Evaluation of Criteria and Alternatives (F-SECA) for Sustainable E-Waste Scenario Management

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Abstract: The process of production, consumption, and final disposal of electrical and electronic equipment usually leads to harmful waste to the environment called e-waste. Eliminating and decreasing this type of waste could be considered as an essential goal for many enterprises working toward sustainable management systems. In this paper, we aim at introducing a new methodology for evaluation of sustainable e-waste management scenarios. The evaluation is defined as an MCDM (Multi-Criteria Decision-Making) problem, and the scenarios are the alternatives of the problem that need to be evaluated with respect to several sustainability criteria. An extended fuzzy SECA (Simultaneous Evaluation of Criteria and Alternatives) integrated with SMART (Simple Multi-Attribute Rating Technique), named F-SECA, is proposed to deal with the evaluation process. The α-cut approach is used to consider different levels of uncertainty and obtain interval values for assessment of criteria and alternatives. The proposed methodology helps us to make the evaluation with incorporation of subjective and objective data, opinions of multiple experts and uncertainty of information. We applied the methodology to evaluate sustainable e-waste management scenarios in a case. Through comparative and sensitivity analyses, the paper shows that the proposed methodology is efficient and gives reliable results.

Keywords: electronic waste (e-waste); waste electrical and electronic equipment (WEEE); sustainability management; multi-criteria decision-making (MCDM); fuzzy MCDM

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Citation: Keshavarz-Ghorabaee, M.; Amiri, M.; Zavadskas, E.K.; Turskis, Z.; Antucheviciene, J. A Fuzzy Simultaneous Evaluation of Criteria and Alternatives (F-SECA) for Sustainable E-Waste Scenario Management. *Sustainability* **2022**, *14*, 10371. https://doi.org/10.3390/su141610371

Academic Editors: Yan Xu and Ling Zhang

Received: 1 August 2022
Accepted: 19 August 2022
Published: 20 August 2022

1. Introduction

Negative impacts of industry and its different products on the environment we live in have become a growing concern in recent years. One of the areas in which there has been much concern is related to high consumption rates of electrical and electronic products (e-products) that have come with the development of the modern society [1]. E-products comprises a wide extent of products such as large and small home appliances, personal computers, smartphones, fiber-optic cables, and so on. Every e-product has a useful life, and it turns into waste at the end of its life cycle. Nowadays, the waste of e-products, called e-waste, forms one of the most problematic waste in the world [2,3]. E-waste could be composed of hazardous substances like mercury, lead and cadmium which may have serious environmental impacts. Therefore, estimating and managing the e-waste of different e-products is very important [4,5].

The rise in sales of e-products makes the management of e-wastes more challenging for societies and governments [6]. Many industrialized and developed countries have established their e-waste management systems, but less industrialized and developing countries have several issues due to lack of proper waste management infrastructure [7]. If we want to avoid environmental impacts of e-waste, we need to use integrated sustainable management systems [8,9]. Accordingly, moving toward new and appropriate sustainable approaches in e-waste management can help practitioners to deal with the challenges of end-of-life e-products [10–12]. To establish a sustainable e-waste management system, we usually need to evaluate several possible scenarios. Moreover, detailed screening of requirements and desired development directions to specify the possible scenarios should be implemented based on the responsibility of top managers. In such a challenging situation, using efficient tools to evaluate different scenarios and choose the most appropriate ones that meet the required preconditions is a necessity in e-waste management [13]. If we can define the evaluation process based on a set of scenarios and a set of criteria, multi-criteria decision-making (MCDM) techniques can be considered as effective tools to make the evaluation [14]. In addition, we are usually confronted with the uncertain information derived from experts' opinions and judgements in such an evaluation process [15]. To deal with the uncertainty, several MCDM methods and techniques have been developed in recent years [16].

The aim of this study is to develop a new fuzzy decision-making approach for evaluation of e-waste management scenarios. The developed approach is based on the SECA (Simultaneous Evaluation of Criteria and Alternatives) method [17], fuzzy sets, α-cut intervals and SMART (Simple Multi-Attribute Rating Technique) [18]. SECA is an efficient and relatively new MCDM method that has been applied to several real-world evaluation problems in different fields of study including battery electric vehicles [19], sustainable manufacturing [20], system resilience analysis [21], hybrid machining processes [22], renewable energy [23], fuel-switching [24], high-rise wall buildings [25], cities smartness [26] and dynamic resource allocation [27]. The approach proposed in this paper enables us to evaluate alternatives and criteria of an MCDM problem simultaneously.

The original SECA method was proposed in 2018 and the evaluation process was made by solving a deterministic multi-objective mathematical model. The original SECA was based on some crisp inputs and one mathematical model. Solving the mathematical model in original SECA yields some crisp outputs (objective criteria weights and alternatives' overall performances). In this study, using the α-cut approach [28], we extend the SECA method based on fuzzy inputs and two mathematical models to handle the uncertainty of information. Moreover, the outputs of the SMART method are used to define another objective function for the proposed fuzzy SECA (F-SECA) method. This additional function enables the proposed approach to give a combination of subjective and objective weights for criteria. Therefore, the subjective criteria weights determined based on decision-makers' (DMs) opinions are also incorporated into the evaluation process. Unlike the original SECA which gives us crisp outputs, solving the two mathematical models of the proposed fuzzy SECA provides us with fuzzy outputs (fuzzy criteria weights and fuzzy alternatives' overall performances) with respect to different values of α. By employing the α-cut approach we can obtain some intervals in fuzzy evaluation of criteria and alternatives. To define different levels of uncertainty, different values of α can be set. Although the original SECA has been employed in fuzzy environments before [20], the defuzzified values were used as the crisp inputs of SECA. The reason why the defuzzified values were used was that the original SECA was not capable of dealing with fuzzy numbers as the inputs of an MCDM problem. The approach proposed in this study is the first version of SECA with fuzzy inputs and fuzzy outputs.

To delineate the application of the developed approach, a case of evaluation of sustainable e-waste management scenarios is addressed. An MCDM problem is defined for the case based on multiple experts' opinions, and twelve e-waste management scenarios are evaluated with respect to several criteria and sub-criteria related to different dimensions of sustainability. Then a sensitivity analysis based upon variation in levels of uncertainty or the values of α is carried out to examine the reliability of the scenario evaluation. Finally, a comparative analysis is made without consideration of uncertainty (just with crisp values) to verify and validate the results.

The remainder of this paper is organized as follows. In Section 2, we present a brief review of some recent studies on the applications of different MCDM methods in the field of e-waste management. In Section 3, the developed methodology is delineated. A brief description of the SECA and SMART methods is given, and then the developed approach is expounded in a step-by-step way. In Section 4, an empirical study is considered to illustrate the applicability of the developed approach in evaluation of e-waste management scenarios. In Section 5, a sensitivity analysis and a comparative analysis are carried out, and the results are discussed. Section 6 presents the discussions, and finally, the concluding remarks are stated in Section 7.

2. Literature Review

According to the literature, we can see that the application of different MCDM methods in the field of e-waste management is increasing recently. The focus of this study is not to review the literature on the e-waste management or MCDM applications; however, to emphasize on the importance of using MCDM methods in e-waste management an overview of some studies in this field are presented in the following. Table 1 represents a brief description of some recent studies made in the field of e-waste management based on MCDM approaches. The MCDM methods used in the reviewed studies include AHP (Analytic Hierarchy Process), VIKOR (Vlse Kriterijuska Optamizacija I Komoromisno Resenje), ANP (Analytic Network Process), BWM (Best-Worst Method), DEMATEL (DEcision MAking Trial and Evaluation Laboratory), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution), CoCoSo (COmbined COmpromise SOlution), PCP (Probabilistic Composition of Preferences), MOORSA (Multi-Objective Optimization on the basis of Simple Ratio Analysis), MULTIMOORA (MULTiplicative form of Multi-Objective Optimization by Ration Analysis), WSM (Weighted Sum Model), FITradeoff (Flexible and Interactive Trade-Off), MICMAC (Matrice d'impacts Croisés Multiplication Appliquée an un Classeement).

Table 1. Description of some recent studies on e-waste management.

No.	Author(s)	Year	Approach	Uncertainty	Description
1	Khoshand, et al. [29]	2019	Fuzzy AHP	✓	An approach based on fuzzy AHP was used to evaluate different e-waste collection and processing options in Tehran. Recycling, exporting and landfilling were the alternatives for processing, and door-to-door, special event and permanent drop-off were the alternatives for collection which were evaluated with respect to economic, social, technical, and environmental criteria.
2	Rimantho, et al. [30]	2019	AHP	✘	The AHP method was used to examine some strategies for minimizing the risk of e-waste management. A questionnaire based on the pairwise comparison and the opinions of five experts from academics, governmental and non-governmental organizations was utilized for the evaluation.
3	Kumar and Dixit [31]	2019	Fuzzy AHP and VIKOR	✓	A three-phase hybrid methodology was presented to evaluate e-waste recycling partners. In the first phase, the literature was reviewed to identify green competencies (GC) criteria. In the second phase, the fuzzy AHP method was applied to calculate relative importance and weights of the criteria, and finally in the third phase, recycling partners or alternatives were evaluated based on the GC criteria weights and VIKOR.

Table 1. *Cont.*

No.	Author(s)	Year	Approach	Uncertainty	Description
4	Xu, et al. [32]	2020	Fuzzy ANP	✓	A new risk-based performance evaluation approach based on the fuzzy ANP was proposed to assess strategies of e-waste management improvement. An empirical study on a company of e-waste recycling in China was carried out using the proposed approach and the benefits, opportunities, costs, and risks (BOCR) model. To improve implementing the strategies under risks, a value-risk matrix analysis was also conducted.
5	Islam and Huda [33]	2020	AHP	✘	A hybrid MCDM approach was presented based on the Delphi and AHP methods for identification and evaluation of potential e-products that can be outside of the National Television and Computer Recycling Scheme (NTCRS) of Australia. Moreover, the authors used an AHP-rating model for minimizing the computation time of the evaluation process in implementing the traditional AHP method.
6	Kumar, et al. [34]	2020	BWM and VIKOR	✘	A guiding framework was developed for managers and policymakers to evaluate sustainable locations for e-waste recycling plant. The methodology was based on the BWM and VIKOR methods. BWM was used to obtain the importance of criteria for evaluation of the sustainable plant locations, and VIKOR was applied to make the final evaluation of the recycling location candidates. The results showed the great importance of environmental and natural and biodiversity conservation criteria.
7	Sharma, et al. [35]	2020	DEMATEL	✘	To identify the key enablers with more impact on e-waste management in circular economies, the literature was reviewed comprehensively, and based on the experts' opinions Mumbai (Maharashtra), which was the highest producer of e-waste, was chosen as the case of the study. The DEMATEL method was applied to examine the importance of causal enablers. The study showed that environmental management system (EMS) was the most significant key enabler which impacts on all the other key enablers. The study also showed that e-waste management efficiency was related to focusing on eco-friendly e-products, proposing tough legislations, making green image and so on.
8	Chen, et al. [36]	2020	BWM and fuzzy TOPSIS	✓	A hybrid MCDM was used for identification and evaluation of barriers and pathways to a successful establishment of e-waste management systems. The proposed approach was based on the Delphi method, BWM and the fuzzy TOPSIS technique. In the first phase, barriers, pathways, and data collection for establishing e-waste management systems were identified using a comprehensive literature review and Delphi. In the second phase, the BWM method was applied to determine the relative importance and weights of the barriers, and in the third phase, the fuzzy TOPSIS method was utilized to evaluate and rank the pathways to implement e-waste management systems.
9	Rani and Mishra [37]	2020	CoCoSo	✓	A methodology was introduces based on an integration of the CoCoSo method and a similarity measure of single-valued neutrosophic sets (SVNSs). They proposed a new similarity measure for SVNSs, compared its efficiency with other existing similarity measures, and determined the criteria weights based on it. The authors used the developed methodology in solving a real-world decision-making problem. The empirical study made for evaluation and selection of e-waste recycling partners.

Table 1. *Cont.*

No.	Author(s)	Year	Approach	Uncertainty	Description
10	Baidya, et al. [38]	2020	AHP	✘	A study was carried out on the issues and challenges of the supply chain network of e-waste processing plants. The study used a multi-criteria decision-making approach based on the AHP method and quality function deployment (QFD) to evaluate the constructs gathered from the literature and supported by different studies. The house of quality (HOQ) was also applied to analyze various stakeholders' requirements. The study showed that the most serious challenges and issues of the supply chain network of e-waste processing plants were formal collection, storage, semi-informal collection, and e-waste quality.
11	Kaya, et al. [39]	2020	Fuzzy AHP	✓	A facility location problem of e-waste recycling plant was investigated by the authors. According to the several conflicting factors of the evaluation process an MCDM method was employed. The uncertainty of human judgments was handled by Pythagorean fuzzy sets. After identification of the criteria for the evaluation process of the locations of e-waste recycling plants, a fuzzy AHP approach was used to determine the weights of criteria, sub-criteria and alternative locations. The results showed that the importance of transportation, recycling, and energy costs are more than the other criteria.
12	Guarnieri, et al. [40]	2020	PCP	✘	A theoretical model was developed to evaluate e-waste reverse logistics based on a multi-criteria decision-making approach. A systematic literature review was conducted to obtain the model's inputs and show the main characteristics of the literature and identify the main criteria and methods used in the field of the study. The proposed model was illustrated with a numerical example for evaluation of e-waste reverse logistics.
13	Narayanamoorthy, et al. [41]	2020	MOOSRA	✓	A multi-criteria decision-making approach based on the MOOSRA method and hesitant fuzzy sets was proposed. The proposed methodology was used to evaluate e-waste recycling sites with respect to five criteria including Social, Hygienically safety, Environmental production, Technical capability and Economic.
14	Rani, et al. [42]	2020	Divergence measure	✓	Some generalizations of probabilistic divergence measures were extended as new fuzzy divergence measures. Then, the authors proposed a new method based on the developed divergence measures for multi-criteria decision-making problems under the fuzzy environment. The proposed methodology was applied to sustainable planning of an e-waste recycling job evaluation problem.
15	Hameed, et al. [43]	2020	Fuzzy VIKOR	✓	A study carried out on the generating e-wastes in Pakistan, the risks of the industry and effects of e-wastes on the population of Pakistan. The authors used a Modified-Safety Improve Risk Assessment (Modified-SIRA) method to identify different risks. A calculated Total Risk Priority Number (TRPN) was assigned to each of the risks. Then, the identified risks were evaluated and ranked using a fuzzy VIKOR method to examine their effect on the sustainability of the e-waste recycling industry. The study showed that air pollution of the e-waste recycling process can be a serious hazard to the population of developing countries like Pakistan.

Table 1. *Cont.*

No.	Author(s)	Year	Approach	Uncertainty	Description
16	Garg [44]	2021	DEMATEL	✓	A study conducted on the essential strategies of resources recovery and treatment and processing of hazardous and toxic components of e-waste. The aim of the study was to mitigate and manage e-waste as an immediate and existing challenge in India. The authors proposed a combined framework using the DEMATEL technique and Grey theory to determine the importance and relationship of the e-waste mitigation strategies based on a cause/effect analysis. The study concluded that top management initiation and commitment towards return management was an important strategy in the e-waste management systems which can affect the other strategies.
17	Menon and Ravi [45]	2021	ANP	✘	The eco-efficiency requirements of an electronics industry were analyzed in the study. To improve the eco-efficiency seven customer requirements and fourteen design requirements were identified for the electronics industry. The ANP method and Quality Function Deployment (QFD) were used to evaluate the customer requirements and design requirements. QFD was utilized as a tool for incorporating the voice of customers in designing and developing new products. The results of the study showed that design requirements to reduce greenhouse gases, air emissions, volatile organic compounds and carbon footprint are more important than the other factors for eco-efficiency in an e-product supply chain.
18	Fetanat, et al. [46]	2021	ANP, DEMATEL and MULTI-MOORA	✓	The study proposed a three-phase multi-criteria decision-making approach that integrates fuzzy ANP, fuzzy DEMATEL and fuzzy MULTIMOORA. Also, a sustainability index was introduced to determine the closeness of the results of the proposed integrated method to the ideal strategies. A real-world case was studied to present the performance of the proposed approach. The case was related to evaluation and selection of the most appropriate circular economy strategies for implementing a sustainable e-waste management system.
19	Xu, et al. [47]	2021	WSM and DEMATEL	✓	An integrated MCDM approach based on the weighted sum model, DEMATEL and fuzzy sets was proposed. The proposed approach was utilized to evaluate and manage the barriers which have significant impact on the e-waste management systems. Direct, indirect and interactive relationships of impacts of the barriers on the sustainable e-waste management system was examined with respect to economic, environmental and social sustainability criteria. To categorize the barriers into planning zones, a strategic planning process was developed based on the overall impact and mitigation level.
20	Fernandes, et al. [48]	2021	FITradeoff	✘	The paper developed a decision-making methodology based on the FITradeoff method which considered different aspects and phases including the collection of information. The methodology was applied to support evaluation of policies for e-waste management systems. The authors recommended that manufacturers should be more responsible in the designing eco-efficient products to decrease their negative environmental effects.

Table 1. *Cont.*

No.	Author(s)	Year	Approach	Uncertainty	Description
21	Sagnak, et al. [49]	2021	Fuzzy BWM and fuzzy TOPSIS	✓	An integrated approach was developed to evaluate different locations of sustainable collection centers for e-waste. Three main criteria (economic, social, and environmental) consist of 23 sub-criteria were identified for the evaluation process, and seven locations (Manisa, Menemen, Gaziemir, Kemalpaşa, Torbalı, Çiğli, and Akhisar) were considered as the alternatives of the case. The developed approach was based on the fuzzy BWM (for weighting criteria) and fuzzy TOPSIS (for final evaluation) methods. The results showed that transportation cost was the most significant criterion for evaluation of sustainable e-waste collection centers.
22	Kumar, et al. [50]	2022	DEMATEL	✓	The paper considered a multi-stakeholder's perspective to study enablers of sustainable e-waste management in India as an emerging economy. Several potential enablers were identified by reviewing the literature and gathering experts' opinions. Then, the identified enablers were examined to find the cause-effect relationships based on an MCDM approach. A grey-based DEMATEL approach was used for the evaluation. The results showed that research and development capability was a more important enabler that the others.
23	Singh, et al. [51]	2022	Fuzzy DEMATEL	✓	Based on the survey of the literature and experts' opinions, the paper identified 23 critical success factors and classified them into 6 dimensions for the e-waste collection policy evaluation. Then the fuzzy DEMATEL approach was applied to analyze the factors for establishment of an e-waste collection policy in India. Cause and effect interrelationship between the factors and their impacts were obtained using the methodology. The results showed that factors such as technology involvement, green practices and environmental program had significant impact on establishment of e-waste collection policies.
24	Jangre, et al. [52]	2022	Fuzzy DEMATEL and fuzzy MICMAC	✓	The paper focused on determination of the barriers and evaluation of them to examine the challenges in e-waste management systems. In addition, an integrated fuzzy approach based on the DEMATEL and Interpretive Structural Modeling (ISM) approaches was applied to find the importance and interrelationship between the barriers. The outcomes of this approach was used to evaluate identified barriers. Based on a fuzzy MICMAC analysis the barriers were sorted into dependent or driving factors. The results showed the more importance of "lack of customer awareness about return."
25	Singh, et al. [53]	2022	Fuzzy AHP and fuzzy VIKOR	✓	The e-waste management problems were analyzed based on the literature and economic sustainability and potential risks were identified as the criteria of the evaluation process. The weights of various criteria and sub-criteria were obtained by a decision-making model and experts' opinions. Ambiguity in experts' opinions was taken into account using a fuzzy linguistic scale. Determination of the importance of the criteria was made by the fuzzy AHP method and evaluation of sustainable e-waste collection methods was performed using the fuzzy VIKOR method.

Although some of the approaches cited in Table 1 have taken uncertainty into account, none of them included different levels of uncertainty in the evaluation process. In addition, distinct methods were usually used for determining criteria weights and making final evaluations in the previous studies. Due to these disadvantages of the existing methodologies, we may be confronted with situations where we cannot make an efficient evaluation of the criteria and alternatives. The proposed methodology can be used to handle such situations.

3. Methodology

In the following subsections, firstly, the SMART and SECA methods are briefly described and then the proposed fuzzy SECA (F-SECA) approach is presented in detail.

3.1. SECA

The SECA method is a relatively new MCDM method that helps us to determine criteria weights and alternatives' overall performances simultaneously. The method is based on a multi-objective mathematical model which considers the variations within the decision-matrix besides maximization of alternatives' performances. Two sets of reference points related to the standard deviations of criteria and correlations between them are used to determine criteria weights.

Firstly, we should define the parameters of the problem. Suppose that we have an MCDM problem with n alternatives and m criteria and x_{ij} shows the performance of ith alternative on jth criterion ($x_{ij} > 0$). According to the type of criteria, i.e., beneficial (BC) and non-beneficial (NC), the normalized values are calculated as follows.

$$x_{ij}^{N} = \begin{cases} \frac{x_{ij}}{\max\limits_{k} x_{kj}} & if \quad j \in BC \\ \frac{\min\limits_{k} x_{kj}}{x_{ij}} & if \quad j \in NC \end{cases} \tag{1}$$

The reference points of criteria weights are calculated based on the standard deviation of each column of decision-matrix (σ_j) and correlations between different columns (r_{jl}).

$$\sigma_j^N = \frac{\sigma_j}{\sum_{l=1}^{m} \sigma_l} \tag{2}$$

$$\pi_j^N = \frac{\pi_j}{\sum_{l=1}^{m} \pi_l} \tag{3}$$

where

$$\pi_j = \sum_{l=1}^{m} \left(1 - r_{jl}\right) \tag{4}$$

The original mathematical model of SECA is shown as follows:

$$max \quad S_i = \sum_{j=1}^{m} w_j x_{ij}^N, \ \ \forall i \in \{1, 2, \ldots, n\} \tag{5a}$$

$$min \quad \lambda_b = \sum_{j=1}^{m} \left(w_j - \sigma_j^N\right)^2 \tag{5b}$$

$$min \quad \lambda_c = \sum_{j=1}^{m} \left(w_j - \pi_j^N\right)^2 \tag{5c}$$

$$s.t. \quad \sum_{j=1}^{m} w_j = 1 \tag{5d}$$

$$w_j \leq 1 \ , \ \ \forall j \in \{1, 2, \ldots, m\} \tag{5e}$$

$$w_j \geq \varepsilon, \ \ \forall j \in \{1, 2, \ldots, m\} \tag{5f}$$

where ε is a small positive number.

3.2. SMART

Simple Multi-Attribute Rating Technique or SMART is a classic MCDM method proposed by Von Winterfeldt and Edwards [18]. It can be applied to the determination of subjective criteria weights. In this method, decision-makers are asked to give their opinions on the importance of each criterion. They can assign points between 0 and 100 to the criteria to address the relative importance. Then the normalized weights are calculated by dividing the points of each criterion by the sum of the points. In this paper, the outputs of this method are used as inputs for the proposed approach.

3.3. Proposed Approach

In this section, a new MCDM approach is proposed based on the SECA method, fuzzy numbers, α-cut intervals and SMART. The aim of the proposed approach is to evaluate alternatives and criteria of an MCDM problem simultaneously. The original SECA method is based on a deterministic multi-objective mathematical model and yields crisp values for objective criteria weights and alternatives' overall performances. On the other hand, the proposed approach can be used in an uncertain environment, and it also incorporates subjective criteria weights, determined based on decision-makers' opinions and SMART. Moreover, using the α-cut of fuzzy numbers we can obtain some intervals for evaluation and analysis of criteria and alternatives. Here, different levels of α can be used in defining different levels of uncertainty. The framework of the proposed approach is illustrated in Figure 1.

The following steps describe the details of using the proposed approach to deal with an MCDM problem with n alternatives and m criteria.

- *Step 1*. Organize a group of decision-makers or experts. In this step, we should form a group of experts for the procedure of decision-making. The experts or decision-makers are usually selected from different departments with different expertise. In normal situations, making a collaborative decision based on the opinions and judgments of a group of experts would often be preferred and could have more benefits than individual decision-making. However, in emergencies or crisis situations, we can skip this step and continue with one expert or decision-maker.
- *Step 2*. Define the problem based on the decision-makers' opinions. The decision-makers define the MCDM problem in this step. Generally, a number of alternatives and criteria should be identified by each expert. Partnership and collaboration are very important in this step to reach a rational consensus on the structure of the problem. Each of decision-makers identify a set of alternatives and criteria. The final and verified set of alternatives and criteria can be identified based on common aspects of different decision-makers' opinions.
- *Step 3*. Get the initial evaluations of the criteria from each decision-maker. In this step, the initial evaluation of the criteria should be done by each expert in the decision-making group. We can use linguistic variables, Likert scale and other scoring techniques to collect the experts' opinions. In accordance with the framework of the proposed approach, a scale between 0 and 100 is used for evaluations (0 for the least and 100 for the most important criteria).
- *Step 4*. Take the initial evaluations of the alternatives' performances on each criterion from all experts. Linguistic variables are used in this step to get decision-makers' opinions on the alternatives' performances. The main advantage of the linguistic variables is that they can easily be transformed into trapezoidal fuzzy numbers to capture the uncertainty of the evaluation process. Here the linguistic variables include a spectrum from "Very Low" (VL) to "Very High" (VH). The complete list of these variables can be seen in Table 2.
- *Step 5*. Use the SMART method to calculate the subjective criteria weights. In this step, the evaluation taken from the experts in Step 3 are used. Suppose that I_{jk} shows the importance or points of jth criterion assigned by kth decision-maker. Then the following equation can be used to determine the subjective weight of each criterion (w_j^s).

$$w_j^s = \frac{\sum_k I_{jk}}{\sum_k \sum_j I_{jk}} \tag{6}$$

- *Step 6*. Aggregate the alternatives' performances and constitute a fuzzy decision-matrix. Using Table 2, arithmetic operations of fuzzy numbers and initial evaluations obtained in Step 4, we can aggregate the alternatives' performances and transform them into trapezoidal fuzzy numbers. It should be noted that this type of fuzzy sets is a very efficient tool to capture uncertainty of the decision-making information. The elements of the fuzzy decision-matrix ($\tilde{x}_{ij}$) are the outcomes of this step.

- *Step 7*. Apply the α-cut approach to obtain an interval decision-matrix. As previously mentioned, $\tilde{x}_{ij}$ denotes the elements of the fuzzy decision-matrix which are defined as trapezoidal fuzzy numbers or $\tilde{x}_{ij} = \left(x_{ij}^a, x_{ij}^b, x_{ij}^c, x_{ij}^d\right)$. The following equations are used to obtain the elements of the interval decision-matrix ($x_{ij}^{\alpha} = \left[x_{ij}^{L\alpha}, x_{ij}^{U\alpha}\right]$).

$$x_{ij}^{L\alpha} = \alpha\left(x_{ij}^b - x_{ij}^a\right) + x_{ij}^a \tag{7}$$

$$x_{ij}^{U\alpha} = x_{ij}^d - \alpha\left(x_{ij}^d - x_{ij}^c\right) \tag{8}$$

- *Step 8.* Normalize the interval decision-matrix. In this step, we should calculate the normalized values ($x_{ij}^{N\alpha} = \left[x_{ij}^{NL}, x_{ij}^{NU}\right]$) using arithmetic operations of the interval numbers. Here we can use the following equation that is based on the characteristics of the interval numbers and the type of each criterion.

$$x_{ij}^{N\alpha} = \begin{cases} \left[\frac{x_{ij}^{L\alpha}}{Ux_j}, \frac{x_{ij}^{U\alpha}}{Ux_j}\right] & if \quad j \in BC \\ \left[\frac{Lx_j}{x_{ij}^{U\alpha}}, \frac{Lx_j}{x_{ij}^{L\alpha}}\right] & if \quad j \in NC \end{cases} \tag{9}$$

where $Ux_j = \max_i x_{ij}^{U\alpha}$, $Lx_j = \min_i x_{ij}^{L\alpha}$ and BC and NC shows the sets of beneficial and non-beneficial criteria, respectively.

- *Step 9.* Calculate the crisp decision-matrix. Using the following equation, we can determine a crisp decision-matrix based on the normalized interval decision-matrix. Actually, the average of the lower and upper bounds is used to reach the crisp matrix. Suppose that $x_{ij}^{C\alpha}$ denotes the elements of this matrix, then we have:

$$x_{ij}^{C\alpha} = \frac{x_{ij}^{NL} + x_{ij}^{NU}}{2} \tag{10}$$

- *Step 10.* Determine the values σ_j^C and π_j^C for each criterion. Two important parameters of the SECA method are calculated in this step. The calculation of these parameters is made based on the crisp decision-matrix (Step 9) and the same equations of the original SECA method. It should be noted that we can also use a simulation-based procedure with the lower and upper bounds of the normalized interval decision-matrix to determine these parameters. However, a simulation-based procedure will lead to a more complicated way to apply the SECA method. The following equations are used in this step.

$$\sigma_j^C = \frac{\sigma_j}{\sum_l \sigma_l} \tag{11}$$

$$\pi_j^C = \frac{\pi_j}{\sum_l \pi_l} \tag{12}$$

where σ_j is the Standard Deviation of each column of the crisp decision-matrix, and π_j is the degree of conflict between a criterion and the other criteria. The values of π_j calculated based on the correlation between jth and lth columns of the matrix (r_{jl}) and the following equation.

$$\pi_j = \sum_{l=1}^{m}\left(1 - r_{jl}\right) \tag{13}$$

- *Step 11.* Solve two individual model based on SECA. In this step, two mathematical models based on the lower and upper bounds of the interval decision-matrix are defined. Here the subjective weights are incorporated as another variable (λ_d) and both models use the same reference points (w_j^s, σ_j^C and π_j^C) for determination of the criteria weights. The following are the defined models. Model 1:

$$Max\ Z^L = \lambda_a^L - \beta\left(\lambda_b^L + \lambda_c^L + \lambda_d^L\right) \tag{14a}$$

$$\lambda_a^L \le S_i^L \qquad \forall i \in \{1, 2, \ldots, n\} \tag{14b}$$

$$S_i^L = \sum_{j=1}^m w_{j1} x_{ij}^{NL} \qquad \forall i \in \{1, 2, \ldots, n\} \tag{14c}$$

$$\lambda_b^L = \sum_{j=1}^m \left(w_{j1} - \sigma_j^C\right)^2 \tag{14d}$$

$$\lambda_c^L = \sum_{j=1}^m \left(w_{j1} - \pi_j^C\right)^2 \tag{14e}$$

$$\lambda_d^L = \sum_{j=1}^m \left(w_{j1} - w_j^s\right)^2 \tag{14f}$$

$$\sum_{j=1}^m w_{j1} = 1 \tag{14g}$$

$$w_{j1} \le 1 \qquad \forall j \in \{1, 2, \ldots, m\} \tag{14h}$$

$$w_{j1} \ge \varepsilon \qquad \forall j \in \{1, 2, \ldots, m\} \tag{14i}$$

Model 2:

$$Max\ Z^U = \lambda_a^U - \beta\left(\lambda_b^U + \lambda_c^U + \lambda_d^U\right) \tag{15a}$$

$$\lambda_a^U \le S_i^U \qquad \forall i \in \{1, 2, \ldots, n\} \tag{15b}$$

$$S_i^U = \sum_{j=1}^m w_{j2} x_{ij}^{NU} \qquad \forall i \in \{1, 2, \ldots, n\} \tag{15c}$$

$$\lambda_b^U = \sum_{j=1}^m \left(w_{j2} - \sigma_j^C\right)^2 \tag{15d}$$

$$\lambda_c^U = \sum_{j=1}^m \left(w_{j2} - \pi_j^C\right)^2 \tag{15e}$$

$$\lambda_d^U = \sum_{j=1}^m \left(w_{j2} - w_j^s\right)^2 \tag{15f}$$

$$\sum_{j=1}^m w_{j2} = 1 \tag{15g}$$

$$w_{j2} \le 1 \qquad \forall j \in \{1, 2, \ldots, m\} \tag{15h}$$

$$w_{j2} \ge \varepsilon \qquad \forall j \in \{1, 2, \ldots, m\} \tag{15i}$$

- *Step 12.* Determine the intervals related to alternatives' overall performances and criteria weights. Based on the results of Step 11 we can determine these intervals as shown as follows:

$$S_i = \left[S_i^L, S_i^U\right] \tag{16}$$

$$w_j = \left[w_j^L, w_j^U\right] = \left[min\left(w_{j1}, w_{j2}\right), max\left(w_{j1}, w_{j2}\right)\right] \tag{17}$$

- *Step 13.* Evaluate the alternatives and criteria. According to the intervals obtained in Step 12, we can use a technique of comparing interval numbers or the average of the lower and upper bounds (like Equation (10)) for making the final evaluations.

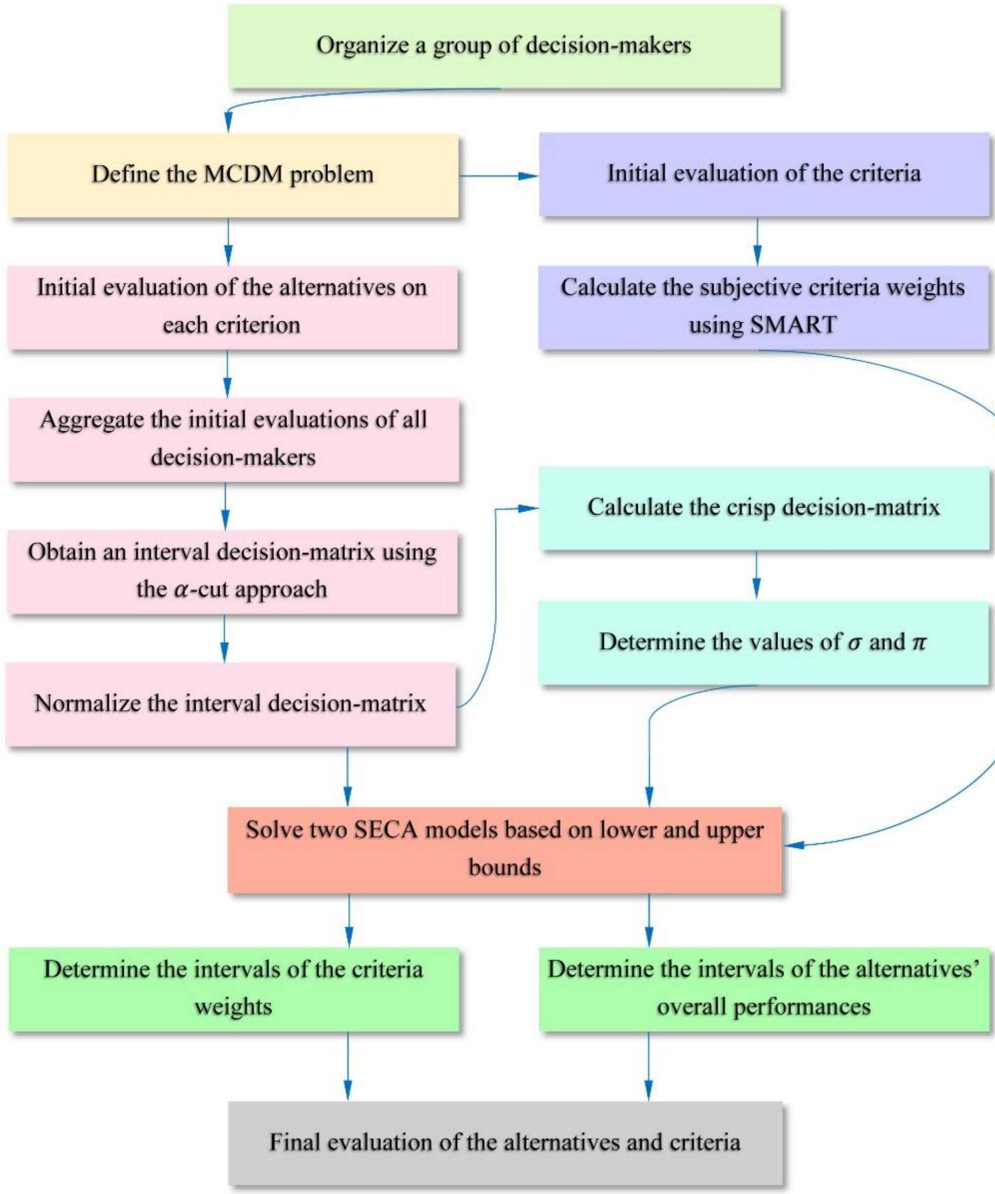

Figure 1. Illustrative diagram of the proposed approach.

Table 2. The linguistic variables and fuzzy numbers.

Linguistic Variables	Fuzz Numbers
Very Low (VL)	(0, 0, 0.1, 0.2)
Low (L)	(0.1, 0.2, 0.2, 0.3)
Medium Low (ML)	(0.2, 0.3, 0.4, 0.5)
Medium (M)	(0.4, 0.5, 0.5, 0.6)
Medium High (MH)	(0.5, 0.6, 0.7, 0.8)
High (H)	(0.7, 0.8, 0.8, 0.9)
Very High (VH)	(0.8, 0.9, 1, 1)

4. An Empirical Study

In this section, the proposed approach is applied to an e-waste scenario evaluation in Iran. Since there are no laws and incentives concerning e-waste management in Iran, companies working in this area should consider different scenarios to choose a feasible and appropriate way. In this case, a waste management company in Iran is studied. The company would like to expand its services by adding new e-waste management processes.

To reach this aim, it needs to consider and evaluate different scenarios that could be helpful in its expansion. Due to the lack of experience in this field, the company have not had a set of standard scenarios. Although several experts in waste management and engineering are working for the company, the focus of them has not been on e-waste management systems. Accordingly, the top managers would prefer to get the opinions of some outside experts as well as the experts working for the company.

In the following, the steps of using the proposed approach for the evaluation of e-waste management scenarios are described in a step-by-step way.

Step 1. To form a group of decision-makers the board of directors designated three experts from the middle-level managers of the company and two outside experts from the academicians with expertise in e-waste management to get involved in evaluation process. Therefore, we have five decision-makers in total (D_1 to D_5).

Step 2. The group of decision makers reached a consensus on the structure of the problems including the sets of scenarios (alternatives) and criteria according to the literature on this topic. Based on a comprehensive study made by Rousis et al. [54], 17 criteria have been defined to evaluate 12 scenarios for e-waste management. Figure 2 represents the structure of the problem and the list of scenarios, and Figure 3 illustrates the evaluation criteria and their descriptions.

Steps 3 to 5. In these steps, the information about each decision-maker's opinion on the importance of the criteria and performance of the alternatives was collected. Using the scores assigned by the experts to each criterion and the SMART method, the subjective weights of the criteria were determined based on Equation (6). The scores and subjective weights are presented in Table 3. Moreover, the performance of the alternatives on each criterion given by each decision-maker are presented in Table 4.

Steps 6 and 7. Based on Table 4 and the linguistic variables and the corresponding trapezoidal fuzzy numbers defined in Table 2, we can aggregate the performances related to different decision-makers and determine the fuzzy decision-matrix. Because of space limitations, this matrix is partially presented in Table 5. As previously mentioned, the elements of the fuzzy decision-matrix and the α-cut approach are used to obtain the interval decision-matrix. In this study, the value of α, which shows the level of uncertainty, is set to 0.5 for calculation of the elements of this matrix with Equations (7) and (8). The interval decision-matrix is also shown in Table 6 partially.

Step 8. As it can be seen in Table 6 the scale of the elements is not in a comparable range. To have a standard range in the elements of the decision matrix, we can use Equation (9) to normalize the interval decision-matrix. The normalized interval decision-matrix is partially presented in Table 7.

Steps 9 and 10. According to the results of the previous step, a crisp decision-matrix are determined. Equation (10) and the normalized interval decision-matrix are used to determine this matrix. The elements of the crisp decision-matrix are shown in Table 8. Then we should determine the values of σ_j^C and π_j^C for each criterion. These parameters, which are also presented in Table 8, are calculated using Equations (11) and (12).

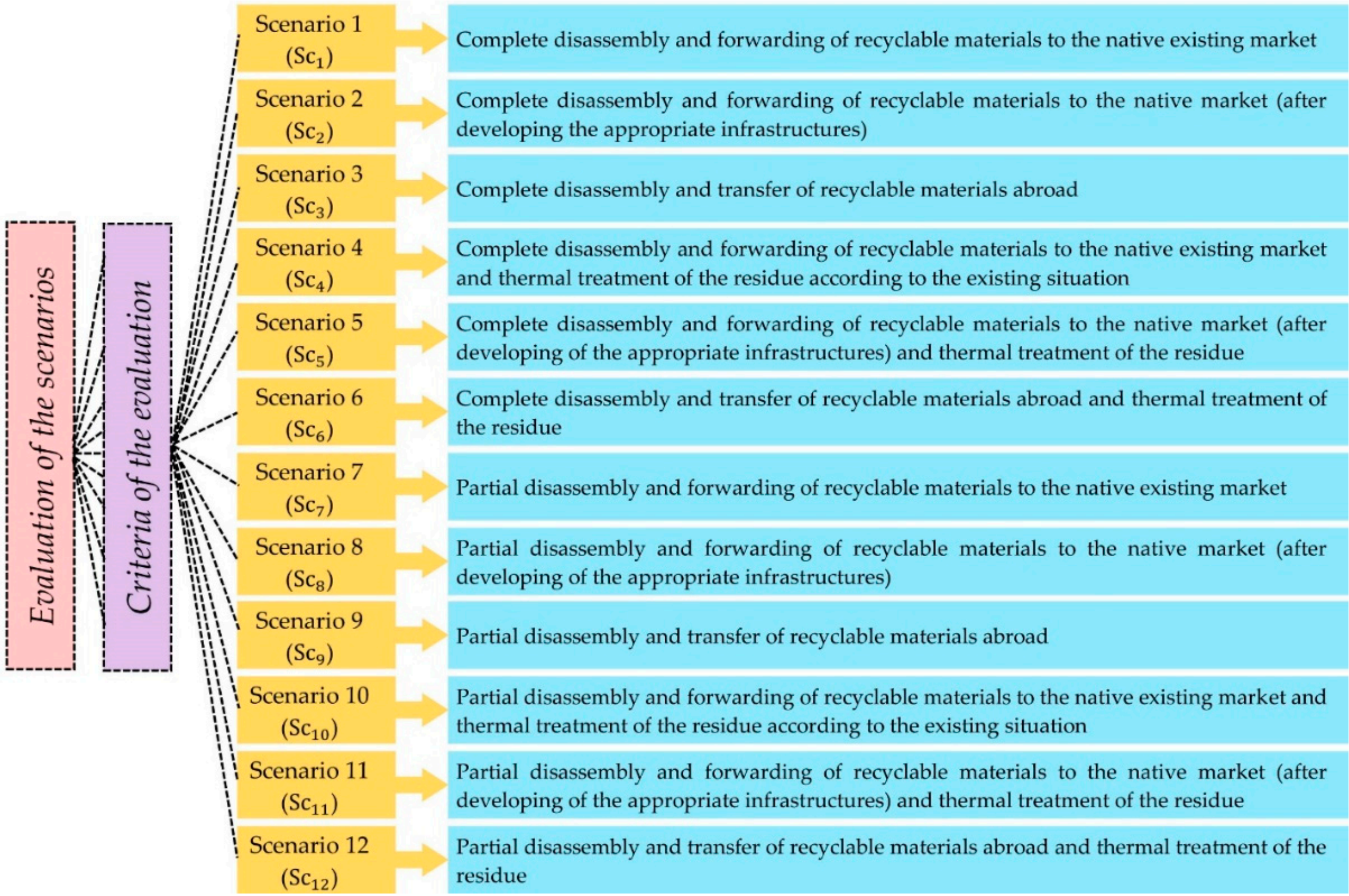

Figure 2. The structure of the problem and the list of scenarios.

Table 3. The scores and subjective weights of the criteria.

		D_1	D_2	D_3	D_4	D_5	**Sum**	w_j^s
C_1	C_{11}	30	40	50	45	30	195	0.047
	C_{12}	40	50	40	40	50	220	0.053
	C_{13}	35	45	30	30	50	190	0.046
	C_{14}	25	35	30	30	30	150	0.036
C_2	C_{21}	60	50	70	40	60	280	0.067
	C_{22}	50	60	60	50	70	290	0.070
	C_{23}	40	50	50	60	60	260	0.063
	C_{24}	60	70	70	60	70	330	0.080
	C_{25}	20	25	25	10	20	100	0.024
	C_{26}	10	20	10	10	10	60	0.014
C_3	C_{31}	100	90	100	80	100	470	0.113
	C_{32}	80	90	100	75	90	435	0.105
	C_{33}	90	80	80	80	100	430	0.104
C_4	C_{41}	60	50	50	70	60	290	0.070
	C_{42}	40	30	30	25	30	155	0.037
	C_{43}	30	30	25	40	20	145	0.035
	C_{44}	40	40	20	30	20	150	0.036

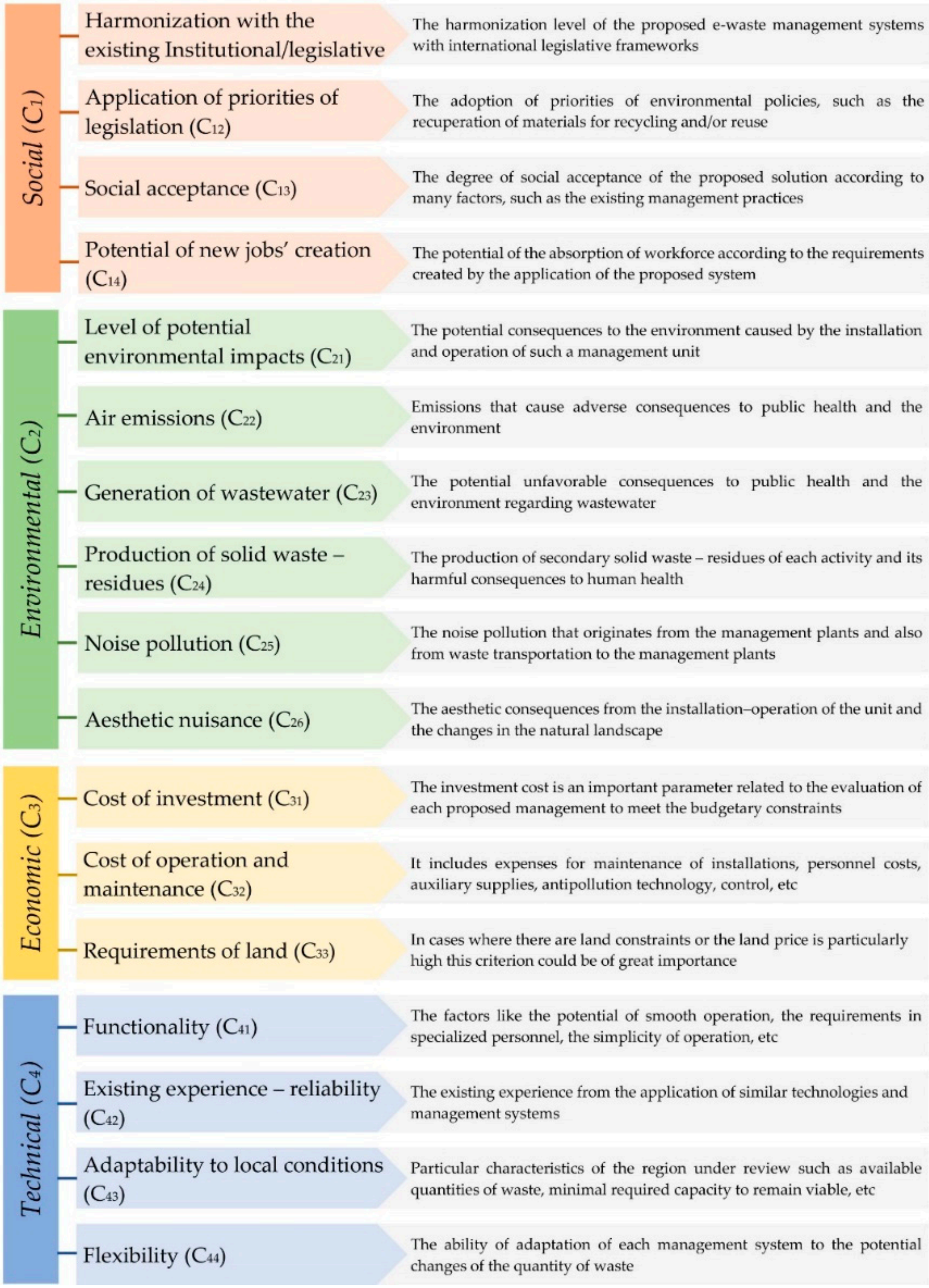

Figure 3. The criteria of the evaluation process.

Table 4. The performance of the alternatives on each criterion given by each DM.

DM	SC	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	C_{31}	C_{32}	C_{33}	C_{41}	C_{42}	C_{43}	C_{44}
D_1	Sc_1	VH	H	ML	H	ML	M	M	M	M	MH	ML	M	H	M	M	ML	MH
	Sc_2	VH	H	MH	MH	VL	VH	MH	MH	MH	MH	M	ML	ML	MH	VL	ML	ML
	Sc_3	MH	MH	H	L	M	M	MH	MH	MH	M	ML	ML	ML	MH	M	H	L
	Sc_4	H	MH	ML	MH	ML	MH	H	MH	L	M	ML	L	M	MH	ML	MH	L
	Sc_5	M	MH	MH	MH	M	ML	VH	MH	L	ML	ML	L	ML	MH	L	M	MH
	Sc_6	MH	MH	H	M	M	ML	M	H	MH	MH	L	ML	ML	ML	ML	ML	MH
	Sc_7	H	H	M	MH	ML	H	MH	MH	M	M	M	MH	ML	H	M	H	M
	Sc_8	H	M	H	ML	H	VH	H	ML	MH	M	H	M	MH	M	L	M	MH
	Sc_9	H	M	H	VL	MH	MH	H	ML	MH	ML	ML	ML	M	MH	M	ML	VH
	Sc_{10}	H	MH	M	M	M	M	M	MH	M	ML	MH	L	M	H	M	MH	ML
	Sc_{11}	MH	H	MH	M	VL	L	M	H	M	M	M	ML	MH	M	MH	MH	MH
	Sc_{12}	H	MH	M	M	MH	M	H	MH	M	MH	ML	M	M	H	M	VH	H
D_2	Sc_1	H	H	MH	MH	ML	MH	M	ML	ML	ML	MH	L	M	ML	L	M	M
	Sc_2	VH	MH	ML	H	ML	H	ML	ML	M	M	ML	ML	MH	ML	VL	ML	ML
	Sc_3	H	M	M	L	M	M	H	H	M	ML	ML	ML	M	MH	ML	M	ML
	Sc_4	MH	H	M	H	M	ML	VH	H	M	L	ML	L	M	ML	ML	M	ML
	Sc_5	MH	VH	MH	VH	M	M	VH	M	L	MH	ML	L	M	M	L	MH	MH
	Sc_6	H	ML	M	MH	ML	M	M	VH	MH	M	ML	L	M	ML	L	M	ML
	Sc_7	VH	VH	H	M	M	H	MH	M	MH	MH	MH	MH	ML	M	ML	MH	H
	Sc_8	VH	M	MH	M	MH	VH	MH	ML	MH	M	H	ML	ML	MH	L	MH	H
	Sc_9	H	MH	MH	ML	ML	MH	H	M	MH	MH	ML	MH	MH	H	MH	M	H
	Sc_{10}	M	H	ML	ML	ML	MH	MH	ML	M	M	H	L	H	MH	ML	M	M
	Sc_{11}	H	MH	M	M	L	ML	ML	M	M	ML	MH	MH	MH	MH	M	MH	H
	Sc_{12}	VH	MH	M	ML	ML	M	MH	M	M	MH	L	ML	ML	VH	MH	VH	MH
D_3	Sc_1	H	M	M	MH	ML	H	H	MH	ML	ML	ML	ML	H	M	L	ML	M
	Sc_2	H	MH	M	MH	ML	H	MH	M	MH	ML	MH	L	MH	MH	VL	ML	ML
	Sc_3	H	MH	MH	M	M	M	MH	MH	MH	L	M	ML	ML	H	L	H	ML
	Sc_4	M	M	MH	H	L	M	VH	M	M	L	MH	VL	M	ML	VL	M	ML
	Sc_5	H	H	M	H	ML	MH	H	H	L	MH	L	VL	ML	M	L	M	MH
	Sc_6	H	M	MH	MH	MH	ML	MH	H	M	MH	L	L	L	MH	ML	M	M
	Sc_7	H	H	MH	H	M	VH	ML	ML	ML	M	MH	M	M	H	M	H	H
	Sc_8	VH	M	M	MH	M	H	MH	MH	MH	MH	H	MH	M	MH	L	MH	MH
	Sc_9	M	MH	MH	L	MH	MH	VH	ML	H	MH	M	ML	MH	H	ML	ML	VH
	Sc_{10}	MH	H	M	MH	ML	MH	H	M	ML	MH	H	L	H	MH	M	H	ML
	Sc_{11}	VH	VH	M	H	L	L	ML	MH	MH	MH	MH	ML	M	M	ML	MH	H
	Sc_{12}	H	ML	MH	L	ML	MH	H	H	H	MH	M	M	M	MH	MH	VH	VH
D_4	Sc_1	H	MH	MH	M	ML	H	MH	MH	M	M	ML	ML	M	M	ML	MH	H
	Sc_2	VH	H	M	H	L	MH	ML	MH	M	MH	ML	ML	M	ML	L	M	ML
	Sc_3	H	ML	M	L	L	M	M	MH	ML	ML	MH	ML	ML	MH	L	MH	M
	Sc_4	H	M	ML	H	ML	M	H	H	L	L	ML	VL	ML	M	VL	H	M
	Sc_5	H	MH	MH	VH	M	MH	VH	MH	L	M	L	VL	M	ML	VL	M	M
	Sc_6	H	ML	H	M	MH	M	MH	MH	ML	M	ML	M	L	MH	ML	MH	MH
	Sc_7	H	H	MH	H	MH	MH	ML	M	ML	MH	MH	ML	ML	H	MH	MH	H
	Sc_8	MH	H	H	M	M	H	M	ML	M	H	M	ML	ML	MH	L	H	MH
	Sc_9	M	ML	H	VL	MH	MH	MH	L	M	ML	M	MH	MH	MH	ML	MH	VH
	Sc_{10}	MH	M	MH	M	L	MH	M	ML	M	M	MH	M	H	H	L	H	M
	Sc_{11}	H	MH	MH	MH	L	M	ML	M	M	M	MH	MH	MH	M	ML	MH	H
	Sc_{12}	VH	MH	M	M	ML	ML	H	M	MH	H	ML	M	L	VH	MH	VH	MH
D_5	Sc_1	H	MH	MH	MH	M	MH	M	ML	M	ML	M	ML	M	M	ML	ML	H
	Sc_2	H	M	ML	MH	VL	H	ML	ML	MH	ML	M	M	M	MH	ML	M	M
	Sc_3	MH	MH	M	L	M	MH	H	MH	ML	L	MH	ML	ML	MH	L	M	M
	Sc_4	H	M	ML	MH	L	M	VH	H	ML	L	M	VL	L	ML	VL	M	L
	Sc_5	M	MH	ML	MH	M	MH	H	M	L	ML	M	ML	ML	ML	VL	M	MH
	Sc_6	MH	ML	MH	ML	MH	M	H	H	M	ML	ML	L	M	MH	ML	MH	ML
	Sc_7	H	VH	MH	MH	ML	H	M	M	M	H	MH	M	ML	M	ML	M	MH
	Sc_8	VH	H	MH	ML	H	VH	H	MH	M	H	MH	ML	ML	H	L	M	H
	Sc_9	H	M	VH	VL	MH	MH	VH	L	H	MH	ML	M	M	H	M	M	H
	Sc_{10}	M	M	MH	M	M	ML	H	MH	M	M	M	M	M	M	M	H	MH
	Sc_{11}	H	H	M	H	VL	M	MH	H	M	M	MH	M	ML	H	M	H	H
	Sc_{12}	MH	M	MH	ML	ML	ML	H	M	H	MH	M	M	ML	MH	MH	H	VH

Table 5. The aggregated fuzzy decision-matrix.

	Sc_1	Sc_2	Sc_3	Sc_4	Sc_5	Sc_6	Sc_7	Sc_8	Sc_9	Sc_{10}	Sc_{11}	Sc_{12}
C_{11}	(3.6,4.1,4.2,4.6)	(3.8,4.3,4.6,4.8)	(3.1,3.6,3.8,4.3)	...	...	...	...	...	...	(2.5,3,3.2,3.7)	(3.4,3.9,4.1,4.5)	(3.5,4,4.3,4.6)
C_{12}	(2.8,3.3,3.5,4)	(2.8,3.3,3.5,4)	(2.1,2.6,3,3.5)	...	...	...	...	...	...	(2.7,3.2,3.3,3.8)	(3.2,3.7,4,4.4)	(2.1,2.6,3,3.5)
C_{13}	(2.1,2.6,3,3.5)	(1.7,2.2,2.5,3)	(2.4,2.9,3,3.5)	...	...	...	...	...	...	(2,2.5,2.8,3.3)	(2.2,2.7,2.9,3.4)	(2.2,2.7,2.9,3.4)
C_{14}	(2.6,3.1,3.4,3.9)	(2.9,3.4,3.7,4.2)	(0.8,1.3,1.3,1.8)	...	...	...	...	...	...	(1.9,2.4,2.6,3.1)	(2.7,3.2,3.3,3.8)	(1.3,1.8,2,2.5)
C_{21}	(1.2,1.7,2.1,2.6)	(0.5,0.8,1.2,1.7)	(1.7,2.2,2.2,2.7)	...	...	...	...	...	...	(1.3,1.8,2,2.5)	(0.3,0.6,0.8,1.3)	(1.3,1.8,2.3,2.8)
C_{22}	(2.8,3.3,3.5,4)	(3.4,3.9,4.1,4.5)	(2.1,2.6,2.7,3.2)	...	...	...	...	...	...	(2.1,2.6,3.,3.5)	(1.2,1.7,1.8,2.3)	(1.7,2.2,2.5,3)
C_{23}	(2.4,2.9,3,3.5)	(1.6,2.1,2.6,3.1)	(2.8,3.3,3.5,4)	...	...	...	...	...	...	(2.7,3.2,3.3,3.8)	(1.5,2,2.4,2.9)	(3.3,3.8,3.9,4.4)
C_{24}	(1.8,2.3,2.7,3.2)	(1.8,2.3,2.7,3.2)	(2.7,3.2,3.6,4.1)	...	...	...	...	...	...	(1.8,2.3,2.7,3.2)	(2.7,3.2,3.3,3.8)	(2.4,2.9,3,3.5)
C_{25}	(1.6,2.1,2.3,2.8)	(2.3,2.8,3.1,3.6)	(1.8,2.3,2.7,3.2)	...	...	...	...	...	...	(1.8,2.3,2.4,2.9)	(2.1,2.6,2.7,3.2)	(2.7,3.2,3.3,3.8)
C_{26}	(1.5,2,2.4,2.9)	(1.8,2.3,2.7,3.2)	(1.,1.5,1.7,2.2)	...	...	...	...	...	...	(1.9,2.4,2.6,3.1)	(1.9,2.4,2.6,3.1)	(2.7,3.2,3.6,4.1)
C_{31}	(1.5,2,2.4,2.9)	(1.7,2.2,2.5,3.)	(1.8,2.3,2.7,3.2)	...	...	...	...	...	...	(2.8,3.3,3.5,4)	(2.4,2.9,3.3,3.8)	(1.3,1.8,2,2.5)
C_{32}	(1.1,1.6,1.9,2.4)	(1.1,1.6,1.9,2.4)	(1,1.5,2,2.5)	...	...	...	...	...	...	(1.1,1.6,1.6,2.1)	(1.8,2.3,2.7,3.2)	(1.8,2.3,2.4,2.9)
C_{33}	(2.6,3.1,3.1,3.6)	(2,2.5,2.8,3.3)	(1.2,1.7,2.1,2.6)	...	...	...	...	...	...	(2.9,3.4,3.4,3.9)	(2.1,2.6,3.,3.5)	(1.3,1.8,2,2.5)
C_{41}	(1.8,2.3,2.4,2.9)	(1.9,2.4,2.9,3.4)	(2.7,3.2,3.6,4.1)	...	...	...	...	...	...	(2.8,3.3,3.5,4)	(2.4,2.9,3,3.5)	(3.3,3.8,4.2,4.5)
C_{42}	(1,1.5,1.7,2.2)	(0.3,0.5,0.9,1.4)	(0.9,1.4,1.5,2)	...	...	...	...	...	...	(1.5,2,2.1,2.6)	(1.7,2.2,2.5,3)	(2.4,2.9,3.3,3.8)
C_{43}	(1.5,2,2.4,2.9)	(1.4,1.9,2.2,2.7)	(2.7,3.2,3.3,3.8)	...	...	...	...	...	...	(3,3.5,3.6,4.1)	(2.7,3.2,3.6,4.1)	(3.9,4.4,4.8,4.9)
C_{44}	(2.7,3.2,3.3,3.8)	(1.2,1.7,2.1,2.6)	(1.3,1.8,2,2.5)	...	...	...	...	...	...	(1.7,2.2,2.5,3)	(3.3,3.8,3.9,4.4)	(3.3,3.8,4.2,4.5)

Table 6. The aggregated interval decision-matrix.

	Sc_1	Sc_2	Sc_3	Sc_4	Sc_5	Sc_6	Sc_7	Sc_8	Sc_9	Sc_{10}	Sc_{11}	Sc_{12}
C_{11}	[3.85,4.4]	[4.05,4.7]	[3.35,4.05]	...	...	...	...	...	...	[2.75,3.45]	[3.65,4.3]	[3.75,4.45]
C_{12}	[3.05,3.75]	[3.05,3.75]	[2.35,3.25]	...	...	...	...	...	...	[2.95,3.55]	[3.45,4.2]	[2.35,3.25]
C_{13}	[2.35,3.25]	[1.95,2.75]	[2.65,3.25]	...	...	...	...	...	...	[2.25,3.05]	[2.45,3.15]	[2.45,3.15]
C_{14}	[2.85,3.65]	[3.15,3.95]	[1.05,1.55]	...	...	...	...	...	...	[2.15,2.85]	[2.95,3.55]	[1.55,2.25]
C_{21}	[1.45,2.35]	[0.65,1.45]	[1.95,2.45]	...	...	...	...	...	...	[1.55,2.25]	[0.45,1.05]	[1.55,2.55]
C_{22}	[3.05,3.75]	[3.65,4.3]	[2.35,2.95]	...	...	...	...	...	...	[2.35,3.25]	[1.45,2.05]	[1.95,2.75]
C_{23}	[2.65,3.25]	[1.85,2.85]	[3.05,3.75]	...	...	...	...	...	...	[2.95,3.55]	[1.75,2.65]	[3.55,4.15]
C_{24}	[2.05,2.95]	[2.05,2.95]	[2.95,3.85]	...	...	...	...	...	...	[2.05,2.95]	[2.95,3.55]	[2.65,3.25]
C_{25}	[1.85,2.55]	[2.55,3.35]	[2.05,2.95]	...	...	...	...	...	...	[2.05,2.65]	[2.35,2.95]	[2.95,3.55]
C_{26}	[1.75,2.65]	[2.05,2.95]	[1.25,1.95]	...	...	...	...	...	...	[2.15,2.85]	[2.15,2.85]	[2.95,3.85]
C_{31}	[1.75,2.65]	[1.95,2.75]	[2.05,2.95]	...	...	...	...	...	...	[3.05,3.75]	[2.65,3.55]	[1.55,2.25]
C_{32}	[1.35,2.15]	[1.35,2.15]	[1.25,2.25]	...	...	...	...	...	...	[1.35,1.85]	[2.05,2.95]	[2.05,2.65]
C_{33}	[2.85,3.35]	[2.25,3.05]	[1.45,2.35]	...	...	...	...	...	...	[3.15,3.65]	[2.35,3.25]	[1.55,2.25]
C_{41}	[2.05,2.65]	[2.15,3.15]	[2.95,3.85]	...	...	...	...	...	...	[3.05,3.75]	[2.65,3.25]	[3.55,4.35]
C_{42}	[1.25,1.95]	[0.4,1.15]	[1.15,1.75]	...	...	...	...	...	...	[1.75,2.35]	[1.95,2.75]	[2.65,3.55]
C_{43}	[1.75,2.65]	[1.65,2.45]	[2.95,3.55]	...	...	...	...	...	...	[3.25,3.85]	[2.95,3.85]	[4.15,4.85]
C_{44}	[2.95,3.55]	[1.45,2.35]	[1.55,2.25]	...	...	...	...	...	...	[1.95,2.75]	[3.55,4.15]	[3.55,4.35]

Steps 11 and 12. According to the values of subjective weights (Table 3), lower and upper bounds of the normalized interval decision-matrix (Table 7) and the values of σ_j^C and π_j^C (Table 8), we can solve two individual models for fuzzy SECA (Model 1 and Model 2 have been presented in the previous section). The intervals of the alternatives' overall performances and criteria weights obtained by solving the models are represented in Table 9. In addition, for final evaluation of the alternatives and criteria, the crisp values (S_i^C and w_j^C) and the rankings (R_i^S and R_j^w) corresponding to the intervals are calculated using the average of the lower and upper bounds (like Equation (10)) and presented in Table 9.

Table 7. The normalized interval decision-matrix.

	Sc_1	Sc_2	Sc_3	Sc_4	Sc_5	Sc_6	Sc_7	Sc_8	Sc_9	Sc_{10}	Sc_{11}	Sc_{12}
C_{11}	[0.77,0.88]	[0.81,0.94]	[0.67,0.81]	...	...	...	...	...	...	[0.55,0.69]	[0.73,0.86]	[0.75,0.89]
C_{12}	[0.61,0.75]	[0.61,0.75]	[0.47,0.65]	...	...	...	...	...	...	[0.59,0.71]	[0.69,0.84]	[0.47,0.65]
C_{13}	[0.47,0.65]	[0.39,0.55]	[0.53,0.65]	...	...	...	...	...	...	[0.45,0.61]	[0.49,0.63]	[0.49,0.63]
C_{14}	[0.57,0.73]	[0.63,0.79]	[0.21,0.31]	...	...	...	...	...	...	[0.43,0.57]	[0.59,0.71]	[0.31,0.45]
C_{21}	[0.29,0.47]	[0.13,0.29]	[0.39,0.49]	...	...	...	...	...	...	[0.31,0.45]	[0.09,0.21]	[0.31,0.51]
C_{22}	[0.61,0.75]	[0.73,0.86]	[0.47,0.59]	...	...	...	...	...	...	[0.47,0.65]	[0.29,0.41]	[0.39,0.55]
C_{23}	[0.53,0.65]	[0.37,0.57]	[0.61,0.75]	...	...	...	...	...	...	[0.59,0.71]	[0.35,0.53]	[0.71,0.83]
C_{24}	[0.41,0.59]	[0.41,0.59]	[0.59,0.77]	...	...	...	...	...	...	[0.41,0.59]	[0.59,0.71]	[0.53,0.65]
C_{25}	[0.37,0.51]	[0.51,0.67]	[0.41,0.59]	...	...	...	...	...	...	[0.41,0.53]	[0.47,0.59]	[0.59,0.71]
C_{26}	[0.35,0.53]	[0.41,0.59]	[0.25,0.39]	...	...	...	...	...	...	[0.43,0.57]	[0.43,0.57]	[0.59,0.77]
C_{31}	[0.35,0.53]	[0.39,0.55]	[0.41,0.59]	...	...	...	...	...	...	[0.61,0.75]	[0.53,0.71]	[0.31,0.45]
C_{32}	[0.27,0.43]	[0.27,0.43]	[0.25,0.45]	...	...	...	...	...	...	[0.27,0.37]	[0.41,0.59]	[0.41,0.53]
C_{33}	[0.57,0.67]	[0.45,0.61]	[0.29,0.47]	...	...	...	...	...	...	[0.63,0.73]	[0.47,0.65]	[0.31,0.45]
C_{41}	[0.41,0.53]	[0.43,0.63]	[0.59,0.77]	...	...	...	...	...	...	[0.61,0.75]	[0.53,0.65]	[0.71,0.87]
C_{42}	[0.25,0.39]	[0.08,0.23]	[0.23,0.35]	...	...	...	...	...	...	[0.35,0.47]	[0.39,0.55]	[0.53,0.71]
C_{43}	[0.35,0.53]	[0.33,0.49]	[0.59,0.71]	...	...	...	...	...	...	[0.65,0.77]	[0.59,0.77]	[0.83,0.97]
C_{44}	[0.59,0.71]	[0.29,0.47]	[0.31,0.45]	...	...	...	...	...	...	[0.39,0.55]	[0.71,0.83]	[0.71,0.87]

Table 8. The crisp decision-matrix and the values of σ_j^C and π_j^C.

	Sc_1	Sc_2	Sc_3	Sc_4	Sc_5	Sc_6	Sc_7	Sc_8	Sc_9	Sc_{10}	Sc_{11}	Sc_{12}	σ_j^C	π_j^C
C_{11}	0.88	0.93	0.79	0.76	0.69	0.79	0.88	0.90	0.72	0.66	0.85	0.87	0.0339	0.0585
C_{12}	0.75	0.75	0.62	0.65	0.81	0.48	0.93	0.68	0.58	0.71	0.84	0.62	0.0477	0.0553
C_{13}	0.67	0.56	0.70	0.52	0.67	0.81	0.77	0.81	0.91	0.63	0.67	0.67	0.0425	0.0613
C_{14}	0.75	0.82	0.30	0.85	0.91	0.61	0.78	0.54	0.18	0.57	0.75	0.44	0.0880	0.0585
C_{21}	0.25	0.50	0.21	0.30	0.19	0.16	0.20	0.14	0.16	0.25	0.71	0.23	0.0646	0.0561
C_{22}	0.43	0.37	0.55	0.59	0.53	0.68	0.37	0.33	0.46	0.53	0.85	0.64	0.0579	0.0551
C_{23}	0.60	0.78	0.52	0.40	0.40	0.57	0.72	0.52	0.43	0.54	0.83	0.46	0.0557	0.0572
C_{24}	0.52	0.52	0.37	0.35	0.41	0.32	0.51	0.56	0.82	0.52	0.39	0.43	0.0515	0.0649
C_{25}	0.35	0.26	0.31	0.44	0.80	0.29	0.33	0.26	0.22	0.32	0.29	0.23	0.0600	0.0607
C_{26}	0.50	0.43	0.69	0.84	0.43	0.41	0.34	0.33	0.41	0.43	0.43	0.31	0.0591	0.0652
C_{31}	0.50	0.46	0.43	0.50	0.69	0.78	0.35	0.30	0.53	0.31	0.35	0.57	0.0578	0.0616
C_{32}	0.18	0.18	0.19	0.66	0.39	0.22	0.12	0.14	0.12	0.19	0.12	0.13	0.0604	0.0636
C_{33}	0.47	0.56	0.81	0.72	0.74	0.85	0.81	0.69	0.50	0.43	0.53	0.79	0.0581	0.0579
C_{41}	0.54	0.61	0.78	0.51	0.54	0.61	0.78	0.75	0.85	0.78	0.68	0.91	0.0511	0.0595
C_{42}	0.45	0.22	0.41	0.26	0.21	0.45	0.66	0.28	0.66	0.58	0.66	0.87	0.0820	0.0545
C_{43}	0.45	0.42	0.67	0.61	0.55	0.55	0.70	0.64	0.48	0.73	0.70	0.93	0.0544	0.0553
C_{44}	0.69	0.40	0.40	0.34	0.66	0.53	0.76	0.76	0.93	0.50	0.82	0.84	0.0752	0.0548

As it can be seen in Table 9, Scenario 11 has the highest overall performance, and it is ranked first. This scenario aims at doing partial disassembly and forwarding of recyclable materials to the native market (after developing of the appropriate infrastructures) and thermal treatment of the residue. Scenario 7 is in the second position of the ranking. This scenario is also about partial disassembly and forwarding of recyclable materials to the native market but developing appropriate infrastructure and thermal treatment will not be considered by following Scenario 7. Moreover, we can see Scenario 12 in third place of the ranking. This scenario seeks to making partial disassembly, transfer recyclable materials abroad and thermal treatment of the residue. As a results, defining a scenario based on the partial disassembly is very important according to the decision-makers' opinions. We can also conclude from Table 9 that C_{33} or requirements of land to expand company's services is the most important criteria to choose an appropriate scenario. In addition, C_{41} (Functionality) and C_{31} (Cost of investment) are identified as second and third ranked criteria, respectively.

Table 9. The final evaluation scores of the alternatives and criteria.

Scenarios	S_i^L	S_i^U	S_i^C	R_i^S	Criteria	w_j^L	w_j^U	w_j^C	R_j^w
Sc_1	0.463	0.610	0.537	8	C_{11}	0.0554	0.0668	0.0611	9
Sc_2	0.446	0.616	0.531	9	C_{12}	0.0616	0.0634	0.0625	6
Sc_3	0.446	0.605	0.525	10	C_{13}	0.0558	0.0583	0.0571	11
Sc_4	0.459	0.644	0.552	6	C_{14}	0.0653	0.0655	0.0654	4
Sc_5	0.482	0.662	0.572	4	C_{21}	0.0468	0.0530	0.0499	15
Sc_6	0.465	0.644	0.554	5	C_{22}	0.0595	0.0631	0.0613	8
Sc_7	0.528	0.683	0.605	2	C_{23}	0.0595	0.0652	0.0623	7
Sc_8	0.454	0.591	0.522	11	C_{24}	0.0625	0.0672	0.0649	5
Sc_9	0.458	0.624	0.541	7	C_{25}	0.0366	0.0376	0.0371	17
Sc_{10}	0.451	0.591	0.521	12	C_{26}	0.0413	0.0466	0.0439	16
Sc_{11}	0.529	0.714	0.622	1	C_{31}	0.0647	0.0743	0.0695	3
Sc_{12}	0.516	0.686	0.601	3	C_{32}	0.0566	0.0600	0.0583	10
					C_{33}	0.0670	0.0792	0.0731	1
					C_{41}	0.0682	0.0760	0.0721	2
					C_{42}	0.0455	0.0626	0.0540	13
					C_{43}	0.0497	0.0603	0.0550	12
					C_{44}	0.0491	0.0560	0.0526	14

5. Sensitivity Analysis and Comparison

According to the empirical study of the previous section, firstly a sensitivity analysis is made in this section based on changing the level of uncertainty (values of α), then the ranking of scenarios resulted from the proposed approach is compared with the results of some existing MCDM approach. Since the weights of criteria are variables of the proposed approach it is not reasonable to make a sensitivity analysis by varying their values, so the value of α is selected as the sensitivity analysis parameter. Another parameter that can be chosen for making an analysis is β; however, according to the original model of SECA, the suggested value (β = 3) is used in this study. In the following, the model is solved with 11 values of α in the range [0,1]. The lower and upper bounds of the criteria weights and alternatives' overall performances are determined according to different values of α. The results can be seen in Tables 10 and 11.

Table 10. The sensitivity analysis results for the criteria weights.

		α = 0	α = 0.1	α = 0.2	α = 0.3	α = 0.4	α = 0.5	α = 0.6	α = 0.7	α = 0.8	α = 0.9	α = 1
w_j^L	C_{11}	0.0579	0.0574	0.0568	0.0563	0.0558	0.0554	0.0552	0.0551	0.0549	0.0548	0.0546
	C_{12}	0.0616	0.0617	0.0617	0.0617	0.0617	0.0616	0.0615	0.0614	0.0614	0.0609	0.0603
	C_{13}	0.0573	0.0571	0.0568	0.0565	0.0562	0.0558	0.0554	0.0551	0.0553	0.0566	0.0571
	C_{14}	0.0635	0.0640	0.0644	0.0648	0.0652	0.0653	0.0646	0.0638	0.0630	0.0622	0.0614
	C_{21}	0.0433	0.0441	0.0448	0.0455	0.0462	0.0468	0.0473	0.0479	0.0484	0.0491	0.0497
	C_{22}	0.0597	0.0597	0.0597	0.0596	0.0596	0.0595	0.0595	0.0594	0.0587	0.0568	0.0550
	C_{23}	0.0584	0.0586	0.0588	0.0590	0.0593	0.0595	0.0597	0.0599	0.0601	0.0603	0.0605
	C_{24}	0.0614	0.0616	0.0618	0.0620	0.0623	0.0625	0.0628	0.0632	0.0639	0.0656	0.0674
	C_{25}	0.0317	0.0327	0.0336	0.0346	0.0356	0.0366	0.0375	0.0383	0.0386	0.0390	0.0396
	C_{26}	0.0381	0.0388	0.0394	0.0401	0.0407	0.0413	0.0418	0.0423	0.0429	0.0434	0.0425
	C_{31}	0.0622	0.0627	0.0632	0.0637	0.0642	0.0647	0.0652	0.0657	0.0662	0.0667	0.0672
	C_{32}	0.0550	0.0553	0.0556	0.0559	0.0563	0.0566	0.0569	0.0573	0.0577	0.0581	0.0586
	C_{33}	0.0656	0.0658	0.0660	0.0663	0.0665	0.0670	0.0678	0.0686	0.0694	0.0701	0.0709
	C_{41}	0.0705	0.0701	0.0697	0.0692	0.0687	0.0682	0.0676	0.0671	0.0667	0.0670	0.0674
	C_{42}	0.0474	0.0472	0.0468	0.0464	0.0460	0.0455	0.0449	0.0443	0.0436	0.0440	0.0443
	C_{43}	0.0539	0.0532	0.0523	0.0515	0.0506	0.0497	0.0488	0.0479	0.0472	0.0476	0.0480
	C_{44}	0.0515	0.0511	0.0507	0.0502	0.0497	0.0491	0.0485	0.0478	0.0485	0.0520	0.0536

Table 10. *Cont.*

		α = 0	α = 0.1	α = 0.2	α = 0.3	α = 0.4	α = 0.5	α = 0.6	α = 0.7	α = 0.8	α = 0.9	α = 1
w_j^U	C_{11}	0.0666	0.0667	0.0668	0.0668	0.0668	0.0668	0.0667	0.0666	0.0665	0.0659	0.0655
	C_{12}	0.0660	0.0655	0.0650	0.0644	0.0639	0.0634	0.0628	0.0622	0.0615	0.0619	0.0622
	C_{13}	0.0604	0.0600	0.0596	0.0591	0.0587	0.0583	0.0581	0.0579	0.0576	0.0574	0.0580
	C_{14}	0.0685	0.0679	0.0673	0.0666	0.0660	0.0655	0.0657	0.0658	0.0659	0.0662	0.0660
	C_{21}	0.0503	0.0507	0.0511	0.0517	0.0523	0.0530	0.0538	0.0548	0.0553	0.0544	0.0534
	C_{22}	0.0611	0.0615	0.0620	0.0624	0.0628	0.0631	0.0631	0.0632	0.0633	0.0634	0.0634
	C_{23}	0.0631	0.0635	0.0638	0.0642	0.0647	0.0652	0.0657	0.0662	0.0664	0.0659	0.0653
	C_{24}	0.0650	0.0655	0.0659	0.0663	0.0668	0.0672	0.0677	0.0682	0.0687	0.0692	0.0697
	C_{25}	0.0367	0.0367	0.0369	0.0371	0.0373	0.0376	0.0379	0.0385	0.0395	0.0405	0.0416
	C_{26}	0.0443	0.0447	0.0451	0.0455	0.0460	0.0466	0.0471	0.0478	0.0475	0.0449	0.0440
	C_{31}	0.0727	0.0730	0.0732	0.0735	0.0739	0.0743	0.0747	0.0751	0.0750	0.0736	0.0722
	C_{32}	0.0615	0.0611	0.0608	0.0605	0.0602	0.0600	0.0598	0.0596	0.0594	0.0591	0.0590
	C_{33}	0.0780	0.0781	0.0784	0.0786	0.0789	0.0792	0.0795	0.0798	0.0801	0.0793	0.0790
	C_{41}	0.0788	0.0782	0.0777	0.0772	0.0766	0.0760	0.0755	0.0749	0.0742	0.0736	0.0730
	C_{42}	0.0640	0.0638	0.0635	0.0633	0.0630	0.0626	0.0618	0.0610	0.0602	0.0594	0.0585
	C_{43}	0.0641	0.0634	0.0626	0.0619	0.0611	0.0603	0.0594	0.0585	0.0576	0.0567	0.0558
	C_{44}	0.0596	0.0589	0.0582	0.0574	0.0567	0.0560	0.0556	0.0552	0.0547	0.0541	0.0551

Table 11. The sensitivity analysis results for the scenarios' performance.

		α = 0	α = 0.1	α = 0.2	α = 0.3	α = 0.4	α = 0.5	α = 0.6	α = 0.7	α = 0.8	α = 0.9	α = 1
S_i^L	Sc_1	0.3767	0.3932	0.4102	0.4275	0.4452	0.4634	0.4820	0.5012	0.5214	0.5430	0.5649
	Sc_2	0.3578	0.3744	0.3914	0.4089	0.4270	0.4455	0.4646	0.4844	0.5048	0.5253	0.5462
	Sc_3	0.3578	0.3744	0.3914	0.4089	0.4270	0.4455	0.4646	0.4844	0.5048	0.5253	0.5465
	Sc_4	0.3606	0.3789	0.3980	0.4177	0.4381	0.4594	0.4817	0.5050	0.5289	0.5520	0.5761
	Sc_5	0.3845	0.4026	0.4214	0.4408	0.4608	0.4816	0.5032	0.5257	0.5495	0.5748	0.6010
	Sc_6	0.3696	0.3875	0.4060	0.4250	0.4446	0.4648	0.4857	0.5073	0.5298	0.5526	0.5762
	Sc_7	0.4425	0.4588	0.4755	0.4925	0.5099	0.5276	0.5457	0.5642	0.5843	0.6072	0.6305
	Sc_8	0.3775	0.3923	0.4073	0.4226	0.4382	0.4541	0.4703	0.4868	0.5048	0.5253	0.5462
	Sc_9	0.3785	0.3937	0.4091	0.4250	0.4412	0.4578	0.4748	0.4923	0.5117	0.5344	0.5578
	Sc_{10}	0.3695	0.3851	0.4009	0.4172	0.4338	0.4508	0.4682	0.4860	0.5048	0.5253	0.5462
	Sc_{11}	0.4344	0.4523	0.4707	0.4896	0.5092	0.5294	0.5504	0.5722	0.5954	0.6204	0.6459
	Sc_{12}	0.4298	0.4462	0.4630	0.4801	0.4977	0.5156	0.5341	0.5530	0.5735	0.5967	0.6204
S_i^U	Sc_1	0.6055	0.6067	0.6077	0.6085	0.6092	0.6098	0.6104	0.6110	0.6113	0.6115	0.6116
	Sc_2	0.6109	0.6123	0.6135	0.6145	0.6153	0.6161	0.6169	0.6177	0.6182	0.6187	0.6191
	Sc_3	0.6043	0.6045	0.6047	0.6047	0.6046	0.6046	0.6047	0.6047	0.6045	0.6043	0.6040
	Sc_4	0.6431	0.6435	0.6438	0.6440	0.6440	0.6441	0.6441	0.6440	0.6438	0.6437	0.6434
	Sc_5	0.6597	0.6605	0.6611	0.6615	0.6618	0.6622	0.6626	0.6630	0.6632	0.6634	0.6634
	Sc_6	0.6484	0.6476	0.6468	0.6458	0.6448	0.6439	0.6433	0.6425	0.6416	0.6406	0.6396
	Sc_7	0.6836	0.6835	0.6834	0.6831	0.6828	0.6827	0.6828	0.6827	0.6825	0.6821	0.6816
	Sc_8	0.5927	0.5924	0.5921	0.5917	0.5911	0.5908	0.5909	0.5909	0.5907	0.5905	0.5900
	Sc_9	0.6228	0.6232	0.6235	0.6238	0.6239	0.6241	0.6244	0.6247	0.6248	0.6248	0.6246
	Sc_{10}	0.5886	0.5893	0.5899	0.5903	0.5906	0.5908	0.5909	0.5909	0.5907	0.5905	0.5900
	Sc_{11}	0.7157	0.7155	0.7151	0.7147	0.7143	0.7137	0.7131	0.7123	0.7115	0.7107	0.7097
	Sc_{12}	0.6811	0.6824	0.6836	0.6846	0.6854	0.6863	0.6872	0.6879	0.6885	0.6889	0.6891

The graphical representations of Tables 10 and 11 are illustrated in Figures 4 and 5, respectively. It can be seen that the values of the lower and upper bounds are changed reasonably, and we can verify the stability of the final evaluation of the criteria and alternatives in different levels of uncertainty. According to Figure 5, the variations of the lower bounds of the alternatives' overall performances is greater than the variations in upper bounds; however, the rank of them are stable. To validate the final ranking of the scenarios, a comparative analysis is performed based on the crisp decision-matrix (Table 8) and subjective criteria weights (Table 3). Five MCDM methods including SAW (Simple Additive Weighting), WASPAS (Weighted Aggregated Sum Product Assessment), COPRAS

(COmplex PRoportional ASsessment), TOPSIS and EDAS (Evaluation based on Distance from Average Solution) are used for making this comparative analysis. We have chosen these methods since they have been used in several problems and different fields of studies. There are also other MCDM methods that can be used for comparison such as VIKOR, CoCoSo [55] and MARCOS (Measurement of Alternatives and Ranking according to COmpromise Solution) [56]. The ranking results of these methods are presented in Table 12. The Spearman's rank correlation coefficient (r_s) between the ranking results of the proposed method and those of the other MCDM methods are calculated and shown in the last row of this table. Since the values of r_s are greater than 0.8, we can conclude a strong relationship between the ranking results. Therefore, the comparison confirms the validity of the results of the proposed approach.

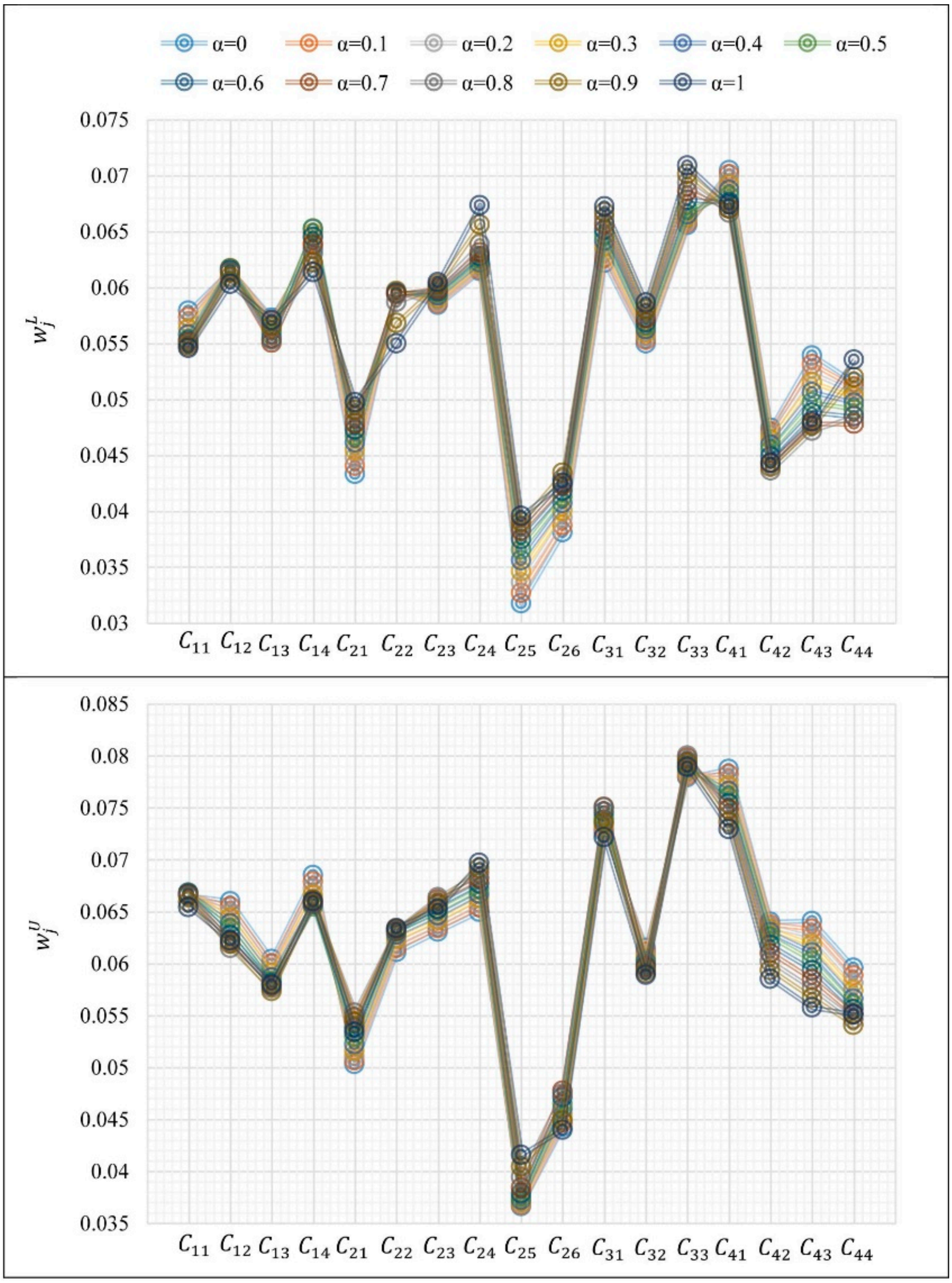

Figure 4. Graphical view of the criteria weights' sensitivity.

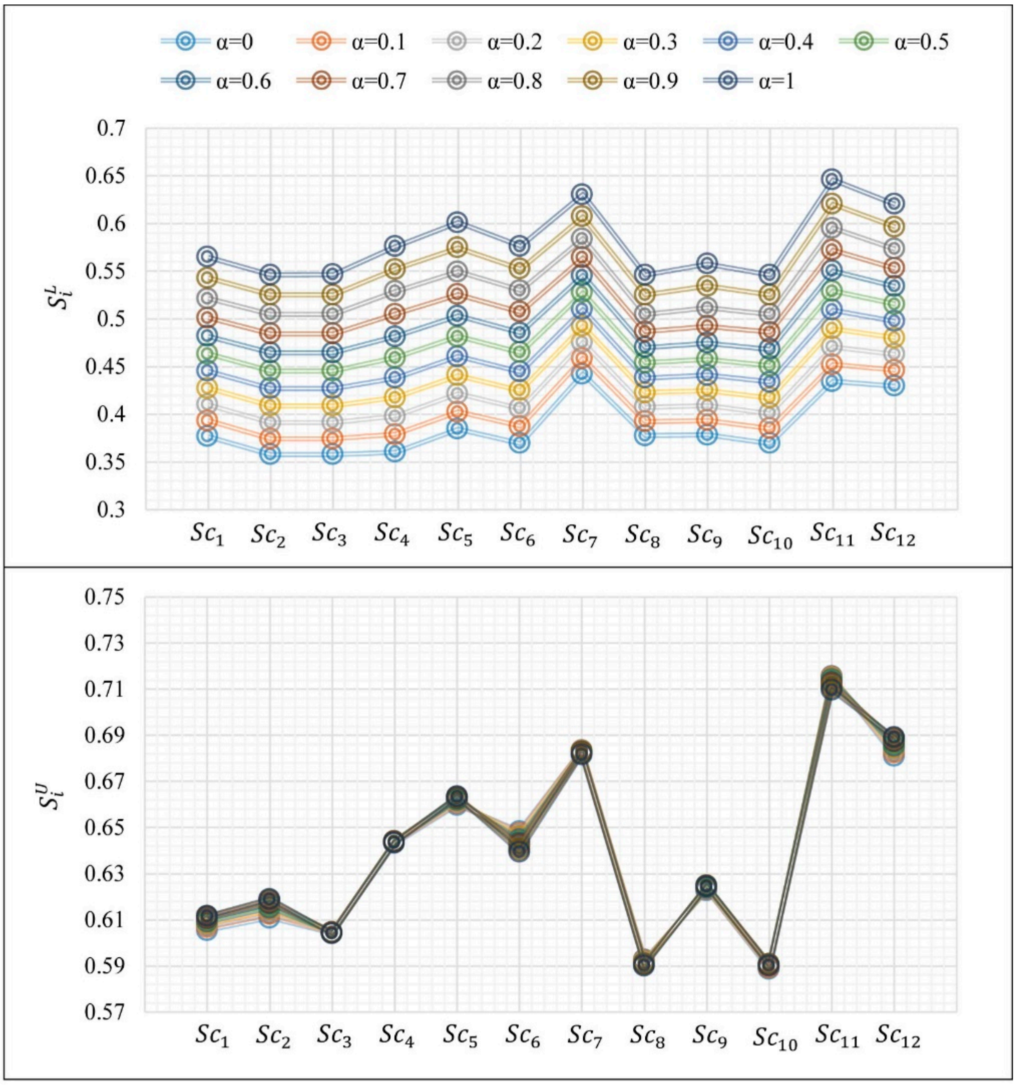

Figure 5. Graphical view of the scenarios' performance sensitivity.

Table 12. The results of the comparison.

	SAW	**WASPAS**	**COPRAS**	**TOPSIS**	**EDAS**	**Proposed Approach**
Sc_1	8	7	8	9	7	8
Sc_2	9	8	7	7	8	9
Sc_3	10	9	10	11	11	10
Sc_4	5	5	2	1	2	6
Sc_5	4	4	3	3	3	4
Sc_6	6	6	6	6	6	5
Sc_7	2	2	5	5	5	2
Sc_8	12	12	12	12	12	11
Sc_9	7	11	9	8	9	7
Sc_{10}	11	10	11	10	10	12
Sc_{11}	1	1	1	2	1	1
Sc_{12}	3	3	4	4	4	3
r_s	0.986	0.909	0.867	0.825	0.860	

6. Discussion

According to the literature review section, it can be seen that the MCDM methods are practical and useful in many studies conducted in the field of e-waste management. Although the use of the MCDM methods in this field is growing, these methods have not been developed so much, and most studies use relatively old methods or their combinations. One of the most important issues that usually exist in decision-making problems and evaluation processes is how to deal with the uncertainty of information. Despite the new approaches developed in dealing with uncertainty, this issue has not been seriously considered in several studies. In this study, we have presented a new approach that can not only be effective in e-waste management problems, but it can also be used to provide solutions for different MCDM problems under uncertainty. Uncertainty in multi-criteria decision-making problems is not always at a fixed and constant level and can change based on different conditions. In this research, fuzzy sets theory has been used as a means of modeling the uncertainty of decision-making information. Using α-cuts of fuzzy sets allows us to consider and define different levels of uncertainty. While the value of α can vary between zero and one, lower values of α indicate high levels of uncertainty and higher values of α define low levels of uncertainty.

Most of the MCDM approaches that have been used for e-waste management employed separate methods to obtain the weights of criteria and the performance of alternatives. Although employing distinct methods sometimes has advantages, it could make the problem-solving process more complicated in some cases. The proposed approach can give us the criteria weights and alternatives' performances simultaneously. In this approach, the criteria weights are determined in such a way as to maximize the performance of alternatives. In addition, there are reference points for the criteria weights. The closer the weights are to the reference points, the more realistic the results of the model will be. Determining these reference points in a fuzzy environment is one of the issues that can affect the outputs of the proposed approach. In this study, a deterministic way has been used to calculate these points. Although this can provide a good approximation and greatly reduce the complexity of the problem, it does not cover the entire feasible region. Therefore, other ways such as simulation can be used to increase the efficiency of the proposed approach. It should be noted that the original SECA used two reference point to obtain the objective criteria weights. On the other hand, in the proposed F-SECA method, another reference point has been added to incorporate the experts' opinions and compute a combination of subjective and objective criteria weights.

The results obtained from using the proposed approach in the evaluation of e-waste management scenarios not only show the applicability of this approach but can also provide us with new insights to achieve sustainable e-waste management systems. Land restrictions have always been one of the influential factors in waste management systems, and this issue can also be concluded based on the results obtained from this study. The need for specialized personnel and the smoothness and simplicity of operations, which are defined as the functionality criteria, are other important factors according to the results of the study. Like many other real-world decision-making problems, in this case, the cost is an influencing factor in the evaluation process. After evaluating the scenarios, it has been found that to have the best scenario, in addition to considering partial disassembly, forwarding of recyclable materials to the native market and thermal treatment of the residue, the development of the appropriate infrastructures should also be taken into account.

7. Conclusions

Management of nonoperational and undesired electrical and electronic products, termed as e-waste, has become increasingly consequential in lessening environmental issues. Since the production, use, and disposal of electrical and electronic products has a complicated nature, we need to make effective decisions to have sustainable processes. Moving toward sustainable scenarios in e-waste management could be one of the most important decisions in industry. In this study, we have introduced a new MCDM methodology to make the evaluation of sustainable e-waste management scenarios in an efficient way. The proposed methodology has three main advantages. Firstly, it can handle an MCDM problem with different level of uncertainty based on the fuzzy logic and α-cut approach. Secondly, the evaluation process of alternatives and criteria can be made simultaneously using the SECA method, and thirdly, the subjective opinions and judgements of the experts and decision-makers have been incorporated into the evaluation process besides the objective decision-making data. Actually, the proposed methodology is an extended fuzzy version of the SECA method which can deal with uncertainty and subjectivity. In this paper, applicability of the methodology has been shown through an empirical study on evaluating sustainable e-waste management scenarios. Twelve scenarios have been evaluated with respect to several criteria defined within the dimensions of sustainability. The results have shown that the best scenario is "partial disassembly and forwarding of recyclable materials to the native market (after developing of the appropriate infrastructures) and thermal treatment of the residue", and the most important criteria is "requirements of land to expand company's services". For verification and validation of the results of the proposed methodology, a sensitivity and a comparative analysis have also been conducted. Stability and reliability of the results can be concluded from these analyses.

Determining the reference points for the objective criteria weights is one of the important limitations of the proposed approach. In this study, we have used the crisp decision-matrix to calculate these values. Although using other techniques like simulation-based approaches could lead to more reliable results, it will increase the complexity of solving the mathematical models. Future research can focus on integration of the proposed methodology with other weighting and MCDM methods like WASPAS [57], EDAS [58], COPRAS [59], SWARA II (Stepwise Weight Assessment Ratio Analysis II) [60], MEREC (MEthod based on the Removal Effects of Criteria) [61], FUCOM (FUll COnsistency Method) [62] etc. Moreover, extension of the proposed methodology in different uncertain environments could be another area for future research.

Author Contributions: Conceptualization, M.K.-G., M.A. and E.K.Z.; Methodology, M.K.-G. and E.K.Z.; Validation, M.K.-G. and J.A.; Formal analysis, M.K.-G. and J.A.; Investigation, M.K.-G. and Z.T.; Writing—Original Draft Preparation, M.K.-G. and J.A.; Writing—Review and Editing, M.K.-G., E.K.Z., J.A. and Z.T. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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