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A Novel Spherical Fuzzy AHP to Managing Waste from Face Masks and Gloves: An Istanbul-Based Case Study

Running Title: Managing Face Masks and Glove Waste in Istanbul Using SF-AHP

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Abstract

Waste management has emerged as a critical issue in the wake of the COVID-19 pandemic and the earthquake that struck southeast Turkey on February 6th, 2023, particularly regarding the disposal of face masks and gloves. Extensively utilized for disease prevention and maintaining personal hygiene, these items are categorized as medical waste, presenting significant disposal challenges in Turkey. This study aims to overcome these challenges by prioritizing key factors in waste management during the COVID-19 era through the application of the Spherical Fuzzy Analytic Hierarchy Process (SF-AHP) in Istanbul. By conducting a comprehensive literature review and consulting with experts, relevant criteria for managing this medical waste have been identified and prioritized. Furthermore, a sensitivity analysis of the decision support model is performed to evaluate its robustness. The data highlight the crucial importance of recycling, landfilling, and incineration capacities, regulatory frameworks, and incineration costs as primary determinants and criteria shaping the waste management landscape. The sensitivity analysis highlights the resilience of our proposed methodology, demonstrating consistent and robust prioritization outcomes even with varying criteria weights, thereby validating the reliability of the methodology in informing policy decisions. The originality of this study lies in its innovative application of spherical fuzzy sets—offering high accuracy and compatibility with human reasoning—to the management of face masks and gloves waste, an area not previously explored using Spherical Fuzzy Multi-Criteria Decision Making (SF-MCDM) in current literature. This novel approach introduces a rigorous and pioneering methodology for investigating this specific aspect of waste management and enriches the academic conversation by providing a practical SF-MCDM framework.

Keywords: Decision support system, Disaster management, healthcare waste, medical waste management, Spherical Fuzzy Sets

1. Introduction

During 21st century, owing to the rapid industrialization and increasing population, the over-production and consumption activities have increased and this increase has contributed to the environmental problems breaking the ecological balance (Sangodoyin and Ipadeola, 2000; Çelik et al., 2022). As a result, sustainability concerns, especially related to waste management have become more important, and many researchers, now, work on this topic (Oweis et al., 2015). It is also well-known that improper management of solid waste cause widespread illnesses and environmental pollution damaging human health (Güleç et al., 2001). Moreover, the increasing trend of healthcare activities to heal diseases caused by environmental pollution result in more medical waste, as a subcategory of solid waste (Windfeld and Brooks, 2015), and the problem becomes a vicious circle.

As medical waste has the potential to transport disease containing toxic chemicals (Dehghanifard and Dehghani, 2018), its management is very crucial because of its harmful effects (Vasistha et al., 2018; Çetinkaya et al., 2020). Moreover, face masks and gloves used during COVID-19 pandemic are causing microplastic pollution to the environment (Abbasi et al., 2020; Selvaranjan et al.,2021). Taking into consideration that Turkey is a country hit by COVID-19 widely, medical waste became a big problem producing environmental and health concerns, especially in Istanbul as the most populated city in the country (Hanedar et al., 2022). As the face mask amount could reach up to 26 million for daily use in Turkey during that period, the microplastic waste pollution can have enormous consequences (Sangkham, 2020).

Also, it is observed that the capacity to manage the medical waste during COVID-19 and disaster periods such as floods, earthquakes (as in the earthquake of magnitude 7.6 hitting 10 cities in southeast Turkey on February the 6th), and other disasters can be lower than the ordinary periods, since the workforce is also affected by the pandemic and the disasters (Zhao et al., 2021; Klemeš et al., 2020; Cao et al., 2022).

It's worth noting that the volume of waste generated by healthcare services in Turkey constitutes a noteworthy proportion of the overall waste produced. Consequently, the effective management and control of healthcare waste necessitate dedicated regulatory frameworks and systems (Birpınar et al., 2009). Especially, the escalating number of private and government hospitals across Istanbul and Turkey contributes to a continuous rise in the generation of medical waste (Eker et al., 2010). Another factor to be taken into consideration is that deficiencies or unsuitability in temporary waste storage areas contribute to the dissemination of medical wastes into the environment, thereby posing significant risks to public health and the ecosystem in Turkey (Eren and Tuzkaya, 2019). Annually, around 22,000 tons of medical waste are collected in Istanbul, utilizing a developed technology equipment and specialized garments. Furthermore, waste posing epidemic disease risks, such as infectious and pathological materials, undergo incineration rather than sterilization. Accurately estimating the volume of medical waste and identifying critical factors influencing its generation are crucial for effective management of this hazardous waste in the biggest city of Turkey, Istanbul (Uysal and Tınmaz, 2004; Ceylan et al., 2020). Presently, there is a noteworthy surge in the production of medical waste within healthcare institutions, attributed to the COVID-19 epidemic. With the global escalation in the volume and complexity of medical waste during the COVID-19 pandemic, there is an associated heightened risk of disease transmission, particularly in instances of unsafe transportation and disposal practices in Turkey (Balci et al., 2022). Eren and Tuzkaya (2021) stated that the ongoing COVID-19 pandemic has resulted in an increased production of medical waste in Istanbul and if the current trajectory of rising COVID-19 cases persists, there is a potential for even greater challenges posed by medical waste in the days ahead. In this vein, Korkut (2018) reported that over the past 17 years, there has been a notable increase in unit medical waste generation, rising from 0.43 kg/bed-day to 1.68 kg/bed-day in Istanbul. However, the generation of medical waste is assumed to escalate coinciding with the impact of the COVID-19 pandemic in Istanbul (Hanedar et al., 2022). Given the current circumstances, it is imperative to engage in effective planning, conduct an integrated assessment of medical waste technologies, and comprehend the factors influencing the situation for the formulation of sustainable medical waste management policies in Turkey. Employing appropriate methodologies and tools, such as multi-criteria decision analysis (MCDA), becomes crucial in assisting stakeholders and understanding the required policy for medical waste management in Turkey within this sector (Ciplak,2015; Coskun, 2022). Furthermore, achieving an understanding of the components of healthcare waste and their level of infectiousness is crucial for informed decision-making regarding the adoption of appropriate technologies. To comprehensively analyze the entire system, it is of utmost importance to grasp all factors influencing the healthcare waste management system and policies in Turkey (Ciplak and Barton, 2012; Adar and Delice, 2019).

In Turkey, several scholars conducted MCDM applications in the field of medical waste management and various methods and sets have been employed by different authors in their MCDM applications. For example, Eren and Tuzkaya (2019) utilized AHP with Ordinary Fuzzy Sets, sourcing data from surveys. Özkan (2013) applied Analytic Network Process (ANP) and Elimination Et Choix Traduisant la Réalité (ELECTRE) methods with Ordinary

Fuzzy Sets, also based on surveys. Dursun et al. (2011) employed a hierarchical distance-based fuzzy method with Ordinary Fuzzy Sets, gathered from surveys. Adar and Delice (2019) utilized Multi-Attributive Ideal-Real Comparative Analysis (MAIRCA) and Multi-Attributive Border Approximation Method with Aggregated Constraints (MABAC) methods with Hesitant Fuzzy Sets, sourcing data from surveys. Torkayesh and Simic (2022) applied Combined Compromise Solution (CoCoSo) and Weighted Aggregated Sum Product Assessment (WASPAS) methods with Interval-Valued Intuitionistic Fuzzy Sets, sourced from surveys. Çakir et al. (2021) employed the Analytic Hierarchy Process (AHP) with Circular Intuitionistic Fuzzy Sets, based on interviews. Çelik et al. (2023) utilized the Analytic Hierarchy Process (AHP) with Intuitionistic Fuzzy Sets, also based on surveys. Görçün et al. (2023) employed the Complex Proportional Assessment (COPRAS) method with Interval-Valued Fermatean Fuzzy Sets, sourced from surveys for medical waste management in Turkey.

However, as discussed in several previous studies, to the best of the authors' knowledge, there is a gap in evaluating face mask and glove waste management in Turkey that integrates spherical fuzzy sets and AHP methods. Thus, considering all the challenges associated with managing face mask and glove waste and the identified gap in the literature, this study proposes an approach to understand the factors that significantly impact this process during periods of COVID-19 and disasters in Istanbul. The aim is to prioritize criteria and sub-criteria for waste management of face masks and glove using SF-AHP. The originality of this study lies in the absence of any previous research applying multi-criteria decision support for the waste management process of face masks and gloves using Spherical Sets. Furthermore, beyond the inherent high accuracy and compatibility with human reasoning offered by spherical fuzzy sets, the factors related to the management of face masks and gloves within the context of medical waste management have not previously been studied using spherical fuzzy sets. This novel approach presents a rigorous and original methodology for studying this specific aspect. Furthermore, the sensitivity analysis underscores the robustness of our proposed methodology, showcasing consistent and resilient prioritization results even when criteria weights vary. This validates the dependability of the SF-AHP method in guiding policy formulation.

The recently introduced three-dimensional spherical fuzzy set, as posited by scholars (Mathew et al., 2020; Akram et al., 2021), serves as an advancement beyond traditional fuzzy sets. This extension demonstrates heightened effectiveness in addressing uncertainty and quantifying expert judgments, particularly in the prioritization of factors and decision-making problems across diverse fields including waste management. Ordinary fuzzy sets (FS) and interval-valued fuzzy sets (IFS) are found to be constrained in addressing scenarios discussed in the literature, limiting their applicability in prioritization and decision-making contexts. In response to these limitations and with the aim of aligning more closely with human reasoning, the concept of spherical fuzzy sets has been introduced (Mahmood et al., 2019). Consequently, for the prioritization of factors influencing face masks and gloves waste management, we advocate the use of spherical fuzzy AHP as a robust and effective method. Its inherent alignment with human reasoning and demonstrated high accuracy in decision-making and factor prioritization, as stated by Farrokhizadeh et al. (2021), Dogan (2021), and Yüksel et al. (2022), make it a highly suitable approach for this purpose of our study.

The rest of the paper is organized as follows. In the second part of the study, materials and methods are presented in three parts including our methodology, the case definition and In the third part, which is methodology section, fuzzy sets theory and spherical fuzzy sets are explained. In the application section, which is the fourth part of the study, case study in Istanbul is explained and in the fifth part, the results are discussed. The last part is handled as conclusion.

Date and location of the research: February, 2024, Istanbul

2. Materials and Methods

2.1. Fuzzy Set Theory and Multi-Criteria Decision Making (MCDM)

Fuzzy Set Theory has been introduced by Zadeh to solve complex decision problems with fuzzy judgements under uncertainty and inadequate knowledge during decision making process (Zadeh, 1978; Çelik et al., 2022) and the extensions of fuzzy sets in MCDM are shown in Figure 2.1 as a timeline-based.

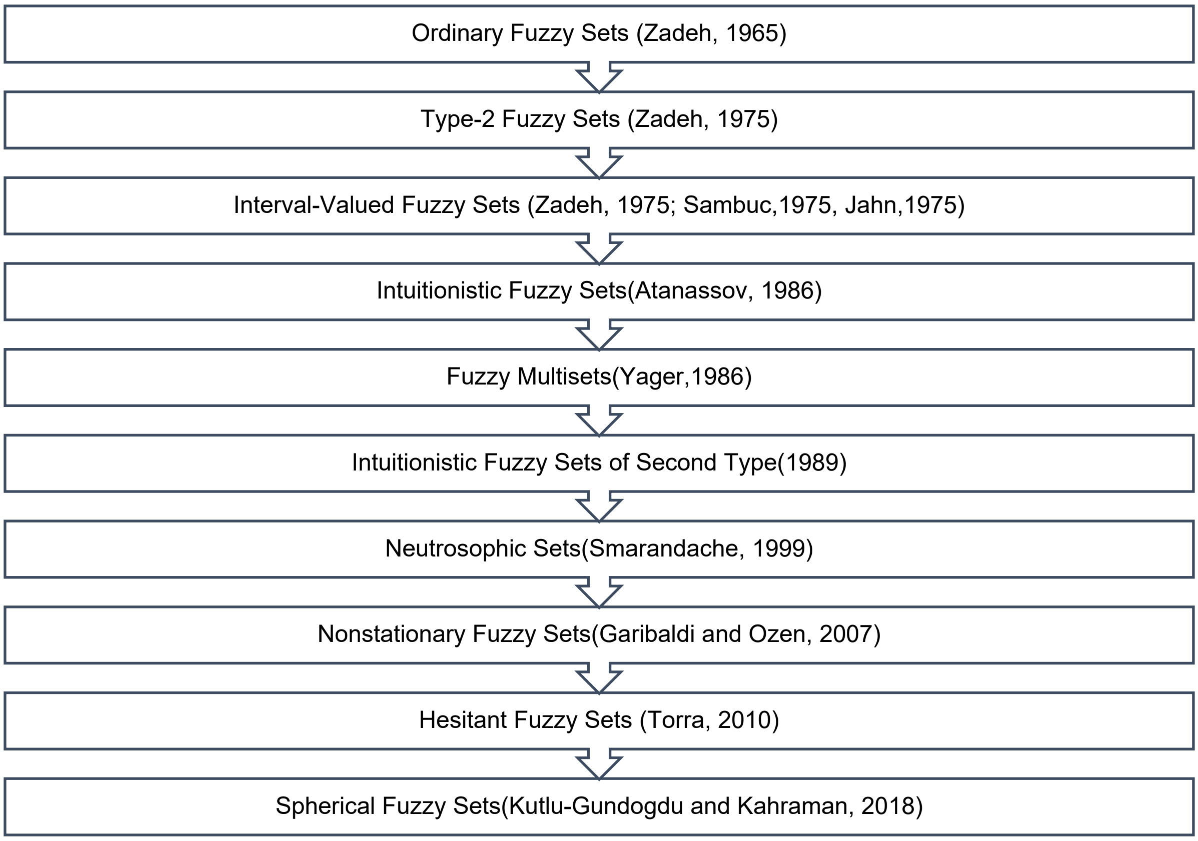

Figure 2.1. Extensions of Fuzzy Sets (Adapted from Kutlu-Gundogdu and Kahraman, 2018)

Making decision under uncertainty and inadequate information is excessively difficult. However, it can be easier by the aid of fuzzy logic MCDM (Kutlu-Gundogdu and Kahraman, 2020a). In this case, spherical fuzzy sets (SFS), introduced by Kutlu-Gundogdu and Kahraman (2018) is very beneficial in order to handle uncertainty effectively. Spherical fuzzy sets can be considered as an extension of Neutrosophic sets Pythagorean fuzzy sets. The principal distinction between them is mainly dependent on the hesitancy definition, whose hesitancy degrees in SFS are taken at most as 1 (Dogan, 2021). Furthermore, in Spherical Fuzzy Sets, there exist three membership degrees which are respectively the degree of membership, non-membership degree and the indeterminacy/degree of hesitancy (Mathew et al., 2020) and hesitancy degree in spherical fuzzy sets is beneficial for dealing with the ambiguity of decision-making problems (Liao et al., 2020). In the literature, spherical fuzzy sets have been used as an extension of other fuzzy sets to deal with the uncertainty and the differences between spherical fuzzy sets and other fuzzy sets as seen in Figure 2.2.

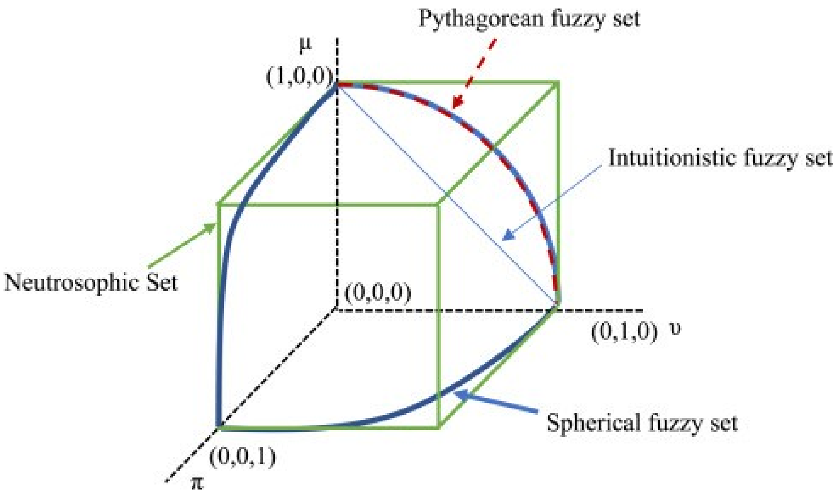

Figure 2.2. SFS and other fuzzy sets' geometric representations (Kutlu-Gündoğdu and Kahraman, 2020a)

The proposed methodology of the current paper is triggered by two main factors as follows: (1) In the literature, there is not any study integrating spherical fuzzy sets and face masks and glove waste management during COVID-19 and disaster periods (2) Considering the fact that COVID-19 period is still going on, spherical fuzzy sets provide a mitigation and consensus of how to manage those waste based on experts' and decision makers' judgements.

In the literature, the scholars state that the newly introduced three-dimensional spherical fuzzy set represents an extension of traditional fuzzy sets, offering enhanced effectiveness in managing uncertainty and quantifying expert judgments for prioritization of factors and decision-making problems in different fields (Mathew et al., 2020; Akram et al., 2021). Ordinary fuzzy sets (FS) and interval-valued fuzzy sets (IFS) exhibit limitations in addressing situations discussed in the literature due to their restricted structures for prioritization and decision-making problems. To address such scenarios and develop a concept that closely aligns with human reasoning, spherical fuzzy sets have been introduced (Mahmood et al., 2019). Thus, for the prioritization of face masks and gloves waste management affecting factors, we suggest that spherical fuzzy AHP is very robust and effective method as its close nature to human reasoning and high level of accuracy in decision making and factor prioritisation problems as stated by Farrokhizadeh et al. (2021), Dogan (2021) and Yüksel et al. (2022). In addition to the high accuracy and its alignment with human nature of fuzzy sets, face masks and glove waste management factors under medical waste management have not been considered studied by using spherical fuzzy sets, which provides us a rigorous and an original approach. Moreover, some authors conducted waste management studies using spherical fuzzy sets to evaluate food waste (Buyuk and Temur, 2020; Buyuk and Temur, 2022), landfill site selection for medical waste in Iran (Ghoushchi et al., 2021), location for waste disposal in Iran (Haseli and Ghoushchi, 2022) and medical waste disposal planning considering healthcare units (Menekşe and Akdağ, 2023).

Figure 2.3. shows the proposed methodology to apply Spherical fuzzy AHP for the prioritization of affecting factors of face masks and glove waste management in Istanbul. In the proposed spherical fuzzy AHP context, it should be firstly known to highlight that the importance levels of each decision makers differ from their qualifications in the waste management area in Istanbul based on field experiences and knowledge. As a result, linguistic terms which are identified by Kutlu-Gundogdu and Kahraman (2018) are applied and the significance of DMs is identified as equal.

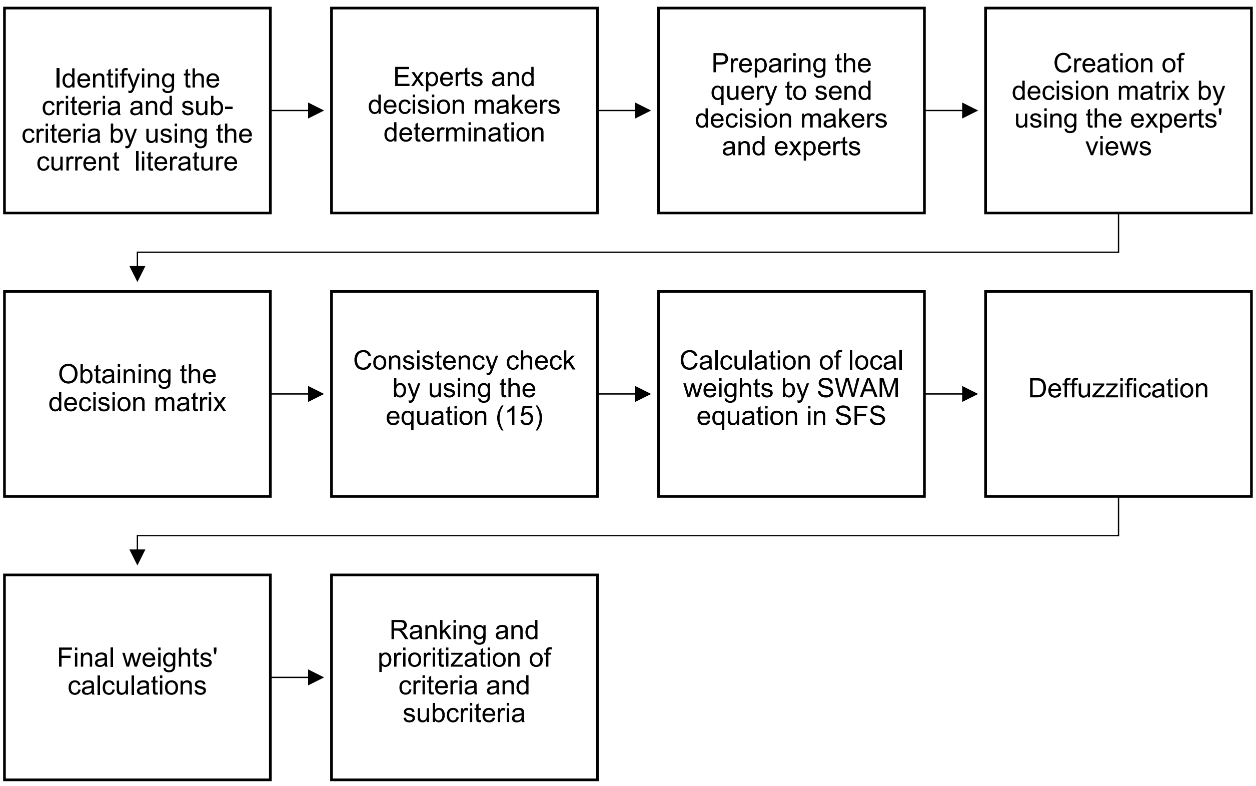

Figure 2.3. The proposed methodology of SF-AHP

2.2. Spherical Fuzzy Analytic Hierarchy Process (SF-AHP)

Spherical Fuzzy Sets (SFS) proposed by Kutlu-Gündoğdu and Kahraman (2020a) and Spherical Analytic Hierarchy Process (SF-AHP) are now aimed to use for waste management factors prioritization of face masks and gloves. In this part of methodology section, SFS and SF-AHP methodologies are defined by the study of Gündoğdu and Kahraman (2020a), who proposed SF-AHP methodology.

In order to explain the methodology of SF-AHP, let U_1 and U_2 be defined as two different universes and related spherical fuzzy sets for U_1 and U_2 as $\tilde{A}_S$ and $\tilde{B}_S$ respectively. In this case, let $\tilde{A}_S$ be defined as given in the equation (1) (Gündoğdu and Kahraman, 2020a).

$$\tilde{A}_S = \left\{x, \left(\mu_{\tilde{A}_S}(x), \nu_{\tilde{A}_S}(x), \pi_{\tilde{A}_S}(x)\right) | x \epsilon U_1\right\} \qquad (1)$$

Where
$$\mu_{\tilde{A}_S}(x): U_1 \rightarrow [0,1], v_{\tilde{A}_S}(x): U_1 \rightarrow [0,1]$$
$$\pi_{\tilde{A}_S}(x): U_1 \rightarrow [0,1]$$
and
$$0 \leq \mu^2_{\tilde{A}_S}(x) + v^2_{\tilde{A}_S}(x) + \pi^2_{\tilde{A}_S}(x) \leq 1 \forall x \in U_1 \qquad (2)$$

In this context, each of $\mu_{\tilde{A}_S}(x), \nu_{\tilde{A}_S}(x), \pi_{\tilde{A}_S}(x)$ belongs to U_1 set and their ranges are of [0,1] given in (3) that

$$0 \leq \mu^2_{\tilde{A}_S}(x) + v^2_{\tilde{A}_S}(x) + \pi^2_{\tilde{A}_S}(x) \leq 1 \quad \forall u \epsilon U_1 \qquad (3)$$

It is noted that $\mu_{\tilde{A}_S}(x), \nu_{\tilde{A}_S}(x), \pi_{\tilde{A}_S}(x)$ defines respectively membership, non-membership, and hesitancy belonging to U_1 which are on the surface of the sphere. it can be written as given in (4) if the equality holds.

$$\mu^2_{\tilde{A}_S}(x) + v^2_{\tilde{A}_S}(x) + \pi^2_{\tilde{A}_S}(x) = 1. \quad \forall u \epsilon U \quad (4)$$

Another definition in SFS as a basic operation of Cartesian product is defined as given in (5).

$$\tilde{A}_S \times \tilde{B}_S = \left\{ \left((x,y), \min\left(\mu_{\tilde{A}_S}(x), \mu_{\tilde{B}_S}(y)\right), \max\left(v_{\tilde{A}_S}(x), v_{\tilde{B}_S}(y)\right), \min\left(\pi_{\tilde{A}_S}(x), \pi_{\tilde{B}_S}(y)\right) \right) \mid x \in U_1, y \in U_2 \right\} \quad (5)$$

In multiplication symbol, $let\ us$ define $\left\{ \left\langle x, \left(\mu_{\tilde{A}_i}(x), v_{\tilde{A}_i}(x), \pi_{\tilde{A}_i}(x) \right) \right| x \in U_i \right\}$ in SFS. Thus, Cartesian product of SFS is given in (6).

$$\tilde{B}_S^n = \prod_{i=1}^{n} \tilde{A}_{si} = \left\{ \left((x_1, x_2, \dots x_n), \min_{i=1}^{n} \mu_{\tilde{A}_{si}}(x_i), \max_{i=1}^{n} v_{\tilde{A}_{si}}(x_i), \min_{i=1}^{n} \pi_{\tilde{A}_{si}}(x_i) \right) \mid \forall x_i \in U_i, i = 1, \dots, n \right\} \text{ is a SFS on is } \prod_{i=1}^{n} U_i \quad (6)$$

For the addition and multiplication operators, the following equations (7) and (8) are defined to obtain.

$$\tilde{A}_S \oplus \tilde{B}_S = \left\{ z, \left(\max_{z=x+y} \min\left\{ \mu_{\tilde{A}_S}(x), \mu_{\tilde{B}_S}(y) \right\} \right), \left(\min_{z=x+y} \max\left\{ v_{\tilde{A}_S}(x), v_{\tilde{B}_S}(y) \right\} \right), \left(\min_{z=x+y} \min\left\{ \pi_{\tilde{A}_S}(x), \pi_{\tilde{B}_S}(y) \right\} \right) \right\} \quad (7)$$

$$\tilde{A}_S \otimes \tilde{B}_S = \left\{ z, \left(\max_{z=x*y} \min\left\{ \mu_{\tilde{A}_S}(x), \mu_{\tilde{B}_S}(y) \right\} \right), \left(\min_{z=x*y} \max\left\{ v_{\tilde{A}_S}(x), v_{\tilde{B}_S}(y) \right\} \right), \left(\min_{z=x*y} \min\left\{ \pi_{\tilde{A}_S}(x), \pi_{\tilde{B}_S}(y) \right\} \right) \right\} \quad (8)$$

Furthermore, Kutlu Gündoğdu and Kahraman (2020a) have introduced some operations including union, intersection, addition, multiplication and power for spherical fuzzy sets as given in (9), (10), (11), (12)

Union can be seen in the equation (9) while intersection, addition multiplication, multiplication by a scalar and power of the value are followed in (10), (11), (12), (13) and (14) respectively.

$$\tilde{A}_S \cup \tilde{B}_S = \left\{ \max\left\{ \mu_{\tilde{A}_S}, \mu_{\tilde{B}_S} \right\}, \min\left\{ v_{\tilde{A}_S}, v_{\tilde{B}_S} \right\}, \min\left\{ \left(1 - \left(\left(\max\left\{ \mu_{\tilde{A}_S}, \mu_{\tilde{B}_S} \right\} \right)^2 + \left(\min\left\{ v_{\tilde{A}_S}, v_{\tilde{B}_S} \right\} \right)^2 \right) \right)^{1/2}, \max\left\{ \pi_{\tilde{A}_S}, \pi_{\tilde{B}_S} \right\} \right\} \right\} \quad (9)$$

$$\tilde{A}_S \cap \tilde{B}_S = \left\{ \min\left\{ \mu_{\tilde{A}_S}, \mu_{\tilde{B}_S} \right\}, \max\left\{ v_{\tilde{A}_S}, v_{\tilde{B}_S} \right\}, \max\left\{ \left(1 - \left(\left(\min\left\{ \mu_{\tilde{A}_S}, \mu_{\tilde{B}_S} \right\} \right)^2 + \left(\max\left\{ v_{\tilde{A}_S}, v_{\tilde{B}_S} \right\} \right)^2 \right) \right)^{\frac{1}{2}}, \min\left\{ \pi_{\tilde{A}_S}, \pi_{\tilde{B}_S} \right\} \right\} \right\} \quad (10)$$

$$\tilde{A}_S \oplus \tilde{B}_S = \left\{ \left(\mu_{\tilde{A}_S}^2 + \mu_{\tilde{B}_S}^2 - \mu_{\tilde{A}_S}^2 \mu_{\tilde{B}_S}^2 \right)^{1/2}, v_{\tilde{A}_S} v_{\tilde{B}_S}, \left(\left(1 - \mu_{\tilde{B}_S}^2 \right) \pi_{\tilde{A}_S}^2 + \left(1 - \mu_{\tilde{A}_S}^2 \right) \pi_{\tilde{B}_S}^2 - \pi_{\tilde{A}_S}^2 \pi_{\tilde{B}_S}^2 \right)^{1/2} \right\} \quad (11)$$

$$\tilde{A}_S \otimes \tilde{B}_S = \left\{ \mu_{\tilde{A}_S} \mu_{\tilde{B}_S}, \left(v_{\tilde{A}_S}^2 + v_{\tilde{B}_S}^2 - v_{\tilde{A}_S}^2 v_{\tilde{B}_S}^2 \right)^{1/2} \left(\left(1 - v_{\tilde{B}_S}^2\right) \pi_{\tilde{A}_S}^2 + \left(1 - v_{\tilde{A}_S}^2\right) \pi_{\tilde{B}_S}^2 - \pi_{\tilde{A}_S}^2 \pi_{\tilde{B}_S}^2 \right)^{1/2} \right\} \quad (12)$$

Multiplication by a scalar; $\lambda > 0$ is given in (13).

$$\lambda \cdot \tilde{A}_S = \left\{ \left(1 - \left(1 - \mu_{\tilde{A}_S}^2\right)^{\lambda} \right)^{1/2}, v_{\tilde{A}_S}^{\lambda}, \left(\left(1 - \mu_{\tilde{A}_S}^2\right)^{\lambda} - \left(1 - \mu_{\tilde{A}_S}^2 - \pi_{\tilde{A}_S}^2\right)^{\lambda} \right)^{1/2} \right. \quad (13)$$

And Power of $\tilde{A}_S$; $\lambda > 0$ in (14)

$$\tilde{A}_S^{\lambda} = \left\{ \mu_{\tilde{A}_S}^{\lambda}, \left(1 - \left(1 - v_{\tilde{A}_S}^2\right)^{\lambda} \right)^{1/2}, \left(\left(1 - v_{\tilde{A}_S}^2\right)^{\lambda} - \left(1 - v_{\tilde{A}_S}^2 - \pi_{\tilde{A}_S}^2\right)^{\lambda} \right)^{\frac{1}{2}} \right\} \quad (14)$$

The steps for Spherical Fuzzy AHP is explained as follows (Gündoğdu and Kahraman, 2020a).

Step 1. A hierarchical structure for the main selection problem is constructed. Spherical fuzzy pairwise comparison matrices are formed by the questionnaire sent to the experts.

Step 2. Consistency Ratio (CR) and Consistency Index (CI) given in the equation (15) for each pairwise comparison matrices of AHP, denoted also as CR, are checked and all has been found as consistent (Saaty, 1980). In the realm of decision-making using Saaty's Analytic Hierarchy Process (AHP), the notation λ_{max} denotes the largest eigenvalue of pairwise comparison matrices, while n represents the order (dimension) of these matrices. The term R.I. refers to the random index, a value contingent on the matrices' size, indicative of the average Consistency Index (C.I.) derived from a substantial number of randomly generated multiplicative preference relations (Saaty, 1980)

$$CI = \frac{\lambda_{max} - n}{n - 1}, CR = \frac{CI}{RI} \quad (15)$$

Step 3. In order to obtain spherical fuzzy global weights, hierarchical layer sequencings have been constructed and calculated

Step 4. For each alternative, the score values and local values are calculated and the alternatives are ranked based on calculations.

These steps can be seen in Fig. 2.3. in detail.

For the calculations of decision matrices, Table 2.1 has been used to convert linguistic measures into numerical values in SF-AHP (Gündoğdu and Kahraman, 2020a).

Table 2.1. Linguistic measures of importance used for pairwise comparisons(Gündoğdu and Kahraman, 2020a).

	(μ, v, π)	Score Index (SI)
Absolutely more importance (AMI)	(0.9, 0.1, 0.0)	9
Very high importance (VH1)	(0.8, 0.2, 0.1)	7
High importance (HI)	(0.7, 0.3, 0.2)	5
Slightly more importance (SMI)	(0.6, 0.4, 0.3)	3
Equally importance (El)	(0.5, 0.4, 0.4)	1
Slightly low importance (SU)	(0.4, 0.6, 0.3)	1/3
Low importance (LI)	(0.3, 0.7, 0.2)	1/5
Very low importance (VU)	(0.2, 0.8, 0.1)	1/7
Absolutely low importance (ALI)	(0.1, 0.9, 0.0)	1/9

In this context, based on experts' views given in (16), pairwise comparisons have been realized and SWAM operator was applied by weighted arithmetic mean for calculating fuzzy local weights.

$$\text{SWAM}_w\ (A_{S1},\dots,A_{Sn}) = w_1A_{S1} + w_2A_{S2} + \cdots + w_nA_{Sn} \qquad (16)$$

$$= \left\langle \left[1-\prod_{i=1}^{n}\left(1-\mu_{A_{Si}}^2\right)^{w_i}\right]^{1/2}, \prod_{i=1}^{n} v_{A_{Si}}^{w_i}, \left[\prod_{i=1}^{n}\left(1-\mu_{A_{Si}}^2\right)^{w_i} - \prod_{i=1}^{n}\left(1-\mu_{A_{Si}}^2-\pi_{A_{Si}}^2\right)^{w_i}\right]^{1/2} \right\rangle$$

where $w = 1/n$.

Then, the score function given in (17) has been used to defuzzify the criteria and sub-criteria.

$$S\left(\tilde{w}_j^s\right) = \sqrt{\left|100 * \left[\left(3\mu_{\tilde{A}_S} - \frac{\pi_{\tilde{A}_S}}{2}\right)^2 - \left(\frac{v_{\tilde{A}_S}}{2} - \pi_{\tilde{A}_S}\right)^2\right]\right|} \qquad (17)$$

In order to then normalize the criteria and sub-criteria weights, the Eq. (18) has been taken into consideration.

$$\bar{w}_j^s = \frac{S\left(\tilde{w}_j^s\right)}{\sum_{j=1}^{n} S\left(\tilde{w}_j^s\right)} \quad (18)$$

Finally, under spherical fuzzy multiplication given in (12), the equation (19) was applied for final defuzzification.

$$\tilde{A}_{S_{ij}} = \bar{w}_j^s \cdot \tilde{A}_{S_i} = \left\langle \left(1-\left(1-\mu_{\tilde{A}_S}^2\right)^{\bar{w}_j^s}\right)^{1/2}, v_{\tilde{A}_S}^{\bar{w}_j^s}, \left(\left(1-\mu_{\tilde{A}_S}^2\right)^{\bar{w}_j^s} - \left(1-\mu_{\tilde{A}_S}^2 - \pi_{\tilde{A}_S}^2\right)^{\bar{w}_j^s}\right)^{1/2} \right\rangle \quad (19)$$

Finally, in order to rank the criteria and sub-criteria for prioritization, final spherical fuzzy AHP score has been found by Eq. (20).

$$\tilde{F} = \sum_{j=1}^{n} \tilde{A}_{S_{ij}} = \tilde{A}_{S_{i1}} \oplus \tilde{A}_{S_{i2}} \cdots \oplus \tilde{A}_{S_{in}} \forall i$$

$$\text{i.e. } \tilde{A}_{S_{11}} \oplus \tilde{A}_{S_{12}} = \left\langle \left(\mu_{\tilde{A}_{S_{11}}}^2 + \mu_{\tilde{A}_{S_{12}}}^2 - \mu_{\tilde{A}_{S_{11}}}^2 \mu_{\tilde{A}_{S_{12}}}^2\right)^{1/2}, v_{\tilde{A}_{S_{11}}} v_{\tilde{A}_{S_{12}}}, \left(\left(1-\mu_{\tilde{A}_{S_{12}}}^2\right)\pi_{\tilde{A}_{S_{11}}}^2 + \left(1-\mu_{\tilde{A}_{S_{11}}}^2\right)\pi_{\tilde{A}_{S_{12}}}^2 - \pi_{\tilde{A}_{S_{11}}}^2 \pi_{\tilde{A}_{S_{12}}}^2\right)^{1/2} \right\rangle \quad (20)$$

2.3. Application: Evaluating face masks and glove waste management factor prioritization

In the application section, the steps given in Figure 2.3 have been conducted.

2.3.1. Case Definition: Medical Waste of Face Masks and Gloves in Istanbul

Istanbul is the most-populated city in Turkey, which generates 23,7% of total medical waste of Turkey (TUIK, 2021). As there already existed many hospitals consuming face masks and gloves during operations, this ratio of medical waste has been increased during COVID-19 pandemic and recently happened earthquake hit Turkey. Thus, it is important to take into consideration that ineffective medical waste management of face masks and gloves, like all medical waste, will result in health downturn, increasing cost and environmental pollution that directly affect on all human beings living in Istanbul (Hanedar et al., 2022).

2.3.2. Determining the criteria and sub-criteria

The criteria and sub-criteria to be prioritized are defined thanks to the current literature and the experts' views.

The initial step of the decision-making is to identify the main purpose of the model, and to identify criteria, sub-criteria and alternatives. In this context, it is very essential to identify and know the model's accuracy (Çelik et al., 2022). Fuzzy systems endowed with a specified approximation accuracy can be derived, and their respective approximation accuracies can be scrutinized and compared through the application of sensitivity analysis (Zeng and Singh, 1996). Thus, in the fifth section, we provide a sensitivity analysis to measure the accuracy of our SF-AHP application in the field of face masks and glove waste management criteria and sub-criteria.

Table 2.2. presents criteria and sub-criteria followingly based on the literature and practitioners' views.

Table 2.2. Criteria and sub-criteria of face masks and gloves waste management in Istanbul

Criteria	Sub-criteria	Attributes and Explanations	References
Financial and Cost Related Criteria(C1)			
	Recycling Cost(C11)	After disinfection process, face masks and gloves can be effectively recycled. Furthermore, recycling cost in Istanbul is assumed to be an effective factor based on the experts.	Ray et al., 2022; Teymourian et al., 2021;Aung et al., 2019
	Collection and Transportation Cost(C12)	Studies show that collection and transportation cost are very important for waste management network design. Thus, designing a sustainable waste management network for medical waste are dependent upon collection and transportation cost in Istanbul considering there are still traffic problems in Istanbul. These costs are prone to variation based on factors such as the volume of healthcare waste treated, the frequency and distance of pick-up, and equipment design.	Tirkolaee et al.,2020;Li et al., 2019; Arifoğulları et al., 2022; Dursun et al., 2011

	Incineration Cost(C13)	Due to special methods of incineration of face masks and gloves, which are infected by COVID-19 virus, incineration cost is taken as an important factor to decide the decision-making process efficiency. The factor taken into consideration for waste management process of face masks and gloves in Istanbul is seen to be a decisive factor according to the studies in the literature. Furthermore, A well-designed waste system not only leads to lower operating costs but also results in reduced incineration costs and greater economic benefits.	dos Santos et al., 2020; Cherubini et al., 2009; Xin-Gang et al., 2016
	Landfill Cost(C14)	Proper decision of managing waste is also affected by landfilling cost since many parameters exist in decision process. Landfill cost directly affects on decision making process as landfill site selection is not easy to handle as well as the operation of landfilling.	Bartolacci et al., 2019;Kamaruddin et al., 2017;Wang et al., 2009
	Economic benefits of waste management of face masks and gloves(C15)	Contaminated waste such as face masks, gloves and syringes under medical waste have more economic benefits when recycled since recycling process is more benefitable compared to incineration. Thus, it is an important criterion during decision process because of the fact that face masks and gloves contain plastic waste. Skrzyniarz et al. (2022) state that the pyrolysis and recycling of plastic waste, including face masks and gloves, generated during the COVID-19 pandemic emerge as an effective and environmentally solution with significant economic and environmental potential for widespread application.	Huysveld et al., 2019; Liu et al., 2022; Skrzyniarz et al. (2022)
Organization Related Criteria(C2)			
	Personnel Qualifications(C21)	Waste management personnel qualifications should be aligned with the medical waste policy to handle medical waste in Turkey. The regulations of the waste management of face masks and gloves are protected by the Ministry of Environment and Municipalities. Thus, these personnel are assumed to identify how to manage and have a sufficient information.	Aung et al., 2019; MWCR,2017

	Regulations and Laws(C22)	Applicability and strictness of regulations and laws in medical waste management can be a contributing factor to decide waste treatment options. In Istanbul, there are important regulations to manage infectious and medical waste. Despite the regulations developed by the Ministry of Environment, Urbanisation and Climate Change to ensure proper handling and processing of medical waste, there are challenges and shortcomings in enforcing these regulations in practice. Achieving compliance may necessitate integrated efforts from local administrations. Istanbul, being a model city in Turkey for medical waste management, can provide valuable insights for other cities in the country.	Agamuthu and Barasarathi, 2021; Balci et al., 2022; Berkun et al., 2011
	Infrastructure of Health Institution(C23)	During COVID-19 pandemic, it is seen that infrastructure of organization to manage infectious waste is an affecting factor to compare potential opportunities with post-pandemic waste infrastructure. Moreover, health institutions should be aware of the possibility to manage waste since waste should be controlled by the qualified personnel.	Jayasinghe et al., 2023; Manzoor and Sharma,2019
	Organizational Structure(C24)	Organizations should be managed by qualified managers in waste management area.	Abduli, 1995
	Organizational Awareness to manage waste(C25)	Organizational awareness is assumed to increase environmental sustainability mindset. It is well-known that environmental sustainability is directly related to effectively manage waste.	Vazquez et al., 2011; Ramli et al.,2023
Technique Related Criteria (C3)			
	Supply Chain Management Policy(C31)	Supply chain management policy has a direct impact on benefits and costs of waste. Experts in academia indicate that supply chain type has an effect on waste management efficiency for medical waste	Alberti et al., 2000; Vachon et al., 2007
	Quality of Material(C32)	Type and quality of the material, directly face masks and glove waste quality and type affect on waste management effectiveness since quality of materials has a big influence on effectiveness of waste management policy.	Zorpas. 2016

	Recycling, Landfilling and Incineration Capabilities (C33)	The capability and capacity of facilities to treat waste are discussed in terms of an effective and effective waste management plan in the current literature. Recycling, landfilling and incineration equipment to manage waste should be adapted based on the characteristics of waste type.	Yin et al., 2021; Luttenberger, 2020
	Existence of the facility to manage waste(C34)	Another issue to be taken into consideration is the existence of facility to recycle, incinerate and landfill. It is known that there is not any facility specified in the area of face masks and gloves waste management in Istanbul. This non-existence may cause spreading infection without recycling them. Furthermore, the non-existence of the facility in the city can increase transportation and logistics costs.	Coker et al., 2009; Akarsu et al.,2021
	Incentives for people and companies(C35)	Regular incentives supported by government and municipalities are assumed to increase recycling and collections. In Istanbul, for the waste of gloves and face masks, the transportation and collection are freely realised. It is also shown in the literature that there are some important incentives for citizens to increase collection and recycling rate.	Massoud et al., 2010; Onan et al., 2016, Sezer et al., 2003
	Citizens' Awareness for waste management techniques and issues (C36)	People awareness in a country is largely supported by the existing literature to increase recycling ratio and reusing activities.	Almulhim, 2022; Hasan, 2004
	Regular Technical Controls of waste(C37)	Waste minimization objective is provided by the fact that the technical control of facilities and waste appropriateness to recycle, landfill or to incinerate. Regular technical controls are assumed to be different based on the waste type and the facility.	Kumar and Samadder, 2017; Gentil et al., 2010

As explained in Table 2.2., the hierarchical illustration of the prioritization can be seen in Figure 2.4. This hierarchical illustration provides a broader understanding about how to construct our decision-making model to prioritize face masks and glove waste management affecting factors in Istanbul.

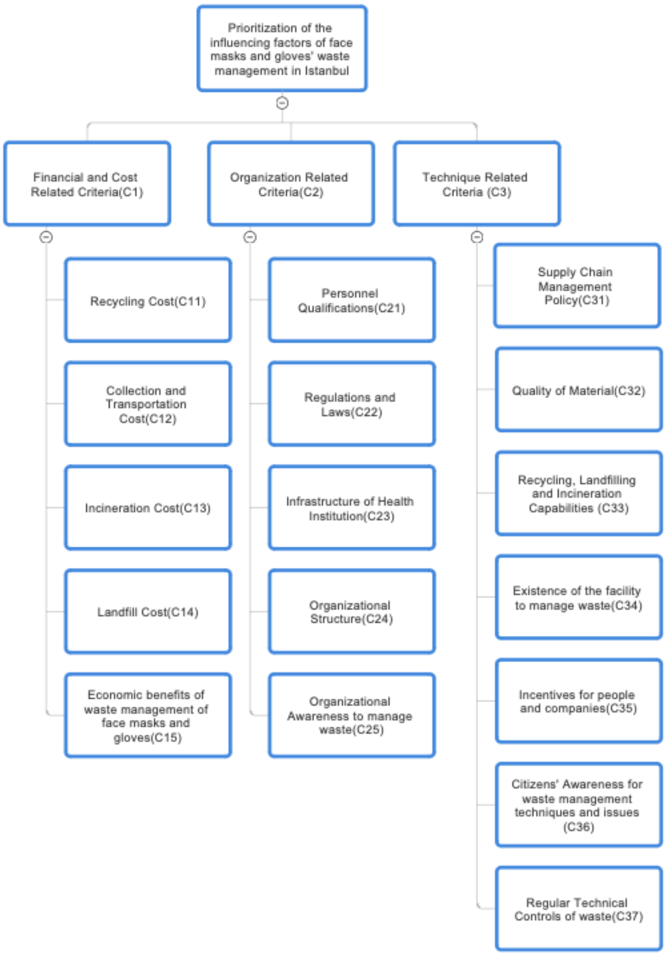

Figure 2.4. The hierarchical illustration of the prioritization problem

2.3.3. Determining the decision makers and experts

In this study, decision makers have been selected based on their theoretical or practical knowledge in the field associated with face masks and gloves waste management. In order to gather and unify the responses, a comprehensive and technical study has been conducted. As all the respondents were experts, the importance weights have been equally taken for decision making matrix. Table 2.3 shows the information of decision makers responding the questionnaire.

Table 2.3. Decision makers' information about face masks and gloves waste management in Istanbul

Profession	Number	Properties of Decision Makers
Academicians	3	Academicians who have knowledge about the related area and published scientific papers in medical waste management topic are involved in this study.
Environmental Engineers	2	Environmental Engineers are responsible for inspecting and developing waste management processes in the facility in Istanbul.
Medical Doctors	2	Medical Doctors use a high amount of face masks and gloves during surgery and routine controls. Thus, they have knowledge about criteria and sub-criteria of this research.
Industrial Engineers	2	Industrial Engineers are assumed to inspect and build the waste management facilities in an effective and efficient way.

2.3.4. Sensitivity analysis of the results

After applying SF-AHP, one dimensional sensitivity analysis has been conducted in order to analyze the variations of criteria and sub-criteria. Sensitivity analysis is used to identify the variations and deviations in the existence of uncertainty (Karande et al., 2016), because methods such as ANP and AHP may have subjectivity, as they are based on personal opinions (Chang et al., 2006). Another reason of conducting a sensitivity analysis in decision making models is stated as the fact that sensitivity analysis in AHP and ANP provide a robustness of the results showing which criteria and sub-criteria are the most important factors affecting the main purpose (Butler et al., 1997). In this context, the equation 21 shows the weight contribution constraint for understanding how to conduct one-dimensional sensitivity analysis.

$$\sum_{l=1}^{n} w_j = 1. w_j w_j' \qquad (21)$$

where, w_j is the most important criterion or sub-criterion weight and it can be fluctuated between 0 and its value obtained by SF-AHP process. $w_j'$is defined as given in the equation (22).

$$w_j' = \left[w_{jmax} + (n-1)w_{jmin}\right] \qquad (22)$$

where, w_{jmax} and w_{jmin} are respectively the highest and lowest level of the related criterion and sub-criterion (Butler et al., 1997).

3. Results and Discussion

In the context of weighted criteria, the data from both practitioners and researchers must be jointly considered. Hence, the perspectives of practitioners, researchers, and academicians are accorded equal importance in the criteria ranking. The decision matrix for criteria weighting is presented in Table 3.1 in terms of linguistic variables. The consistency ratio has been found as 0,01 as calculated in the equation given in (15).

Table 3.1. Criteria evaluation results by experts (decision matrix)

Main Criteria	**Financial and Cost Related Criteria(C1)**	**Organization-Related Criteria(C2)**	**Technique-Related Criteria(C3)**
Financial and Cost Related Criteria(C1)	EI	SLI	ALI
Organization-Related Criteria(C2)	SMI	EI	ALI

Technique-Related Criteria(C3)	AMI	VHI	EI

The initial segment of the questionnaire, as outlined in Table 4.1, was primarily administered to practitioners and academicians. It is crucial to note that comprehensive information regarding the criteria was provided to ensure informed responses, thus facilitating an accurate ranking. The questionnaire comprised multiple inquiries designed to elicit importance weights for each criterion through pairwise comparisons.

Additionally, it is noteworthy that the Consistency Ratio (CR) for the pairwise comparison matrices of both main and sub-criteria were determined to be less than 0.10 (Saaty, 1980). Specifically, for the decision matrix related to technique sub-criteria, the CR was calculated as 0.0809. Similarly, the CRs for the decision matrices associated with Organization-Related sub-Criteria and Financial and Cost-Related sub-Criteria were found to be 0.070633 and 0.0807, respectively. This suggests a satisfactory level of consistency in the obtained results as stated by Saaty (1980). Table 3.2 reveals the decision matrix evaluation for each sub-criterion.

Table 3.2. Sub-criteria evaluation results by experts (decision matrix) for each criterion

Financial and Cost-Related Criteria	**C11**	**C12**	**C13**	**C14**	**C15**		
C11	**EI**	**SLI**	**LI**	**HI**	**SMI**		
C12	**SLI**	**EI**	**EI**	**HI**	**AMI**		
C13	**HI**	**EI**	**EI**	**HI**	**AMI**		
C14	**LI**	**LI**	**LI**	**EI**	**SMI**		
C15	**SLI**	**ALI**	**ALI**	**HI**	**SLI**		
Organization-Related Criteria	**C21**	**C22**	**C23**	**C24**	**C25**		
C21	**EI**	**SLI**	**SLI**	**SMI**	**HI**		
C22	**SMI**	**EI**	**SMI**	**VHI**	**AMI**		

C23	**SMI**	**SLI**	**SLI**	**EI**	**VHI**		
C24	**SLI**	**VLI**	**EI**	**EI**	**SMI**		
C25	**LI**	**ALI**	**VLI**	**SLI**	**SLI**		
Technique Related Criteria	**C31**	**C32**	**C33**	**C34**	**C35**	**C36**	**C37**
C31	**EI**	**SLI**	**VLI**	**HI**	**SLI**	**HI**	**HI**
C32	**SMI**	**VLI**	**LI**	**VHI**	**HI**	**SMI**	**SMI**
C33	**VHI**	**HI**	**EI**	**VHI**	**VHI**	**HI**	**VHI**
C34	**EI**	**VLI**	**VLI**	**SLI**	**EI**	**EI**	**EI**
C35	**SMI**	**LI**	**VLI**	**EI**	**EI**	**SLI**	**EI**
C36	**EI**	**SLI**	**LI**	**EI**	**SMI**	**EI**	**EI**
C37	**VLI**	**SLI**	**VLI**	**EI**	**EI**	**EI**	**LI**

Considering the importance of criteria and sub-criteria for face masks and glove waste management in Istanbul, which has been obtained by using SF-AHP, Technique-Related Criteria (C3) has the highest weight, which is the first priority amidst criteria while Recycling, Landfilling and Incineration Capabilities (C33), Supply Chain Management Policy (C31) and Quality of Material (C32) are followed as the most important sub-criteria respectively. Technique-Related criteria are about technical issues for the process of waste management including recycling, incineration or landfill. Thus, it is assumed that any complication arising from technical issues may result in the deterioration of the process of face masks and glove waste management in Istanbul. Integrated solid waste management, including medical waste, policies in developing countries contribute to minimizing the burden on landfills, thereby advancing the achievement of UN Sustainable Development Goals (Pujara et al., 2019).As an example, inexistence or incapability of waste treatment techniques can cause the increase of costs and deterioration of human health (Yu and Ma, 2022). This result is aligned with the previous findings that implementing effective safety measures, strategic capacity planning for recycling and reusing, and the adoption of well-defined working strategies can facilitate proper healthcare waste management, mitigating the risk of virus transmission. Disinfecting waste, coupled with meticulous segregation and on-site treatment, further enhances the overall quality and effectiveness of healthcare waste management practices based on UN Development Goals for waste management (Das et al., 2021).

As the second most important criteria, organizational-related criteria affect the management of the waste as well. Turkey has regulations and laws of waste management that supports the organizations, and increases the public awareness. It is stated by the calculations of SF-AHP that Regulations and Laws(C22) is the most significant sub-criteria under organizational-related criteria, which forces each citizen, hospitals and companies to treat the infectious and medical waste. Regarding the results of SF-AHP, it is seen that Infrastructure of Health Institution(C23) and Personnel Qualifications(C21) have significant importance since the infrastructure of the health institutions should be aligned with the collection, separation and storage policies of the government and municipalities. Face masks and gloves should be separated from other type of waste since they can be infectious, which results in spreading infections. This can be only achieved by the fact that elevating the level of education, infrastructure of healthcare institutions and comprehension in healthcare waste management significantly contributes to improving the overall situation of healthcare waste management. It is imperative to develop continuous training and educational programs for staff members, as this approach serves to mitigate the likelihood of inappropriate healthcare waste management in developing countries, especially in Turkey (Qaiser, 2012; Khan et al., 2019).

Among the criteria prioritized by the calculations given in methodology section, Financial and Cost-Related Criteria has the lowest weight. However, this result does not mean that the criteria could not be developed. Each institution including municipalities and governmental ones should aim to seek ways to reduce their waste management costs, and to provide not only environmentally but also economically and socially sustainable city to the citizens. Considering the sub-criteria, Incineration Cost(C13) is the most significant sub-criterion among the others. This can be explained by the fact that there is no policy to recycle and reuse face masks and gloves after disinfection process in Istanbul (Akarsu et al., 2021). The second most significant one is followed by the Collection and Transportation Cost(C12) implying that the consumption of fuel are seriously taken into consideration to collect the waste from places who generate face masks and gloves and transfer them to the facilities. In high-index level countries, the collection costs of healthcare waste typically constitute less than 10% of the waste management budget. These countries, employing mechanized, efficient, and frequent collection methods, can achieve remarkably high collection rates, ranging from 76% to 100%. OECD countries exemplify this trend, boasting the highest collection rates at 98%. However, in upper-middle-income countries like Turkey, the collection rate may vary, falling within the range of 50% to

95%, which is relatively lower compared to developed countries in OECD (Margallo et al., 2019; Ranjbari et al., 2022).

When all sub-criteria are taken into consideration together, the most significant and effective ones for the face masks and gloves waste management process in Istanbul are Recycling, Landfilling and Incineration Capabilities (C33), Regulations and Laws(C22), Incineration Cost(C13) and Incineration Cost(C13) subsequently. On the contrary, Organizational Awareness to manage waste(C25), Regular Technical Controls of waste(C37), Existence of the facility to manage waste(C34) and Landfill Cost(C14) have the least importance sub-criteria, respectively. Table 3.3 and 3.4. show Final Results of Criteria and Sub-Criteria respectively.

Table 3.3. Final Results of Criteria

Main Criteria	**Local Weights (μ,v,π)**			**Score Value**	**Ranking**
Financial and Cost Related Criteria(C1)	0,3814	0,6003	0,3080	9,902	3
Organization-Related Criteria(C2)	0,4685	0,5245	0,3089	12,501	2
Technique-Related Criteria(C3)	0,8363	0,1590	0,1519	24,318	1

Table 3.4. Final Results of Sub-criteria

	Local Weights (μ,v,π)			Score Value	Ranking
Financial and Cost-Related Criteria	μ	v	π		
Recycling Cost(C11)	0,5337	0,6093	0,2913	14,5530	3
Collection and Transportation Cost(C12)	0,6474	0,4743	0,2829	18,0031	2
Incineration Cost(C13)	0,7152	0,4129	0,2428	20,2398	1
Landfill Cost(C14)	0,4290	0,6454	0,2855	11,4360	5
Economic benefits of waste management of face masks and gloves(C15)	0,4338	0,6949	0,2203	11,8429	4

Organization-Related Criteria	μ	v	π		
Personnel Qualifications(C21)	0,5442	0,5908	0,3032	14,8100	3
Regulations and Laws(C22)	0,7336	0,3807	0,2233	20,8887	1
Infrastructure of Health Institution(C23)	0,5861	0,5448	0,2821	16,1722	2
Organizational Structure(C24)	0,4681	0,5771	0,3309	12,3823	4
Organizational Awareness to manage waste(C25)	0,3067	0,7796	0,2229	7,9119	5
Technique-Related Criteria	μ	v	π		
Supply Chain Management Policy(C31)	0,5940	0,4137	0,2428	16,6008	2
Quality of Material(C32)	0,5822	0,4406	0,2296	16,3165	3
Recycling, Landfilling and Incineration Capabilities (C33)	0,7639	0,2340	0,1786	22,0169	1
Existence of the facility to manage waste(C34)	0,4267	0,5167	0,3440	11,0471	6
Incentives for people and companies(C35)	0,4505	0,5155	0,3302	11,8426	5
Citizens' Awareness for waste management techniques and issues (C36)	0,4837	0,4591	0,3565	12,6652	4
Regular Technical Controls of waste(C37)	0,3989	0,5597	0,3184	10,3690	7

In order to obtain the robustness of the study, sensitivity analysis has been conducted in one-dimensional way showing the variability of the results. Underneath all, considering the findings of this study, the most important sub-criterion has been obtained as Recycling, Landfilling and Incineration Capabilities (C33) having a maximum priority local weight of 22,0169. In the sensitivity analysis, this weight has been aligned with a proper range as given in the equation 22, and all sub-criterion weights have been equally adapted. Thus, during sensitivity analysis process, the weight of the most important criterion has firstly been decreased to the minimum level and increased up to the top limit by using Eq. (22) and using Eq. (22) based on the local weights. Along the sensitivity analysis process, it has been seen that the sensitivity analysis is conducted and analysed within the range of $13.00 \leq C14 \leq 22{,}0169$. Consequently, new values of criteria and sub-criteria ranking have been obtained as given in Figure 3.1. The weights of C25, C11 and C34 are not assumed to decrease lower than 0,1258 since the weight of C25-Organizational Awareness to manage waste(C25) criterion turns into negative and not have not been able to be enhanced. Considering the sensitivity analysis results, one may argue that the variation in criterion and sub-criterion weights do not seem to have a significant effect on the prioritization which can state that the results of the proposed method obtained by decision makers’ responses are consistent and robust.

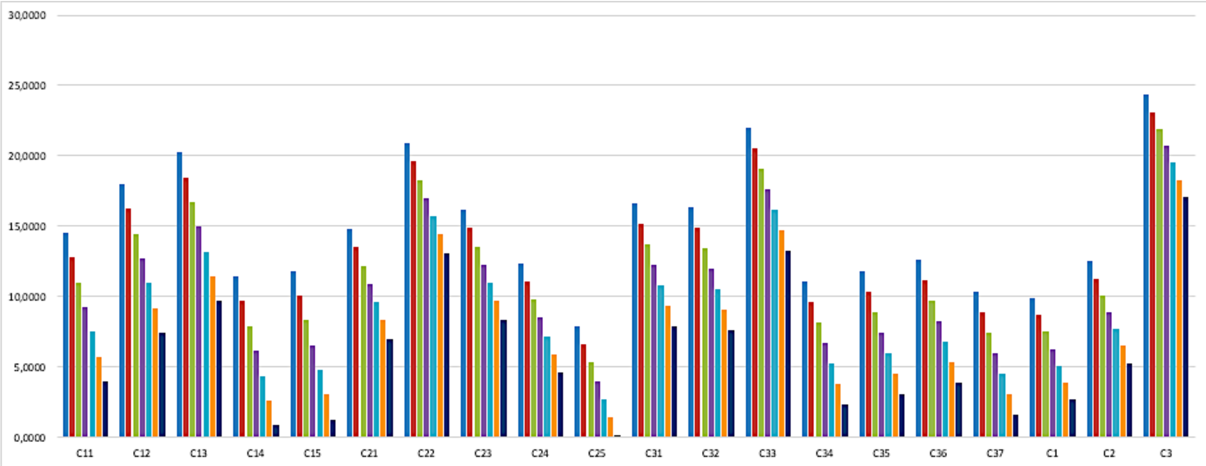

Figure 3.1. The visualisation of sensitivity analysis

4. Conclusion

During the COVID-19 pandemic and earthquake periods in Turkey, the use of face masks and gloves increased significantly. This rise in usage has raised concerns about environmental, economic, and social sustainability due to the harmful effects of their waste on the ecosystem. The impact of this type of waste is especially significant in Istanbul, the most populated city in the country, which generates the majority of Turkey's medical waste.

Moreover, face masks and gloves have the potential to be infectious, and if they are not effectively managed based on the regulations and laws promulgated by the Ministry of Environment, Urbanization and Climate Change of Turkey, they threaten the human health. The collection, separation, storage and facility planning are all involved in face masks and gloves' waste management process. Thus, all the process should be taken as an integrated process in order to eliminate the negative effects. In that sense, it can be stated that waste management of face masks and gloves in Istanbul necessitates researches and practical solutions.

In order to fulfil this need, it is proposed in this study a decision-making approach to evaluate and prioritize the important factors affecting face masks and glove waste management in Istanbul by using Spherical Fuzzy Analytic Hierarchy process. The originality of this paper lies in the fact that there are no similar studies in the literature based on the integration of face masks and gloves' waste management and spherical fuzzy sets. The study mainly concentrated on the factors affecting waste management policies and strategies for the treatment of face masks and gloves during COVID-19 and disaster periods. Moreover, since the experts may have uncertain and subjective opinions, a sensitivity analysis has been conducted to explain the differences among the decision makers, and to test the robustness of the method used. By the aid of the sensitivity analysis, it is seen that SF-AHP is a very robust method to validate our results.

As a result, Recycling, Landfilling and Incineration Capabilities has been seen as the most important sub-criteria, which has an influence of waste management strategy during COVID-19 period in Istanbul. These technical aspects are crucial because any inefficiencies can disrupt the waste management process for face masks and glove, leading to increased costs and health risks. Organizational factors, and Infrastructure of Health Institutions also play a pivotal role, emphasizing the need for robust legal frameworks and well-equipped facilities incorporating municipal and governmental policies for Istanbul. Although Financial and Cost-Related Criteria have the lowest weight, they remain essential for sustainable waste management during crisis periods. High incineration costs highlight the need for policies promoting recycling and reusing medical waste to reduce overall expenses as well as logistics costs as discussed in the previous literature.

To increase the adaptability and resilience of our methodology in the context of Istanbul and Turkey's medical waste management activities, we recommend incorporating a mechanism for periodic review and adjustment of the criteria and their weightings. This approach is essential given the dynamic nature of pandemics and the constantly evolving best practices in waste management. Istanbul, as Turkey's most populous city, presents unique challenges and opportunities in this regard due to its dense population, significant medical infrastructure, and diverse waste generation patterns. The proposed periodic review mechanism should involve systematic data collection and analysis in Istanbul to monitor changes in waste generation, regulatory requirements, technological advancements, and public health directives. For instance, the fluctuations in waste volumes during peak pandemic periods versus regular times in Istanbul necessitate flexible and responsive waste management strategies for an anticipated earthquake or a natural disaster. Regular updates to the criteria and weightings can ensure that the waste management practices remain relevant and effective under varying conditions. Engaging with stakeholders from various sectors is crucial to developing a comprehensive and adaptive waste management strategy. In Istanbul, this would involve medical services, waste management departments under Istanbul municipality or private medical waste management companies in Istanbul. In the specific context of Istanbul, the integration of these diverse perspectives can lead to a more robust and holistic waste management system.

From our perspective, we suggest that regulatory bodies should prioritize the utilization of financial instruments to incentivize diverse forms of recycling activities, aiming to optimize technological advancements in medical waste management in Istanbul, the biggest city of Turkey. Specifically, this approach seeks to enhance the recycling, landfilling, and incineration capabilities of facilities dedicated to managing face masks and gloves, which fall under the purview of medical and solid waste management in Turkey. Such a strategy is anticipated to yield both economic and environmental benefits for Istanbul. To refine the findings of this study, future research endeavours should incorporate local data in Istanbul and construct a more detailed hierarchical structure for the prioritization of face masks and gloves waste management. Additionally, the analysis of innovative technologies in Turkey could be extended to regions with similar characteristics, facilitating the implementation of new medical waste recycling and reusing instruments.

While this study presents a comprehensive decision-making approach for evaluating and prioritizing factors affecting face masks and glove waste management in Istanbul, it is important to acknowledge several limitations. First, the decision-making framework, although robust, is based on specific assumptions that may not hold in all contexts. For instance, SF-AHP relies on expert judgments, which are inherently subjective and may introduce biases for this study. The experts' opinions, though carefully selected and validated through sensitivity analysis, might not fully capture the diversity of perspectives necessary for a holistic approach. Furthermore, the findings are specifically tailored to Istanbul's unique socio-economic and environmental conditions. As a result, the generalizability of the conclusions to other regions with different characteristics may be limited. Future research should consider applying this methodology to various geographical settings and incorporating a broader range of expert inputs to enhance the robustness and applicability of the results. Additionally, exploring alternative decision-making techniques and fuzzy sets, such as neutrosophic or intuitionistic sets, could provide further insights and validate the findings under different scenarios. Additionally, other MCDM techniques such as VIKOR, TOPSIS, and ELECTRE can be considered to enhance objectivity.

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Consent to participate- We affirm that all authors have participated in the research work and are fully aware of ethical responsibilities.

Consent to publish- We affirm that all authors have agreed for submission of the paper to International Journal of Environmental Science and Technology (IJEST) and are fully aware of ethical responsibilities.

Competing Interests- The authors declare that they have no conflict of interest.

Ethical approval: This article does not contain any studies with animals performed by any of the authors.

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