EVALUATING HEALTH-CARE WASTE DISPOSAL ALTERNATIVES FOR ISTANBUL USING FUZYY MULTI-CRITERIA DECISION MAKING APPROACHES

(İSTANBUL İÇİN TIBBİ ATIK BERTARAF ALTERNATİFLERİNİN BULANIK ÇOK ÖLÇÜTLÜ KARAR VERME YAKLAŞIMLARI İLE DEĞERLENDİRİLMESİ)

by

Melis Almula KARADAYI, B.S.

Thesis

Submitted in Partial Fulfillment

of the Requirements

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Today, as in all other organizations, the amount of waste generated in the health-care institutions is rising due to their extent of service. Most developing countries are becoming more and more aware that health-care wastes require special treatment. In this regard, one of the most important problems encountered in Istanbul, is the disposal of health-care waste from health-care institutions.

This study is focused on the detailed multi-attribute evaluation of four health-care waste disposal alternatives to determine the most suitable one for Istanbul. Economic, environmental, technical and social criteria and their related sub-criteria, which incorporate both quantitative and qualitative data, are employed to evaluate the waste disposal alternatives.

I would like to express my sincere gratitude to my supervisor Prof. Dr. E. Ertuğrul Karsak for his scientific guidance and valuable support throughout this study.

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Melis Almula KARADAYI
May, 2009

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LIST OF SYMBOLS

EPA	: Environmental Protection Agency
FMCDM	: Fuzzy multi-criteria decision making
HBF	: Hepatitis B Foundation
HCW	: Health-care waste
HCWM	: Health-care waste management
HIV	: Human Immunodeficiency Virus
ISTAC Co.	: Istanbul Metropolitan Municipality Environmental Protection and Waste Materials Valuation Industry and Trade Co.
MCDM	: Multi-criteria decision making
MSW	: Municipal solid waste
PCDD	: Polychlorinated dibenzodioxin
PCDF	: Polychlorinated dibenzofuran
PIC	: Products of incomplete combustion
TCLP	: Toxicity characteristic leaching procedure
TOPSIS	: Technique for order preference by similarity to ideal solution
WHO	: World Health Organization

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ABSTRACT

Today, as in all other organizations, the amount of waste generated in the health-care institutions is rising due to their extent of service. Disposal of health-care waste management is one of the most common problems of developing countries, including Turkey. Most developing countries are becoming more and more aware that health-care wastes require special treatment. In this regard, one of the most important problems encountered in Istanbul, is the disposal of health-care wastes from health-care institutions. This waste from health-care institutions, excluding the municipal solid waste, shows permanent features in the air, water and soil and disturbs the ecological balance. Therefore, special precautions must be taken about production, transport, storage and disposal of this type of waste. Unless, this waste separately collected and destroyed, many health, environmental and cost problems are inevitable. The purpose of this study, is to determine the most appropriate health-care waste disposal alternative for Istanbul.

Safe and effective disposal of health-care wastes has become an important public and environmental health issue so determining an effective health-care waste disposal system includes both qualitative and quantitative data, large number of performance attributes evaluations. Since, crisp data are inadequate to handle real-world situations, fuzzy set theory can be used in real-life decision making problems. By that manner, fuzzy multi-criteria decision making (FMCDM) has provoked great interest in Decision Science. This ability will facilitate the use of the FMCDM algorithms in HCW disposal alternative selection.

In the scope of this study, “incineration”, "steam sterilization ","microwave" and “landfill” are taken into consideration as health-care waste disposal alternatives for Istanbul. They are evaluated by hierarchical fuzzy MDCM algorithm proposed by Karsak and Ahiska (2005) and the hierarchical fuzzy ranking by similarity to ideal solution (Technique for Order Preference by Similarity to Ideal Solution - TOPSIS)

method proposed by the Kahraman et al. (2007), respectively. A hierarchical evaluation structure including economic, environmental, technical and social criteria and their sub-criteria are employed to evaluate the alternatives.

Karsak and Ahiska's MCDM approach is based on the proximity to ideal solution concept and it enables to incorporate both crisp and fuzzy data expressed in linguistic terms or triangular fuzzy numbers. The origins of the method can be found in the multi-criteria decison aid named TOPSIS. According to this technique, the best alternative would be the one that is nearest to the positive ideal solution and farthest from the negative ideal solution. Since an alternative with the shortest distance from the ideal may not be the farthest from anti-ideal, and vice versa, TOPSIS considers the distances from both the ideal and anti-ideal simultaneously.

Fuzzy hierarchical TOPSIS methodology developed by Kahraman et al. offers a number of benefits. It enables to take into consideration the hierarchical structure in the evaluation model. The hierarchical fuzzy TOPSIS is superior to the fuzzy analytic hierarchy process (FAHP) since the hierarchical structure without making pairwise comparisons among criteria, sub-criteria, and alternatives is considered.

After the evaluation of four HCW disposal alternatives for Istanbul using two fuzzy multiple criteria decision making methods, the rankings are obtained. The results obtained from two MCDM methods appear to be very close. Applying both methods, we obtain "steam sterilization" as the best alternative and it is followed by "microwave". Non-incineration technologies take the first and second rankings as the best alternative disposal technology for Istanbul since they appear to emit fewer pollutants and generate non-hazardous residues. Furthermore, "landfill" is an economic alternative compared with other alternatives; however, due to its several drawbacks for the environment and public health, it should only be used in a limited extent. It is also concluded that like landfilling, "incineration" ranks after non-incineration alternative technologies due to its high costs, adverse environmental and health impacts.

RESUME

Aujourd'hui, comme dans toutes les autres institutions, la quantité de déchets produite dans les institutions médicales a augmenté due à leur ampleur de service. La gestion de la disposition des déchets médicaux est un des problèmes le plus commun des pays en voie de développement, y compris la Turquie. La plupart des pays en voie de développement se rendent compte de plus en plus que les déchets médicaux exigent un traitement spécial. À cet égard, un des problèmes le plus important à Istanbul est l'élimination des déchets médicaux des institutions médicales. Ces déchets des institutions médicales ont des effets permanents sur l'air, l'eau et le sol et dégradent l'équilibre écologique. Par conséquent, les précautions spéciales doivent être prises au stade de la production, du transport, du stockage et de la disposition de ce type de déchet. À moins que, ces déchets se soient séparément collectés et disposés, beaucoup de problèmes de santé, environnementaux et de coût sont inévitables. Le but de cette étude, est de déterminer l'alternative la plus appropriée de dispositions des déchets médicaux pour Istanbul.

La disposition contrôlée et efficace des déchets médicaux est devenue une issue importante de l'environnement, de public et de santé ainsi la détermination d'un système de disposition efficace des déchets médicaux inclut les données qualitatives et quantitatives, grand nombre d'attributs de performance des évaluations. Pour traiter des considérations quantitatives et qualitatives, des techniques de la prise de décision de multi-critères (MCDM) peuvent être employées. Puisque, les données limpides sont insatisfaisantes pour manipuler des situations réelles, la théorie des ensembles floues peut être employée dans des problèmes réels de prise de décision. Ils sont spécifiquement conçus pour représenter mathématiquement l'ambiguité et l'imprécision. De cette façon, la prise de décision multi-critère floue (FMCDM) a provoqué le grand intérêt pour la science de décision. Cette capacité facilitera l'utilisation des algorithmes de FMCDM dans le choix d'alternative de disposition de HCW.

Dans le contenu de cette étude, « incinération » , « la stérilisation par la vapeur » , « micro-onde » , et le « stockage » sont pris en compte en tant que solutions de

disposition des déchets médicaux pour Istanbul. Elles sont évaluées par l'algorithme hiérarchique de MDCM floue proposé par Karsak et Ahiska (2005) et le rang hiérarchique flou par similitude à la solution idéale (Technique pour la préférence d'ordre par Similarité à la solution idéale - TOPSIS) méthode proposée par le Kahraman et autres (2007), respectivement. Une structure hiérarchique d'évaluation comprenant des critères économiques, environnementaux, techniques et sociaux et leurs sous-critères sont utilisés pour évaluer les alternatives.

L'approche de MCDM de Karsak et d'Ahiska est basée sur la proximité au concept de solution idéale et elle permet d'incorporer des données limpides et floues exprimées avec des termes linguistiques ou avec des nombres flous triangulaires. Les origines de la méthode peuvent être trouvées dans la méthode de décision multi-critères appelée TOPSIS. Selon cette technique, la meilleure alternative serait celle qui est la plus proche de la solution idéale positive et la plus loin de la solution idéale négative. Puisqu'une alternative avec la distance la plus courte à l'idéal peut ne pas être loin d'être anti-idéal, et vice versa, TOPSIS considère les distances de l'idéal et anti-idéal simultanément.

La méthodologie hiérarchique floue de TOPSIS s'est développée par Kahraman et autres offre un certain nombre d'avantages. Elle permet de prendre en compte la structure hiérarchique dans l'évaluation du modèle et est également capable de capturer évaluation de l'ambiguïté des hommes quand des problèmes complexes de prise de décision de multi-critères sont considérés. Le TOPSIS flou hiérarchique est supérieur au processus de hiérarchie analytique flou (FAHP) puisque la structure hiérarchisée est considérée, sans faire des comparaisons par paires parmi les critères, les sous-critères, et les alternatives. Ses calculs sont plus efficaces que FAHP.

Après l'évaluation de quatre alternatives de disposition de HCW pour Istanbul utilisant deux méthodes floues de prise de décision à critères multiples, les rangs sont obtenus. Les résultats obtenus à partir de deux méthodes de MCDM semblent être très proches. Appliquant les deux méthodes, nous obtenons la « stérilisation par la vapeur » comme la meilleure alternative et elle est suivie de « micro-onde ». Les technologies de Non-incinération prennent les premiers et deuxièmes rangs comme meilleure technologie alternative de disposition pour Istanbul puisqu'elles semblent émettre peu de polluants et produire des résidus non-nuisibles. En outre, le « stockage » est une alternative économique comparée aux autres alternatives ; cependant, en raison de ses plusieurs inconvénients pour l'environnement et la santé publique, il devrait seulement être employé dans une ampleur limitée. On conclut également que comme la mise en décharge, l' « incinération » se range après les technologies douces de non-incinération dues à ses coûts élevés, ses effets défavorables pour l'environnement et la santé.

ÖZET

Günümüzde, diğer bütün kuruluşlarda olduğu gibi sağlık kuruluşlarında da atık miktarları verdikleri hizmet ölçüsünde her geçen gün hızla artmaktadır. Tıbbi atıkların yönetimi ve bertarafı, Türkiye'de dahil olmak üzere gelişmekte olan ülkelerin en büyük ortak sorunlarından birisidir. Bu doğrultuda İstanbul'da karşılaşılan en önemli sorunlardan biri de, sağlık kuruluşlarından kaynaklanan tıbbi atıkların bertaraflarıdır. Sağlık kuruluşlarından kaynaklanan bu atıklar evsel katı atıkların dışında havada, suda ve toprakta kalıcı özellik göstermekte ve ekolojik dengeyi bozmaktadırlar. Bu nedenle bu tür atıkların üretim, taşıma, depolama ve bertarafına ilişkin özel önlemler alınması gerekmektedir. Bu çalışmanın amacı, İstanbul için en uygun tıbbi atık bertaraf alternatifinin belirlenmesidir

Tıbbi atıkların güvenli ve etkin bir şekilde bertaraf edilmesi konusu önem arz eden çevre ve sağlık konusu olmuştur. Bu yüzden tıbbi atık bertaraf sisteminin seçilmesi problemi hem nitel hem de nicel veriler ile birçok performans ölçütünün değerlendirilmesini içerir. Ayrıca, tıbbi atık bertaraf alternatifinin seçimi problemi hiyerarşik bir yapıya sahip, farklı ölçütler içeren yapısıyla çok ölçütlü karar verme yöntemlerinin uygulanmasına zemin hazırlamaktadır. Klasik çok ölçütlü karar verme yöntemlerinde, ölçütlerin ağırlıklarının veya önem derecelerinin kesin olarak bilindiği varsayılmaktadır. Kesin veriler gerçek hayat durumlarını modellemede yetersiz kalmaktadır. Nitel veriler içeren ölçütlerin sayısallaştırılmasında bulanık küme teorisinden yararlanılabilmektedir.

Çalışma kapsamında, Istanbul için tıbbi atık bertaraf alternatifleri olarak dikkate alınan "yakma", "buhar ile sterilizasyon", "mikrodalga" ve "depolama", Karsak ve Ahiska (2005) tarafından önerilmiş olan hiyerarşik bulanık çok ölçütlü karar verme yöntemi ve Kahraman ve diğerleri (2007) tarafından önerilmiş olan hiyerarşik bulanık TOPSIS yöntemi kullanılarak değerlendirilmiştir. Hiyerarşik değerlendirme yapısında ekonomik, çevresel, teknik ve sosyal ölçütler ile bunların alt ölçütleri dikkate alınmıştır.

Karsak ve Ahiska'nın önermiş olduğu yöntem ideal çözüme yakınlık olgusuna dayanan ve hem bulanık hem de kesin verilerin bir arada değerlendirilmesine olanak sağlayan bir yaklaşımla karar vericiye ışık tutmaktadır. Klasik çok ölçütlü karar verme yöntemlerinde, ölçütlerin ağırlıklarının ve önem derecelerinin kesin olarak bilindiği varsayılmaktadır. Önerilen karar verme yöntemleri, ölçütleri hiyerarşik bir yapıda modellemekle birlikte, karar vericiye sözel değişkenleri kullanma olanağı sağlamaktadır.

Kahraman ve diğerleri tarafından geliştirilmiş olan hiyerarşik bulanık TOPSIS yöntemi ise değerlendirme modelini hiyerarşik bir yapıda modellemekle birlikte, kesin olmayan verileri sayısallaştırmaya olanak sağlayarak karar vericiye bir çok fayda sağlamaktadır. Ayrıca hiyerarşik bulanık TOPSIS yönteminin hiyeraşik yapısı, ölçütler ve alt ölçütler arasında, bulanık analitik hiyerarşi süreci yönteminde olduğu gibi ikili karşılaştırmalar yapmayı gerektirmez.

Sonuç olarak, çalışmada kullanılan karar verme yöntemleri, ölçütleri hiyerarşik bir yapıda modellemekle birlikte, ideal çözüme yakınlık olgusuna dayanan ve hem bulanık hem de kesin verilerin bir arada değerlendirilmesine olanak sağlayan ve sağlıklı sonuçlar veren karar verme yöntemleri olarak belirmektedir. Elde edilen sonuçlar ışığında, tıbbi atık bertaraf alternatifi olarak dikkate alınan "buhar ile sterilizasyon" (S_2) uygulanan her iki yöntemde de diğer alternatif teknolojilerle kıyaslandığında, işletme maliyetlerinin düşük olmasının yanısıra, çevreye ve insan sağlığına olumsuz etkilerinin de az olması nedeniyle, en uygun tıbbi atık bertaraf alternatifi olarak seçilmiştir. "Mikrodalga" (S_3) da çevre ve insan sağlığı için dost bir bertaraf teknolojisi olduğu için "buhar ile sterilizasyon" alternatifinden sonra ikinci sırada yer almıştır. Çevreye ve insan sağlığına olumsuz etkileri fazla olan "yakma" (S_1) ve "depolama" (S_4) alternatifleri ise son sıralarda yer almıştır. Bu doğrultuda belediyeler insan ve çevre odaklı bir yönelimle, yeni yakma tesisleri kurmak ya da mevcut yakma tesislerini revize etmek yerine, yakmasız, çevre dostu teknolojilerle tıbbi atık bertarafını gerçekleştirme yaklaşımını benimsemelidir.

1. INTRODUCTION

Health-care waste (HCW) treatment and management is one of the faster growing segments of the waste management industry. According to rapid spread of the Human Immunodeficiency Virus (HIV), safe and effective treatment and disposal of health-care waste management (HCWM) has become an important public and environmental health issue. Most developing countries are becoming more and more aware that health-care wastes require special treatment [1]. Health-care waste can be defined as waste generated by health-care facilities. It is also possible to classify health-care wastes as in Table 1.1.

Table 1.1 Categories of health-care wastes [2]

Waste Category	Description and examples
Infectious waste	Waste suspected to contain pathogens (e.g. laboratory cultures; waste from isolation wards; tissues, materials, or equipment that have been in contact with infected patients; excreta)
Pathological waste	Human tissues or fluids (e.g. body parts; blood and other body fluids; fetuses)
Sharps	Sharp waste (e.g. needles; infusion sets; scalpels; knives; blades; broken glass)
Pharmaceutical waste	Waste containing pharmaceuticals (e.g. pharmaceuticals that are expired or no longer needed)

Table 1.1 Categories of health-care wastes [2] (cont.)

Waste Category	Description and examples
Genotoxic waste	Waste containing substances with genotoxic properties (e.g. waste containing cytostatic drugs (often used in cancer therapy), genotoxic chemicals)
Chemical waste	Waste containing chemical substances (e.g. laboratory reagents; film developer, disinfectants that are expired or no longer needed; solvents)
Wastes with high content of heavy metals	Batteries, broken thermometers, blood pressure gauges, etc.
Pressurized containers	Gas cylinders, gas cartridges, aerosol cans
Radioactive waste	Waste containing radioactive substances (e.g. unused liquids from radio therapy or laboratory research; contaminated glassware, packages or absorbent paper; urine and excreta from patients treated or tested with unsealed radionuclides; sealed sources)

To deal with the hazards posed by health-care wastes, a large body of regulations has recently enacted. Legal elimination methods of medical wastes have been listed in the Regulation of Medical Waste Control which was published and has gone into effect in the Official Bulletin of Turkish Republic number 25883 on July 22, 2005. With this regulation, alternative elimination technologies excluding the Burning Technology have been allowed in our country; in addition, among alternative technologies the Sterilization has been recommended in the Regulation number 2006/7 published by the Department of Forestry and Environment on March 31, 2006.

As a result health-care wastes have gone from being a component of municipal solid waste, to a highly regulated special waste. Special packing, handling, treatment and diposal precautions are under the control of Medical Waste Control Regulation. By that manner, these issues can make the total costs of health-care waste disposal more expensive than for municipal solid waste . Both the health risks and the significant economic impacts associated with health-care waste management, effective and efficient treatment and disposal is essential.

In the literature, there are a few analytical studies about health-care waste management. Mostly, health-care institutions generating the wastes are surveyed through the prepared questionnaires, field research and personnel interviews. In Turkey, Kılıç [3] developed an integrated health-care waste management plan in order to minimize the risks to the health and human well-being and the environment. It was carried out to assess the optimization of the health-care waste handling and final disposal of the infectious wastes of the health-care institutions in the Anatolian Side of Istanbul. Zeren [4], proposed institutional structure in oder to resolve insufficient management of health-care wastes in the European Side of Istanbul. The research also recommended efficient, sustainable and culturally acceptable methods for the transportation, treatment and disposal of health-care wastes, both within and outside health-care establishments. Alagöz and Kocasoy [5] investigated technical information related to the available treatment technologies and compared capital investment cost, transportation/operational costs for each alternative method.

This study focuses on the detailed evaluation of four health-care waste disposal alternatives to determine the most suitable one for Istanbul by ranking them. In classical multi-criteria decision making (MCDM) methods, the ratings and weights of the criteria are assumed to be known precisely. Crisp data are inadequate to model real-life situations which incorporates vagueness and uncertainty but fuzzy set theory can be used in such decision making problems for quantifying the qualitative data. The need for integrated analysis and decision making is critical when health-care and waste management professionals need to select a health-care waste treatment system. Since the selection of the best health-care waste disposal alternative for Istanbul involves the consideration of numerous criteria, a multi-level hierarchy structure should be constructed in order to conduct an effective analysis. A methodology is needed to incorporate complex, uncertain and vague characteristics of the problem. By that manner, the hierarchical fuzzy MCDM algorithm proposed by Karsak and Ahiska [6] and the hierarchical fuzzy TOPSIS model proposed by Kahraman et al. [7] have been used for evaluating the health-care waste disposal alternatives for Istanbul including

“Incineration”, “Steam sterilization”, “Microwave” and “Landfill ”. Both methods provide a structured hierarchical model for health-care waste disposal alternative evaluation and can handle crisp and fuzzy data expressed in linguistic terms or triangular fuzzy numbers. They also possess advantages in that they are easy to compute, easily understood and reliable distance-based methods. Economic, environmental, technical and social criteria, and their relevant sub-criteria, which include both quantitative and qualitative data, are employed to evaluate the alternative health-care waste disposal alternatives in an integrated manner.

The objective of the study is to provide a decision making tool for health-care and waste management professionals responsible for selecting a health-care waste disposal alternative to contribute to the goal of improving health-care waste management.

The study is organized as follows: In section 2, literature review on health-care wastes is given. Section 3 identifies the health-care waste treatment technology alternatives. Section 4 analyzes the fuzzy decision making methodologies used in this study for the evaluation of health-care waste disposal alternatives. Section 5 presents the application of the proposed methods to Istanbul’s health-care waste management problem. Finally, conclusions are given in Section 6.

2. HEALTH-CARE WASTES

2.1 Definition of the Health-Care Wastes

Health-care waste is waste generated by health-care facilities such as hospitals, clinics, dentist's offices, doctor's offices, laboratories and veterinary hospitals. Although some of the waste from these institutions may be similar to household trash, such as from their cafeterias or offices areas, they also generate waste materials from their health-care operations, such as cultures, infectious agents, liquid human and animal tissues, pathological wastes, serum plasma, surgical, autopsy and laboratory wastes that are not normally found in other waste streams.

The U.S Environmental Protection Agency (EPA) simply defines the health-care wastes as "any solid waste that is generated in the diagnosis, treatment or immunization of human beings or animals, in research pertaining thereto, or in the production or testing of biologicals materials " [8]. There is no single, comprehensive definition of HCW. Some of the widely used terms for health-care wastes can be listed as: "medical waste", "biohazardous waste", "biomedical waste", "biological waste", "pathological waste", "red bag waste", "infectious waste" and "special waste from health-care related facilities". While these terms are not alike, the differences between them depend on which legal or regulatory authority is defining the term.

2.2 Characterization of Health-Care Wastes

The most commonly used definitions of HCW are provided by U.S. Environmental Protection Agency (EPA) and World Health Organization (WHO). In 1986, the EPA defined that infectious waste as those wastes belonging to any of the following six categories [9]:

1. Isolation wastes
2. Cultures and stocks of infectious agents and associated biologicals
3. Human blood and blood products
4. Pathological wastes
5. Contaminated sharps (broken glass, hypodermic needles,etc.)
6. Contaminated animal carcasses, body parts, and bedding

In 1988, the Medical Waste Tracking Act (MWTA) was signed. The law specified 10 categories of waste that could be regulated as medical waste. The categories , which are listed in Subsection 11002(a) of the Act, are as follows [10] :

1. Cultures and stocks of infectious agents and associated biologicals
2. Pathological wastes
3. Waste human blood and blood products
4. Used sharps
5. Contaminated animal carcasses, body parts, and bedding
6. Wastes from surgery or autopsy
7. Contaminated laboratory wastes
8. Dialysis wastes
9. Discarded contaminated medical equipment
10. Biological waste and discarded contaminated materials

The Epa on March 24, 1989 put forward a seven category definition. Citing duplication and redundancy in the categories, the regulation reverted to the EPA's old six category definition, with one addition. The seven classes, with expanded explanations, are as follows [10]:

- Class 1 – Cultures and Stocks

Cultures and stocks of infectious agents and associated biologicals, including: cultures from medical and pathological laboratories; cultures and stocks of infectious agents from research and industrial laboratories; waste from the production of biologicals; discarded live and attenuated vaccines; old culture dishes and device used to transfer, inoculate and mix cultures.

- Class 2- Pathological Wastes

Human pathological wastes including tissue, organs, body parts, and fluids that are removed during surgery or autopsy or other medical procedures, and specimens of body fluids and their containers.

- Class 3 – Human Blood and Blood Products

Waste human blood and products of blood, items saturated and/or dripping with human blood; or items that were saturated and/or dripping with human blood that are now caked with dried human blood; including serum, plasma, and the other blood components, and their containers, which were used or intended for use in either patient care, testing and laboratory analysis, or the development of pharmaceuticals. Intravenous bagsare also included in this category.

- Class 4 – Used Sharps

Sharps that have been used in animal or human patient care or treatment or in medical, research, or industrial laboratories, including hypodermic needles, syringes (with or without needle attached), Pasteur pipettes, scalpel blades, blood vials, needles with attached tubing, and culture dishes (regardless of presence of infectious agents). Also included are other types of broken or unbroken glassware that were in contact with infectious agents, such as slides and cover slips.

- Class 5 – Animal Waste

Contaminated animal carcesses, body parts, and bedding of animals that were known to have been exposed to infectious agents during research (including research in veterinary hospitals), production of biologicals, or testing of pharmaceuticals.

- Class 6 – Isolation Wastes

Biological waste and discarded materials contaminated with blood, excretion, exudate, or secretions from human who are isolated to protect others from certain highly communicable diseases or from isolated animals known to be infected with highly communicable diseases.

- Class 7 - Unused Sharps

Unused discarded sharps, including the following : Hypodermic needles, suture needles, syringes, and scalpel blades.

Medical Waste Control Regulation (MWCR) was published and has gone into effect in the Official Bulletin of Turkish Republic number 25883 on July 22, 2005. According to this regulation, wastes from health-care services were classified into four main groups, given in Table 2.1.

Table 2.1 Classification of wastes generated by health-care services [11]

MUNICIPAL WASTES		MEDICAL WASTES			HAZARDOUS WASTES	RADIOACTIVE WASTES
A:General Wastes	B:Waste Packaging	C: Infectious Wastes	D:Pathological Wastes	E:Sharp Wastes	F:Hazardous Wastes	G:Radioactive Wastes
Wastes derived from normal inpatient wards, outpatient examination rooms, first aid areas, administration, cleaning services , kitchens, stores and workshops:	All wastes reusable or recylable generated within the health-care centre by administration, kitchen, warehouses, workshops : - paper - cardboard - plastics - glass - metal, etc.	Potentially infectious wastes that require special management inside and outside the health-care center, comprising: I.Microbiological labratory wastes: - Cultures and stocks - Infectious body fluids - Serologic wastes - Othercontaminated laboratory wastes II. Blood and blood containers III.Discarded surgery wastes such as soiled dressings, drapes, gowns, gloves. IV. Wastes from dialysis V.Quarantine wastes VI.Air filter that contain bacteria and viruses. VII. Infectious animal carcasses, body parts, blood and all the objects in contact with them.	Tissues, organs and body parts and fluids removed by trauma or during surgery or autopsy or other medical procedure. - parts of human bodies generated in operating theatres, delivery rooms, morgues, autopsies, etc. -corps of animals usedf or biological experimentation	Wastes that could cause a cut or puncture - needles - syringes - pasteur pipettes - blood vials - scalpel blades - slides-cover slips - broken glassware etc.	Wastes that are subject to special handling due to their physical or chemical properties or because of legal reasons. - Hazardous chemicals - Cytotoxic and cytostatic medicines - Amalgam wastes - Gynotoxic and cytotoxic wastes - Pharmaceutics wastes - Heavy-metal containing wastes - Pressurized vessels	Collected and removed according to Turkey Atomic Energy Council Act.

2.3 Composition of the Health-Care Wastes

The type of source of HCW often characterizes the composition of wastes. The different units within the health-care establishment would generate different types of wastes.

Besides, the composition of health-care wastes from the minor sources has also different composition. Composition of a hospital solid waste stream is presented in Table 2.2.

Table 2.2 Composition of a hospital solid waste stream [12]

Waste	Weight (%)
Paper	45
Organics (including yard wastes)	13
Plastics	15
Metals	10
Glass	7
Other (including disposable diapers)	10
Total	100

In addition, the typical breakdown of the overall hospital solid waste stream is given in Table 2.3.

Table 2.3 Breakdown of typical hospital waste [13]

Waste	Weight (%)
General solid waste	56.4
Medical waste	17.5
Corrugated cardboard	10.9
Patient waste	8.5
Paper	3.1
Hazardous waste	2.0
Wooden pallets	0.4
Dry cell batteries	0.4
X-ray film	0.3
Other	0.4

2.4 Generation of the Health-Care Wastes

Waste generation has increased considerably worldwide in the last few decades. Hospitals produce a tremendous amount of HCW. It has also been a significant problem in Turkey. The amount of waste from health-care facilities in Turkey constitutes a large portion of the total waste generated.

The health-care wastes generated differ from one health-care setting to another and from one department to another according to the nature of care and services that are provided [14]. Table 2.4 and Figure 2.1 summarize types and production quantity of health-care wastes in Turkey.

Table 2.4 Types and production quantities of health-care wastes in Turkey [15]

Types of Waste	Average Production (kg/bed/day)
Municipal solid waste	1.351
Recyclable materials	0.319
Pathological wastes	0.131
Infectious wastes	0.398
Sharps	0.151
Radioactive wastes	0.001
Chemical wastes	0.034
Pharmaceutical wastes	0.075
Pressurized containers	0.056
Total	2.516

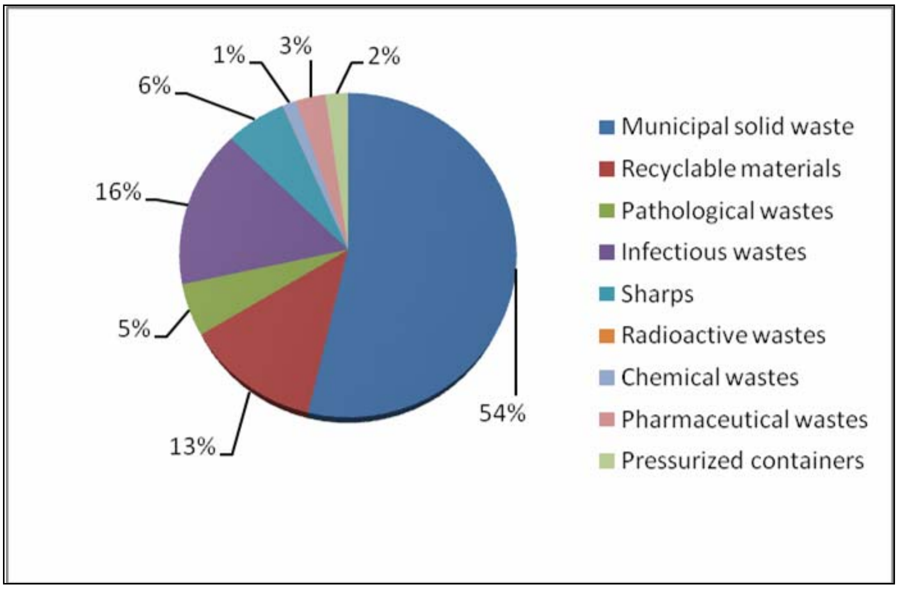

Figure 2.1 Percentage distribution of health-care wastes in Turkey [15]

In addition, by using bed capacities of the health-care institutions with respect to the administrative categories, the composition and the average waste generation of the health-care wastes for both sides of Istanbul are represented in Table 2.5.

Table 2.5 Daily production of health-care wastes generated from the health-care institutions on Asian and European sides of Istanbul [16]

Type of Waste	European Side		Asian Side	
	Average Production (kg/bed/day)	Percentage	Average Production (kg/bed/day)	Percentage
Domestic	0.910	49.18	1.1097	51.11
Pathological	0.110	5.94	0.1594	7.34
Radioactive	0.011	0.01	0.0045	0.21
Chemical	0.035	1.89	0.1164	5.36
Infectious	0.320	17.92	0.3919	18.05
Sharps	0.110	5.94	0.0692	3.19
Pharmaceutical	0.024	1.29	0.0464	2.14
Pressurized containers	0.042	2.27	0.0141	0.65
Recyclable	0.288	15.56	0.2594	11.95
Total	1.85	100	2.171	100

In the scope of this study, the management of health-care wastes in Istanbul, as the largest Metropolitan City of Turkey, is analyzed and all related data about HCW are gathered and updated. Waste generation depends on numerous factors such as waste management methods, administrative categories of the hospital establishment, specialization of the hospital, ratio of reusable items in use and the number of day-care patients [17]. Data about the health-care institutions at the Istanbul Metropolitan Area is given in Table 2.6.

Table 2.6 Number of bed capacity according to the administrative categories and yearly production of health-care wastes generated from health-care institutions in the Istanbul Metropolitan Area (ISTAC Co., 2008)

	Number of Hospitals			Bed Capacity			Amount of health-care waste (ton)		
Institutions	2006	2007	2008	2006	2007	2008	2006	2007	2008
State hospitals	60	66	67	26555	28452	25732	4553	6100	5642
Private hospitals	147	158	162	9764	10098	10961	4700	6600	6229
Total	207	224	229	36319	38550	36693	9253	12700	11871

When the amount of the HCW generated is evaluated, it is determined that the HCW generation has increased gradually. The change in the amount of the generated health-care wastes from 2003 to 2008 in Istanbul is presented in Figure 2.2.

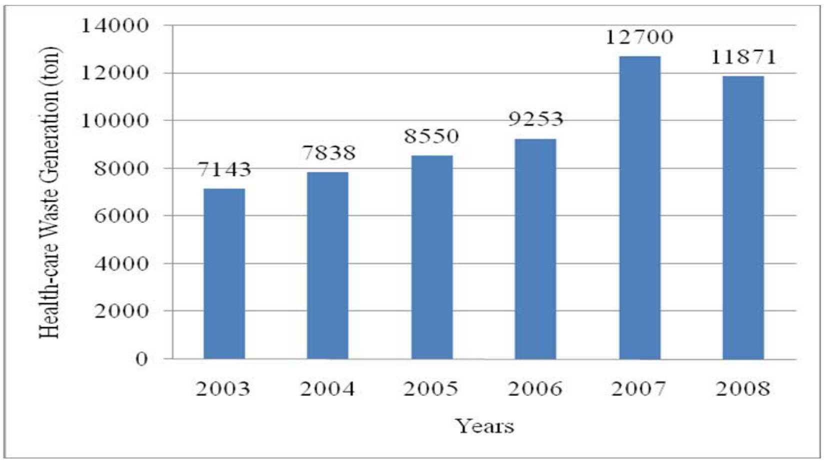

Figure 2.2 Quantity of health-care wastes collected in Istanbul (ISTAC Co., 2008)

In Istanbul, ISTAC Co (Istanbul Metropolitan Municipality Environmental Protection and Waste Materials Valuation Industry and Trade Co.) collects the HCW from hospitals having more than 20 beds, and the district municipalities collect the HCW from the rest of the health-care institutions within their region. Data of total amount of health-care wastes generated in year 2008 is given in Table 2.7.

Table 2.7 Total amount of health-care wastes generated (ISTAC Co., 2008)

			Total Amount of Health-care Waste (ton)
District Municipality	Lower than 20 beds	Asian Side	871
		European Side	1557
		Total (ton)	2428
ISTAC Co.	More than 20 beds	Asian Side	4776
		European Side	7095
		Total (ton)	11871

In addition, Table 2.8 is given the amount of health-care wastes collected by ISTAC Co. on a monthly base from both sides of Istanbul.

Table 2.8 Monthly amount of health-care wastes collected from health-care institutions on the Asian and European sides of Istanbul (ISTAC Co., 2008)

	Asian Side	European Side
Month	Average production (ton)	Average production (ton)
January	470	555
February	439	517
March	420	605
April	398	619
May	394	616
June	383	633
July	380	601
August	351	559

Table 2.8 Monthly amount of health-care wastes collected from health-care institutions on the Asian and European sides of Istanbul (ISTAC Co., 2008) (cont.)

	Asian Side	European Side
Month	Average production (ton)	Average production (ton)
September	369	598
October	361	595
November	390	609
December	421	587
Total	4776	7095

The medical wastes unidentified in their waste generation characteristics or types or infection status are mostly treated by incineration incurring high treatment costs. This implies that clear labelling or description of characteristics of each waste at the waste generating point can contribute to the reduction of treatment and disposal costs of medical wastes since treatment or disposal cost of infectious wastes can be 10-20 times more than that of non-infectious wastes [14].

2.5 Impact of Health-Care Wastes

Several accidents have been reported that mishandling of health-care wastes led to infectious [16]. The possibility of disease transmission is one of the first concerns in working with health-care wastes. The best way to reduce the risk of exposure to any potential disease while working with HCW is to use cautious procedures and protective equipment. The risks that may be posed by health-care wastes and associated hazards and pathways are given in Table 2.9.

Table 2.9 Risks, pathways and hazards of health-care wastes [3]

Risk	Pathway	Hazard
Contraction of disease/infection	Direct or indirect contact through a carrier	Pathological wastes and infectious wastes may transmit diseases and infection through direct or via vectors
Cuts	Direct contact	Sharps wastes including syringes, glasses and scalpels may cause cuts which provide an entry into the body for infection: for example, used syringes may be recycled by medical practitioners or played with by children are potential transmission routes for HIV and Hepatitis B
Ineffective medical care	Direct	Consumption of expired pharmaceuticals possibly through inappropriate prescription by medical practitioners
Cancer	Direct or indirect contact,or proximity to waste	Radioactive wastes
Burns and skin irridation	Direct or indirect contact,or proximity to waste	Toxic chemicals Radioactive wastes
Injury from explosion	Being within the vicinity when explosion occurs	Pressurized containers
Pollution of groundwater, surface water and the air	Direct or indirect contact with polluted water or release to the atmosphere	Toxic chemicals wastes, Pharmaceuticals waste with high heavy metal content

In addition, the distribution of health-care settings according to risk categories in relation to biomedical waste segregation processes differ between departments. It was revealed that 60% of the intensive care units studied are considered high risk departments, followed by 40% of operating rooms, laboratories and health-care units as they do not segregate any items of biomedical waste. Table 2.10 shows the distribution of health-care settings according to risk categories in relation to biomedical waste segregation processes.

Table 2.10 Health-care settings distribution according to risk categories in relation to biomedical waste segregation processes [17]

Department	N	Risk category		
		High risk	Moderate risk	Low Risk
Operating rooms	5	2 (40%)	0	3 (60%)
Labor department	2	0	2 (100%)	0
Surgical departments	5	0	2 (40%)	3 (60%)
Medical departments	5	1 (20%)	1 (20%)	3 (60%)
Intensive care units	5	3 (60%)	0	2 (40%)
Hemo-peritoneal dialysis departments	3	1 (33.33%)	1 (33.33%)	1 (33.33%)
Laboratories	5	2 (40%)	0	3 (60%)
Primary health-care settings	10	4 (40%)	6 (60%)	0
Total	40	13 (32.5%)	12(30%)	15 (37.5%)

3. HEALTH-CARE WASTE TREATMENT TECHNOLOGIES

Waste generated from medical activities can result in negative impacts to public health and to the environment if inappropriate treatment and disposal [18].

The objective of HCW treatment is to eliminate or significantly reduce health risks posed by primarily pathogens in the waste. The pathogens of greatest concern are HIV and HBF. There are currently six proven technologies for achieving significant pathogen destruction as "Incineration", "Steam Sterilization", "Microwave", "Chemical Disinfection", "Irradiation" and "Landfill".

3.1 Incineration

Incineration is the existing technology in order to dispose HCW generated by health-care instiutions in Istanbul. The health-care waste collected by ISTAC Co. and the district municipalities are incinerated at the Kemerburgaz-Odayeri incineration plant located on the European side of Istanbul, which was constructed in 1995. The operation of the plants, licensing and emission control are the responsibility of the Ministry of Environment and Foresty of Turkey The HCW incineration plant is capable of incinerating 24 tons per day [19].

Amount of health-care waste (ton) received by Kemerburgaz-Odayeri incineration plant from 1995 to 2008 is given in Figure 3.1.

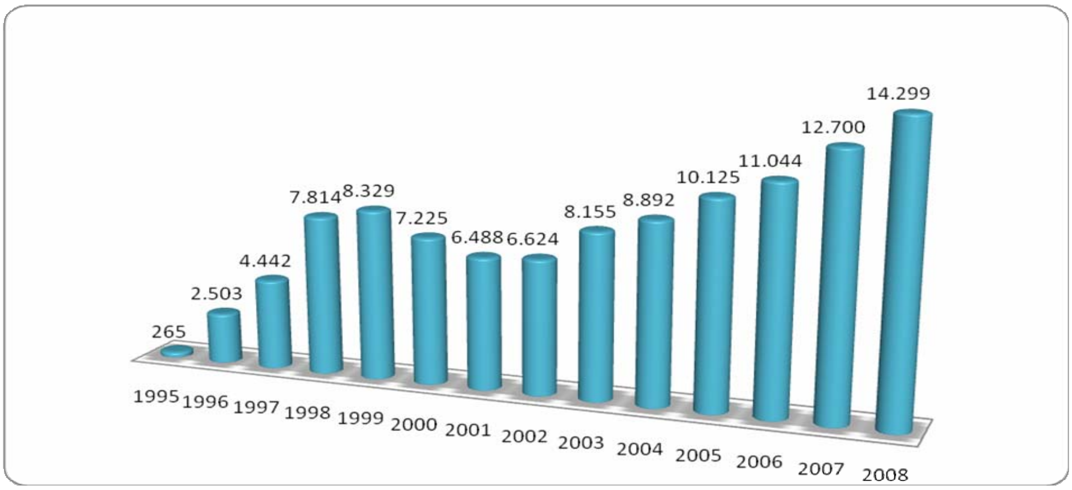

Figure 3.1 Amounts of health-care wastes received by incineration plant (ISTAC Co., 2008)

The amount HCW received by incineration plant from both sides of Istanbul is given in Table 3.1 and percentage distribution of HCW received from Asian and European side of Istanbul is presented in Figure 3.2

Table 3.1 Amount of health-care waste received by incineration plant (ISTAC Co., 2008)

	Health-care waste received (ton)
Lower than 20 beds- Asian	871
Lower than 20 beds- European	1557
Lower than 20 beds- Total	2428
More than 20 beds- Asian	4776
More than 20 beds- European	7095
More than 20 beds- Total	11871

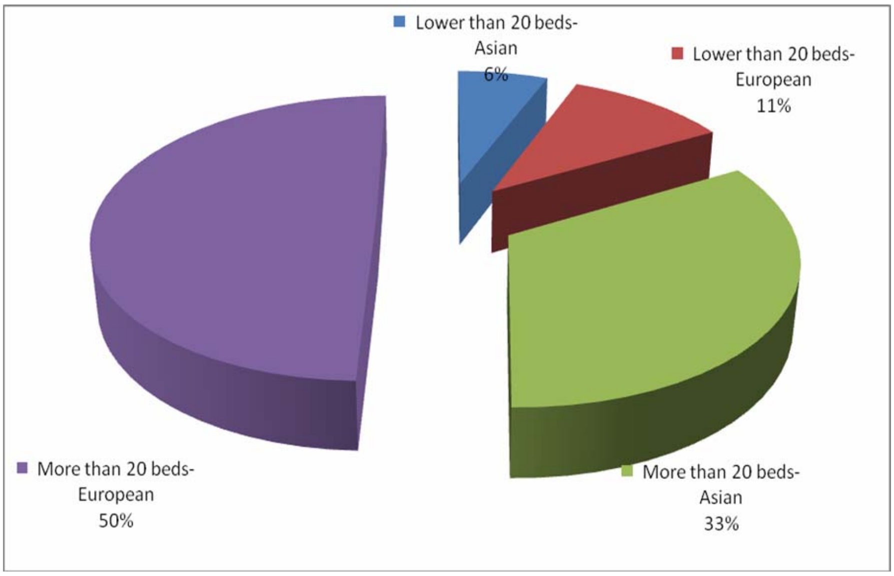

Figure 3.2 Percentage distribution of health-care waste received by incineration plant from both sides of Istanbul (ISTAC Co., 2008)

Incineration is widely recognized as an acceptable means of disposal for infectious wastes. In Turkey, incineration is the preferred method for the disposal of HCW. There are seven incineration facilities in Turkey, which are located in Istanbul, Ankara, Antalya , Sivas, Muğla and Kocaeli [19].

Incineration utilizes combustion to decline waste materials to noncombustible residue or ash and exhaust gases. In many jurisdictions, it is the the only approved method for disposing of pathological wastes. It has been found to be the most effective overall for destroying infectious and toxic components and for significantly reducing volume and weight [20]. However, the main disadvantage of medical waste incineration is the emission of pollutants to the atmosphere, some of which are extremely toxic. Pollutants include: particulate matter, acid gases, trace metals, products of incomplete combustion (PIC) and polynuclear organic matter. Pollutants are usually emitted either in condensed or in gaseous phases. Many organic and metallic compounds have known effects on human health and environment [21]. Among the latter compounds, polychlorinated dibenzofuran (PCDD) and PCFD in exhaust gases are of major concern. PCDDs and PCFDs are among the most toxic chemicals in the environment. Generation and release of PCDD/Fs have created great public concerns due to their acute and chronic health effects, such as, immune, endocrine, reproductive and carcinogenic potential [22].

Directive of the European Parliament and of the Council Concerning the Incineration of Waste emission limit values for incineration plants aims to prevent or reduce possible negative effects on the environment of emissions to air, water, soil, surface and groundwater, as well as any resulting risk to human health. Implementing the directive will mean that many existing plants throughout the European Union (EU) will either have to shut down or install supplementary flue gas cleaning equipment. Air emission measured and limit values at Kemerburgaz- Odayeri Incineration Plant in Istanbul is given in Table 3.2.

Table 3.2 Air Emission Measured and Limit values at Kemerburgaz-Odayeri Incineration Plant in Istanbul (ISTAC CO., 2009)

Pollutants	Measured Values (mg/Nm^3)	Limit Values (mg/Nm^3)
Total particles	22.37	100
Pb	0.0015	5
Cr	0.0027	5
Cu	0.0081	5
Mn	0.0021	5
Ni	0.0018	5
As	< 0.00001	5
Hg	0.0016	5
Cd	0.0010	5
HCL	3.73	100
HF	0.07	1

Table 3.2 Air Emission Measured and Limit values at Kemerburgaz-Odayeri Incineration Plant in Istanbul (ISTAC CO., 2009) (cont.)

Pollutants	Measured Values (mg/Nm^3)	Limit Values (mg/Nm^3)
CO	111	100
SO_2	1	300
NO_2	7	100
Total Organik C	0.2	100
Total dioxin ve furan (ng/m^3)	0.066	<1

Infectious agents are killed by the excessive temperatures reached in the incinerator, exhaust gases are vented to the atmosphere, and only the ash must be landfilled.

If the conditions of combustion are not properly controlled, toxic carbons monoxide will be produced. Thus, to protect public health, incinerators should be provided with air pollution control devices in order to reduce pollutant concentrations to levels even lower than the legal ones [23].

The ash and wastewater produced by the incineration process also contain toxic compounds, which have to treated to avoid adverse effects on health and the environment [2]. HCW ashes are a special type of wastes containing relatively large amounts of heavy metals, which make these ashes different from MSW ashes. Toxicity characteristic leaching procedure (TCLP) results indicate that Cd, Pb, Cu and Zn in HCW fly ashes have high mobility and their leaching amouts exceeded the USEPA regulatory values; thus HCW fly ashes should be properly treated before landfilling to avoid contamination of the environment. Thus ash management plan is critical [24].

Although incineration is widely used, non-incineration technologies are winning increasing support in Europe. By that manner, in order to minimize the risks to the public health and well-being of humans and damage to the environment, non-incineration HCW treatment technology should take into consideration. There is a slow but concerted effort to discontinue the reliance on incineration for the treatment of health-care wastes. It is expected that the incineration of health-care wastes in developing countries will be phased out within the next ten years [1].

3.2 Steam Sterilization (Autoclaving)

Steam sterilization or autoclaving, is a process to sterilize medical wastes prior to disposal in a landfill. Since the mid-1970s, steam sterilization has been a preferred treatment method for microbiological laboratory cultures.
Steam sterilization treatment combines moisture, heat and pressure to inactivate microorganisms. All steam autoclaves are constructed with a metal chamber to withstand the increased pressure/temperature. Autoclaves come in two basic varieties, gravity displacement and prevacuum autoclaves. The size of the devices may vary from benchtop models to large commercial models which can treat more than a ton of waste per cycle.
The factors that affect the efficacy of steam autoclave treatment of medical waste are those affecting the internal waste load temperature, steam penetration of the waste, and the duration of treatment [25].

These factors include:

- temperature and pressure achieved by the autoclave
- size of the waste load
- composition of the waste load
- steam penetration of the waste
- packaging of the waste for treatment
- orientation of the waste load within the autoclave

Steam autoclave operate most efficiently when the temperature measured at the waste load approaches 121 ^{o}C and there is adequate steam penetration of the waste load under pressure. Certain components of the medical waste stream should not be treated by autoclaving . Autoclaving is not recommended for pathological wastes including human organs and body parts, animal carcasses and body parts, contaminated animal bedding, bulk fluids, or sealed containers. In addition, chemical wastes such as antineoplastic agents used for chemotherapy, low level radiological medical wastes, and medical wastes contaminated with chemical or radioactive wastes) should not be autoclaved either [25]. It is estimated that 10% of the medical wastes generated are inappropriate for autoclaving [26].

Steam Sterilization do provide some advantages over incinerators, which may increase their attractiveness as a disposal option, particularly if incineration regulations become much more stringent and thereby increase incineration costs. For example, operation and testing of incinerators is more complex and difficult than that for autoclaves. A major difficulty associated with steam sterilization is ensuring the sufficient residence time to ensure pathogen destruction and the more limited capacity of most autoclaves compared with incineration [27].

3.3 Microwaving

The application of microwave technology to disinfect medical waste was introduced in Europe several years ago. Large microwave irradiation medical waste treatment units include an initial destruction phase. The waste is automatically fed into a waste grinding device where it is shredded and sprayed with steam to increase the moisture content of the waste to approximately 10 percent. The moist ground waste is then heated by exposure to six microwave irradiation units over a 2 hour period. This process heats the waste to greater than 90^{o}C [25]. The shredding process results in a volume reduction of 80 percent prior to disposal [27].

The factors which affect microwave treatment of medical waste include the frequency and wavelength of the irradiation, the duration of the exposure, destruction and moisture content of the waste material, process temperature and the mixing of the waste during treatment [25].

Microwave treatment units can adequately handle most medical waste streams components. However, it is not recommended that large metal objects, human organs and body parts, and animal carcasses not be microwaved. Also, the technology is inappropriate for chemical waste, such as antineoplastic agents used for chemothrepy, and low level radiological waste [25].

3.4 Chemical Disinfection

This type of technology, which has been available since the mid-1980s is referred to as mechanical/chemical because of mechanical maceration and chemical disinfection as result of forcing a reaction that occurs to volatilize waste material and expose all of the pathogens to a chemical disinfectant (usually sodium hypochlorite, commonly known as chlorine bleach) in a controlled environment [28].

The effectiveness of treatment depends upon the characteristics of the disinfectant, the concentration of active ingredient, the contact time of the disinfectant with the waste, and the characteristics of the waste being disinfected [25].

Most medical waste items are suitable for treatment by chemical disinfection with the exceptions of body parts and contaminated animal carcasses which are excluded from treatment by chemical disinfection because of aesthetic reasons. Radioactive , hazardous and cytotoxic wastes are also inappropriate for treatment by chemical disinfection [25].

3.5 Irradiation

It is a common practice to treat medical products with radiation for sterilization purposes. Gamma radiation sterilizes infectious waste by penetrating the waste and inactivating microbial contaminants [27].

Large radiofrequency irradiation medical waste treatment units include an initial destruction phase. The waste is automatically fed into a waste grinding device where it is shredded and sprayed with steam to increase the moisture content of the waste to approximately 10 percent. The moist ground waste is then heated by exposure to radiofrequency irradiation. This process heats the waste to greater than 90^oC [25].

The factors which affect radio frequency irradiation treatment of medical waste include the frequency and wavelength of the irradiation, the duration of the exposure, destruction and moisture content of the waste material, temperature achieved throughout the waste load during treatment and waste storage duration [25].

Radiofrequency irradiation treatment unit can treat most infectious waste with the exception of cytotoxic, hazardous or radioactive wastes. Contaminated animal carcasses, body parts, human organs and large metal items may also be unsuitable for treatment by RF irradiation [23].

3.6 Landfill Disposal

Sanitary landfills are the primary disposal method for the nation's solid waste. Sanitary landfilling is the preferred method of solid waste disposal in most situations due to its low cost, when designed and operated correctly, minimal environmental impacts and effectiveness in controlling health risks. Landfills must have high performance bottom and sidewall liner systems to prevent leachate (Leachate is the liquid that is created when water percolates through garbage, and can be significantly more concentrated than raw sewage) from escaping the landfill and contaminating surrounding ground water. To minimize water infiltrating the refuse and creating leachate, drainage systems and cover systems must be designed and built to meet specified performance standards [1].
A sanitary landfill is an engineered waste disposal facility that, among other aspects, includes in its design:

- sitting in accordance with hydrological, geological, social, and other factors.
- a bottom liner composed of a natura lor synthetic layer of a low permeability material;
- measures to ensure that leachate and landfill gas are collected and properly managed;
- groundwater monitoring wells;
- use of daily, intermediate and final covers and;
- a comprehensive closure and post-closure plan

Hospitals are employing many different waste stream analysis of treatment and disposal methods for their medical wastes. Categories of biomedical wastes and methods of their treatment and disposal are given in Table 3.3 as shown below:

Table 3.3 Categories of biomedical wastes and methods of their treatment and disposal [28]

Category No.	Type of waste	Treatment and disposal
1	Human anatomical waste	Incineration / deep burial
2	Animal waste	Incineration / deep burial
3	Microbiology and biotechnology waste	Autoclave/microwave/ incineration
4	Waste sharps	Disinfection (chemical treatment) / autoclaving/ microwaving and mutilation/ shredding
5	Discarded medicines and cytotoxic drugs	Incineration / destruction and drugs disposal in secured landfills
6	Contaminated solid waste	Incineration / autoclaving / microwaving
7	Solid waste	Disinfection by chemical treatment autoclaving/ microwaving and mutilation/ shredding
8	Liquid waste	Disinfection by chemical treatment and discharge into drains
9	Incineration ash	Disposal in municipal landfill
10	Chemical waste	Chemical treatment and discharge into drain for liquids and secured landfill for solids

Table 3.4 as shown below presents the medical waste classes appropriate for treatment by each of the major medical waste treatment technologies. Classes have already been explained in Literature Review section. All types of wastes may be treated by incineration, however, a special permit is required to incinerate low level radioactive waste or hazardous or cytotoxic waste. However, incineration does not change the

radioactive characteristics of medical waste, thus the ash from incineration of medical waste will remain radioactive. No other treatment technology may be used for radioactive, hazardous or cytotoxic wastes. Steam autoclaving is appropriate for most other wastes with the exception of body parts or animal carcasses, which are too dense to allow for stream penetration. Animal carcasses and body parts are also excluded from treatment by mechanical/chemical, microwaves, radiofrequency, and gamma irradiation for aesthetics reasons [9].

Table 3.4 Medical waste types appropriate for treatment by technology [9]

TECHNOLOGY	CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS 5	CLASS 6	CLASS 7	RADIO-ACTIVE	HAZ. AND CYTOTOXIC
INCINERATION	X	X	X	X	X	X	X	X[1]	X[1]
STEAM AUTOCLAVE	X	X[2]	X	X	X[2]	X	X		
CHEMICAL TREATMENT	X	X[2]	X	X	X[2]	X	X		
MICROWAVE	X	X[2]	X	X	X[2]	X	X		
RADIOFREQUENCY	X	X[2]	X	X	X[2]	X	X		
GAMMA IRRADIATION	X	X[2]	X	X	X[2]	X	X		

1 The treatment of radioactive antineoplastic and hazardous waste which are mixed with medical wastes can be treated with incineration. However, special permits are usually required for this type of treatment. Additionaly, incineration does not inactivate radioactive waste. Thus the ash from these processes may be radioactive and/or contain hazardous constituents.

2 Technology not recommended for treatment of body parts because the density of the waste may prevent adequate treatment. Grinding the waste may increase treatment efficacy however, the grinding process may present aesthetically unacceptable results.

In addition, the effective treatment and disposal through specific methods of health-care wastes are given in Table 3.5 “Yes” and ” No”s appearing indicate that if the method is considered to be capable of effectively dealing with a specific waste category. “Min” (minimum) indicates if the method can only deal with small quantities of a specific waste.

Table 3.5 Handling method alternatives for the the health-care wastes [29]

Waste Category	Treatment and Disposal Methods					Mictcrowave irradiation	Chemical treatment	Encapsulation	Safe burail	Sanitary landfilling
	Incineration			Wet thermal						
	Single-chamber	Pyrolytic	Rotary kiln	Autoclave	Sterilizer					
Infectious wastes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
Pathological wastes	Yes	Yes	Yes	No	No	No	No	No	Yes	No
Sharps	Yes	Yes	Min	Yes	Yes	Yes	Yes	Yes	Yes	No
Pharmaceutical wastes	Min	Yes	No	No	No	No	No	Yes	No	No
Genotoxic wastes	No	Yes	No	No	No	No	No	Min	No	No
Chemical wastes	Yes	Min	No	No	No	No	No	Min	Min	No

A lot of research has gone into the development of suitable treatment tecnologies for the safe and effective management of medical waste. New technologies are being introduced rapidly to meet the needs and demands. A study in China summarizes the main advantages and disadvantages of different technologies for HCW in Table 3.6

Table 3.6 Main advantages and shortcomings of the different technologies for HCW [30]

Type	Advantages	Disadvantages
Incineration	Mature and widely used technology Volume and weight Unrecognizable waste Complete disinfection Heat recovery potential for large systems Broad applicability, acceptable for all waste types Large scale system of waste Related standards and specifications completed	Public opposition High investment and operation costs High maintenance cost Expensive control equipment required to reduce emissions Skilled operator needed Bottom and fly ash may be hazardous
High temperature steam based	Low investment cost Low operating cost Ease of biological tests Low hazard residue PCDD/PCFDs emission free	Appearance, volume unchanged Not suitable for all waste types, chemical waste and pharmaceutical waste can not be treated Possible incomplete disinfection
Microwave	Unrecognizable waste Significant volume reduction Absence of liquid discharge PCDD/PCFDs emission free	Mod-High investment cost Not suitable for all waste types, chemical waste and pharmaceutical waste can not be treated Possible incomplete disinfection
Chemical	Significant volume reduction Unrecognizable waste Rapid processing Waste deodorization PCDD/PCDFs emission free	Mod-High investment cost Not suitable for all waste types, chemical waste and pharmaceutical waste can not be treated Possible incomplete disinfection Need for chemical storage

Each technology has its advantages and disadvantages. It is necessary to determine which technology best meets the local waste management needs while minimizing the impact on the environment and protecting public health.

4. FUZZY MCDM FRAMEWORK

Selection of the best HCW disposal alternative for Istanbul involves the consideration of numerous performance attributes, yielding in general a multi-level hierarchical structure. While some of the attributes are objective and measurable, the others are subjective attributes that are difficult to measure. Although subjective attibutes cannot be easily measured, it is necessary that they are included in the selection process. Since the judgements from experts are usually vague rather than certain, a judgement needs to be expressed by using fuzzy sets which have the capability of representing vague data. In the literature, there exist many fuzzy AHP and TOPSIS methods for multi-attribute decision making problems. There are two main differences between AHP and TOPSIS. Pairwise comparisons for attributes and alternatives are made in AHP while there is no pairwise comparison in TOPSIS. By that manner, the hierarchical fuzzy MCDM algorithm proposed by Karsak and Ahiska [6] and the hierarchical fuzzy TOPSIS model proposed by Kahraman et al. [7] have been used for evaluating the health-care waste disposal alternatives for Istanbul. Both methods provide a structured hierarchical model for health-care waste disposal alternative evaluation and can handle crisp and fuzzy data expressed in linguistic terms or triangular fuzzy numbers. They also possess advantages in that they are easy to compute, easily understood and reliable distance-based methods. In this section, we present these two alternative fuzzy MCDM methodologies for the evaluation of health-care waste disposal alternatives.

4.1 Hierarchical Fuzzy MCDM Approach

Multiple criteria decision making (MCDM) is widely used in ranking alternatives in a set of available alternatives with respect to multiple criteria. The use of multiple criteria analysis in waste management decision making has the advantage of rendering subjective and implicit decision making more objective and transparent [31]. Instead of money-based considerations, there appears to be a growing body of literature reporting on actual applications of multiple criteria methods. This trend may bring about better solutions to the pressing environmental problems, as the methods employed compel decision makers to take explicitly into account a variety of other viewpoints apart from the costs involved [32].

The decision process of selecting an appropriate alternative usually has to take many factors into consideration. Several qualitative and quantitative criteria may affect mutually when alternatives are evaluated, which may make the selection process complex and challenging. Since some critical factors are basically determined by subjective perceptions towards each of evaluated criteria, the fuzzy MCDM approach can explain more appropriately how decision-makers make their evaluation of available alternatives and select the best solution [33].

In this study, the hierarchical distance-based fuzzy MCDM algorithm introduced by Karsak and Ahiska [6] is employed for evaluating HCW disposal alternatives based on a comprehensive list of quantitative and qualitative performance attributes in a multi-level hierarchical structure. This decision approach enables the decision-maker to use linguistic terms while making qualitative assessments. In addition, the precisely defined criteria values, and vaguely defined quantitative as well as qualitative criteria values are integrated in the method. It tackles the problem that an alternative with the shortest distance from the ideal may not have the farthest distance from the anti-ideal by considering the weighted distances from both the ideal and anti-ideal simultaneously [34].

The origins of the method can be found in the multi-criteria decison aid named TOPSIS (technique for order preference by similarity to ideal solution) [35]. According to this technique, the best alternative would be the one that is nearest to the positive ideal solution and farthest from the negative ideal solution [36]. Since an alternative with the shortest distance from the ideal may not have the farthest anti-ideal, and vice versa, TOPSIS considers the distances from both the ideal and anti-ideal simultaneously [34]. The traditional TOPSIS approach uses the Euclidean norm to normalize the original attribute values, and the Euclidean distance to calculate each alternative’s distance from the ideal and anti-ideal solutions. The ideal solution is named as the one having the best attribute values attainable, and the anti-ideal solution is determined as the one possessing the worst environmental problems, as the methods employed compel decision makers to take explicitly into account a variety of other viewpoints apart from the costs involved [32].

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In the scope of this study, an easily applicable decision-making algorithm, that can handle crisp data and fuzzy data expressed in linguistic terms or triangular fuzzy numbers, is used. This ability will facilitate the use of the algorithm in HCW disposal alternative selection process requiring both quantitative and qualitative aspects to be taken into account [34].

The steps of the algorithm are as follows:

***Step* 1.** Construct the decision matrix by identifying the criteria values as crisp data, triangular fuzzy numbers or linguistic terms for the considered alternatives.

***Step* 2.** Normalize the decision matrix so that criteria values are unit-free and comparable. The normalized values for crisp data regarding benefit-related as well as cost-related quantitative sub-criteria are calculated via a linear scale transformation as

$$y'_{ijk} = \begin{cases} \dfrac{y_{ijk} - y^-_{jk}}{y^*_{jk} - y^-_{jk}}, & k \in CB_j \\ \dfrac{y^*_{jk} - y_{ijk}}{y^*_{jk} - y^-_{jk}}, & k \in CC_j, \end{cases} \tag{4.1}$$

where y'_{ijk} denotes the normalized value of y_{ijk}, which is the crisp value assigned to alternative i with respect to the sub-criterion k of criterion j, m is the number of alternatives, n is the number of criteria, CB_j is the set of benefit-related crisp sub-criteria of criterion j and CC_j is the set of cost-related crisp sub-criteria of criterion j, $y^*_{jk} = \max_i y_{ijk}$ and $y^-_{jk} = \min_i y_{ijk}$. The normalized values for crisp data can be represented as $\tilde{y}_{ijk} = (y'_{aijk}, y'_{bijk}, y'_{cijk})$ in triangular fuzzy number format, where $y'_{aijk} = y'_{bijk} = y'_{cijk} = y'_{ijk}$. For fuzzy data denoted by triangular fuzzy numbers as

(a_{ijk}, b_{ijk} , c_{ijk}) , the normalized values for benefit-related criteria $\left(k \in CB_j\right)$ and cost-related criteria $\left(k \in CC_j\right)$ are:

$$\tilde{y}_{ijk} = (y'_{aijk}, y'_{bijk}, y'_{cijk}) = \begin{cases} \left(\dfrac{a_{ijk} - a^-_{jk}}{c^*_{jk} - a^-_{jk}}, \dfrac{b_{ijk} - a^-_{jk}}{c^*_{jk} - a^-_{jk}}, \dfrac{c_{ijk} - a^-_{jk}}{c^*_{jk} - a^-_{jk}}\right), k \in CB_j \\ \left(\dfrac{c^*_{jk} - c_{ijk}}{c^*_{jk} - a^-_{jk}}, \dfrac{c^*_{jk} - b_{ijk}}{c^*_{jk} - a^-_{jk}}, \dfrac{c^*_{jk} - a_{ijk}}{c^*_{jk} - a^-_{jk}}\right), k \in CC_j, \end{cases} \tag{4.2}$$

where $c^*_{jk} = \max_i c_{ijk}$ and $a^-_{jk} = \min_i a_{ijk}$

***Step* 3.** Aggregate the performance ratings of alternatives at the sub-criteria level to criteria level as follows:

$$\tilde{x}_{ij} = (x_{aij}, x_{bij}, x_{cij}) = \frac{\sum_k \tilde{w}^1_{jk} \otimes \tilde{y}_{ijk}}{\sum_k \tilde{w}^1_{jk}}, \forall i, j \tag{4.3}$$

where $\tilde{x}_{ij}$ represents the aggregate performance rating of alternative i with respect to criterion j, $\tilde{w}^1_{jk}$ indicates the average importance weight assigned to sub-criterion k of criterion j, and $\otimes$ is the fuzzy multiplication operator.

***Step* 4.** Normalize the aggregate performance ratings at criteria level using a linear normalization procedure, which results in the best value to be equal to 1 and the worst one to be equal to 0, as follows:

$$\tilde{r}_{ij} = (r_{aij}, r_{bij}, r_{cij}) = \left(\frac{x_{aij} - x^-_{aj}}{x^*_{cj} - x^-_{aj}}, \frac{x_{bij} - x^-_{aj}}{x^*_{cj} - x^-_{aj}}, \frac{x_{cij} - x^-_{aj}}{x^*_{cj} - x^-_{aj}}\right), \forall i, j \tag{4.4}$$

where $x_{cj}^{*} = \max_{i} x_{cij}$, $x_{aj}^{-} = \min_{i} x_{aij}$, and $\widetilde{r}_{ij}$ denotes the normalized aggregate performance rating of alternative *i* with respect to criterion *j*.

***Step* 5.** Define the ideal solution $A^{*} = (r_1^{*}, r_2^{*}, \ldots, r_n^{*})$ and the anti-ideal solution $A^{-} = (r_1^{-}, r_2^{-}, \ldots, r_n^{-})$, where $r_j^{*} = (1,1,1)$ and $r_j^{-} = (0,0,0)$ for $j = 1,2,\ldots,n$.

***Step* 6.** Calculate the weighted distances from ideal solution and anti-ideal solution (D_i^{*} and D_i^{-}, respectively) for each alternative as

$$D_i^{*} = \sum_j 1/2 \left\{ \max(w_{aj}^{1} \left| r_{aij} - 1 \right|, w_{cj}^{1} \left| r_{cij} - 1 \right|) + w_{bj}^{1} \left| r_{bij} - 1 \right| \right\} \quad i = 1,2,...,m \tag{4.5}$$

$$D_i^{-} = \sum_j 1/2 \left\{ \max(w_{aj}^{1} \left| r_{aij} - 0 \right|, w_{cj}^{1} \left| r_{cij} - 0 \right|) + w_{bj}^{1} \left| r_{bij} - 0 \right| \right\} \quad i = 1,2,...,m. \tag{4.6}$$

***Step* 7.** Calculate the proximity of the alternatives to the ideal solution (P_i^{*}) by considering the distances from ideal and anti-ideal solutions as

$$P_i^{*} = \frac{D_i^{-}}{\left(D_i^{-} + D_i^{*} \right)}, \quad i = 1,2,...,m \tag{4.7}$$

Step 8. Rank the alternatives according to P_i^{*} values in descending order. Select the alternative with the highest P_i^{*} as the best alternative.

4.2 Hierarchical Fuzzy TOPSIS

In the literature, there exist several fuzzy TOPSIS methods for multi-attribute decision making problems. Chen and Hwang [37] transform Hwang and Yoon's [35] method to fuzzy case. Liang [36] presents a fuzzy multi-criteria decision making based on the concepts of ideal and anti-ideal points. The concepts of fuzzy set theory and hierarchical structure analysis are used to develop a weighted suitability decision matrix to evaluate the weighted suitability of different alternatives versus criteria. Chen [39] identifies the rating of each alternative and the weight of each criterion by linguistic terms which can be expressed in triangular fuzzy numbers. Then, a vertex method for TOPSIS is used to calculate the distance between two triangular fuzzy numbers. Tsaur et al. [40] apply the fuzzy set theory to evaluate the service quality of airline. Chu [41] presents a fuzzy TOPSIS model for the problem of solving the facility location selection. Chu and Lin [42] propose a fuzzy TOPSIS approach for robot selection where the ratings of various alternatives under different subjective attributes and the importance weights of all attributes are assessed in linguistic terms indicated via fuzzy numbers. Zhang and Lu [43] propose an integrated fuzzy group decision-making method in order to deal with the fuzziness of preferences of the decision maker. Kahraman et al. [7] apply hierarchical fuzzy TOPSIS for evaluating and selecting logistics information technologies. Wang et al. [44] apply the hierarchical fuzzy TOPSIS for supplier selection.

A comparison of fuzzy TOPSIS methods in the literature is presented in Table 4.1 The comparison includes the computational differences among the methods.

Table 4.1 Comparisons of different Fuzzy TOPSIS Methods [45]

Source	Attribute Weights	Type of Fuzzy Numbers	Ranking Method	Normalization Method
Chen and Hwang (1992)	Fuzzy Numbers	Trapezoidal	Lee and Li's (1988) generalized mean Method	Linear Normalization
Liang (1999)	Fuzzy Numbers	Trapezoidal	Chen's (1985) ranking with maximizing set and minimizing set	Linear Normalization
Chen (2000)	Fuzzy Numbers	Triangular	Chen (2000) assumes the fuzzy positive and negative ideal solutions as (1,1,1) and (0,0,0) respectively.	Linear Normalization
Chu (2002)	Fuzzy Numbers	Triangular	Liou and Wang's (1992) ranking method of total integral value with =1 /2	Linear Normalization
Tsaur et al. (2002)	Crisp Values	Triangular	Zhao and Govind's (1991) center of area method	Vector Normalization
Zhang and Lu (2003)	Crisp Values	Triangular	Chen's (2000) fuzzy positive and negative ideal solutions as (1,1,1) and (0,0,0) respectively.	Linear Normalization
Chu and Lin (2003)	Fuzzy Numbers	Triangular	Kaufmann and Gupta's (1988) mean of the removals method	Linear Normalization

In the scope of this study, in order to take hierarchical structure into account, we use the hierarchical fuzzy TOPSIS model of Kahraman et al [7]. Fuzzy AHP has the capability of taking pairwise comparisons of attributes into consideration with a hierarchical structure. The chosen method has this ability without making pairwise comparisons. The hierarchy in Figure 5.1 will be considered.

Assume that we have *n* main attributes, *m* sub-attributes and *k* alternatives. Each main attribute has r_i sub-attributes where the total number of sub-attributes *m* is equal to $\sum_{i=1}^{n} r_i$.

The method can be described using the following steps:

Step 1. The expert used the linguistic variables "very low (VL)", "low (L)", "moderate (M)", "high (H)" and "very high (VH)" to evaluate the importance of the attributes and sub-attributes, and also the ratings of alternatives with respect to various subjective attribute and sub-attribute.

Step 2. Construct the first matrix $\tilde{I}_{MA}$ using the weights of main attributes with respect to the goal.

$$\tilde{I}_{MA} = \begin{matrix} MA_1 \\ MA_2 \\ \vdots \\ MA_p \\ \vdots \\ MA_n \end{matrix} \overset{Goal}{\begin{bmatrix} \tilde{w}_1 \\ \tilde{w}_2 \\ \vdots \\ \tilde{w}_p \\ \vdots \\ \tilde{w}_n \end{bmatrix}} \quad (4.8)$$

Step 3. Construct the second matrix $\tilde{I}_{SA}$ using the weights of sub-attributes with respect to the main attributes. Write the weights vector obtained from $\tilde{I}_{MA}$ above this $\tilde{I}_{SA}$ as follows:

$$\tilde{I}_{SA} = \begin{array}{c} \\ \\ SA_{11} \\ SA_{12} \\ \vdots \\ SA_{1r_1} \\ SA_{21} \\ SA_{22} \\ \vdots \\ SA_{2r_2} \\ \vdots \\ SA_{pl} \\ \vdots \\ SA_{n1} \\ SA_{n2} \\ \vdots \\ SA_{nr_n} \end{array} \begin{array}{c} \begin{array}{cccccc} \tilde{w}_1 & \tilde{w}_2 & \cdots & \tilde{w}_p & \cdots & \tilde{w}_n \\ MA_1 & MA_2 & \cdots & MA_p & \cdots & MA_n \end{array} \\ \begin{bmatrix} \tilde{w}_{11} & 0 & \cdots & 0 & \cdots & 0 \\ \tilde{w}_{12} & 0 & \cdots & 0 & \cdots & 0 \\ \vdots & \vdots & & \vdots & & \vdots \\ \tilde{w}_{1r_1} & 0 & \cdots & 0 & \cdots & 0 \\ 0 & \tilde{w}_{21} & \cdots & 0 & \cdots & 0 \\ 0 & \tilde{w}_{22} & \cdots & 0 & \cdots & 0 \\ \vdots & \vdots & & \vdots & & \vdots \\ 0 & \tilde{w}_{2r_2} & \cdots & 0 & \cdots & 0 \\ \vdots & 0 & & & & \vdots \\ 0 & 0 & \cdots & \tilde{w}_{pl} & \cdots & 0 \\ \vdots & & & & & 0 \\ 0 & 0 & \cdots & 0 & \cdots & \tilde{w}_{n1} \\ 0 & 0 & \cdots & 0 & \cdots & \tilde{w}_{n2} \\ \vdots & \vdots & & \vdots & & \vdots \\ 0 & 0 & \cdots & 0 & \cdots & \tilde{w}_{nr_n} \end{bmatrix} \end{array} \tag{4.9}$$

Step 4. Construct the decision matrix $\tilde{I}_A$ using the scores of the alternatives with respect to the sub-attributes. Write the weights vector obtained from $\tilde{I}_{SA}$ above this $\tilde{I}_A$ as follows:

$$\tilde{I}_A = \begin{array}{c} \\ \\ A_1 \\ A_2 \\ \vdots \\ A_q \\ \vdots \\ A_k \end{array} \begin{array}{c} \begin{array}{ccccccccc} \tilde{W}_{11} & \tilde{W}_{12} & \cdots & \tilde{W}_{1r_1} & \cdots & \tilde{W}_{pl} & \cdots & \tilde{W}_{nr_n} \\ SA_{11} & SA_{12} & \cdots & SA_{1r_1} & \cdots & SA_{pl} & \cdots & SA_{nr_n} \end{array} \\ \begin{bmatrix} \tilde{c}_{111} & \tilde{c}_{112} & \cdots & \tilde{c}_{11r_1} & \cdots & \tilde{c}_{1pl} & \cdots & \tilde{c}_{1nr_n} \\ \tilde{c}_{211} & \tilde{c}_{212} & \cdots & \tilde{c}_{21r_1} & \cdots & \tilde{c}_{2pl} & \cdots & \tilde{c}_{2nr_n} \\ \vdots & \vdots & & \vdots & & \vdots & & \vdots \\ \tilde{c}_{q11} & \tilde{c}_{q12} & \cdots & \tilde{c}_{q1r_1} & \cdots & \tilde{c}_{qpl} & \cdots & \tilde{c}_{qnr_n} \\ \vdots & \vdots & & \vdots & & \vdots & & \vdots \\ \tilde{c}_{k11} & \tilde{c}_{k12} & \cdots & \tilde{c}_{k1r_1} & \cdots & \tilde{c}_{kpl} & \cdots & \tilde{c}_{knr_n} \end{bmatrix} \end{array} \tag{4.10}$$

where,

$$\tilde{W}_{pl} = \sum_{j=1}^{n} \tilde{\mathrm{w}}_{\mathrm{p}} \tilde{w}_{pj} \tag{4.11}$$

Since $\tilde{w}_{pl} = 0$ for $j \neq 1$, use Eq. (4.12) instead of Eq. (4.11)

$$\tilde{W}_{pl} = \tilde{w}_p \, \tilde{w}_{pl} \tag{4.12}$$

Step 5. Normalize the decision matrix using Eq. (4.1) and (4.2) for crisp and fuzzy data, respectively and obtain r_{ij} .

Step 6. Compute the weighted normalized decision matrix as follows:

$$\tilde{V}_{ij} = \tilde{r}_{ij} \, \tilde{W}_{ij} \quad \forall \text{ i,j} \tag{4.13}$$

Step 7. Obtain the positive ideal solution (PIS), A^*, and the negative ideal solution (NIS). PIS and NIS are defined as:

$$A^* = \left[v_1^*, ..., v_n^* \right], \tag{4.14}$$

$$A^- = \left[v_1^-, ..., v_n^- \right], \tag{4.15}$$

where $v_j^* = \max_i v_{ij}$ and $v_j^- = \min_i v_{ij}$.

In case of fuzzy data, v_j^* and v_j^- are fuzzy numbers with the largest generalized mean and the smallest mean, respectively . Since triangular fuzzy numbers (*a,b,c*) are used in this application, can be represented in trapezoidal form as (*a,b,b,c*). The generalized mean for fuzzy number v_j^- $\forall$ j , j is computed as:

$$M(v_{ij}) = \frac{-a_{ij}^2 + d_{ij}^2 - a_{ij} \; b_{ij} \; + b_{ij} \; d_{ij}}{3(-a_{ij} + d_{ij})} \tag{4.16}$$

Step 8. Calculate the seperation measures S_i^* and S_i^- as follows:

$$S_i^* = \sum_{j=1}^{n} D_{ij}^*, \text{ i} = 1, ..., \text{m} \tag{4.17}$$

and

$$S_i^- = \sum_{j=1}^{n} D_{ij}^-, \text{i} = 1, ..., \text{m} \qquad (4.18)$$

For crisp data, the difference measures D_{ij}^* and D_{ij}^- are obtained as:

$$D_{ij}^* = \left| v_{ij} - \text{v}_\text{j}^* \right| \qquad (4.19)$$

$$D_{ij}^- = \left| v_{ij} - \text{v}_\text{j}^- \right| \qquad (4.20)$$

In the case of fuzzy data difference measures are obtained as :

$$D_{ij}^* = \begin{cases} 1- \dfrac{c_{ij} - a^*}{b^* + c_{ij} - a^* - b_{ij}} \; for \;\; b_{ij} \prec b^* \\ 1- \dfrac{c^* - a_{\text{ij}}}{b_{ij} + c^* - a_{ij} - b^*} \; for \;\; b^* \prec b_{ij} \end{cases} \quad \forall \text{ i , j} \qquad (4.21)$$

$$D_{ij}^- = \begin{cases} 1- \dfrac{c^- - a_{ij}}{b_{ij} + c^- - a_{ij} - b^-} \; for \;\; b^- \prec b_{ij} \\ 1- \dfrac{c_{ij} - a^-}{b^- + c_{ij} - a^- - b_{ij}} \; for \;\; b_{ij} \prec b^- \end{cases} \quad \forall \text{ i , j} \qquad (4.22)$$

where $v_j^* = \left(a^*, b^*, c^*\right)$ and $v_j^- = \left(a^-, b^-, c^-\right)$ are the fuzzy numbers with the largest generalized mean and the smallest generalized mean, respectively.

Step 9. Compute the relative closeness to ideal as

$$C_i = S_i^- \,/\, (\, S_i^* + S_i^- \,) \qquad (4.23)$$

Step 10. Rank the alternatives in descending order of C_i values. Identify the alternative with the highest C_i as the best alternative.

5. CASE STUDY

5.1 Criteria to Consider in Selecting an Alternative Health-Care Waste Treatment Technology

Determining the best technology depends on many specific factors [46]. In this study, benefiting from literature on the evaluation of HCW disposal alternatives, economic, environmental, technical and social criteria are identified as the selection criteria. Several relevant sub-criteria corresponding to these criteria are also identified in order to conduct a comprehensive evaluation of disposal alternatives. These factors and their related sub-criteria can be identified as follows:

1. Economic Factors (ECO)

1.1. Capital Costs (CC)

1.2. Operating Costs (OC)

2. Environmental Factors (ENV)

2.1. Possible Air Emissions (PAE)

2.2. Solid Residuals and Environmental Impacts (SREI)

2.3. Water Residuals and Environmental Impacts (WREI)

2.4. Air Residuals and Environmental Impacts (AREI)

2.5. Noise (N)

2.6. Odor (O)

2.7. Release with Health Effects (RHE)

3. Technical Factors (TEC)

3.1. Reliability (REL)

3.2. Treatment Effectiveness (TE)

3.3. Volume Reduction (VR)

3.4. Ease of Use (Automation) (EU)

3.5. Need for Skilled Operators (NSO)

3.6. Occupational Hazards Occurance Frequency at Treatment Site (OF)

3.7. Occupational Hazars Occurance Impact at Treatment Site (OI)

4. Social Factors (SOC)

4.1. Adaptability to Environmental Policy (AEP)

4.2. Public Acceptance Obstacles (PAO)

4.3. Land Requirement (LR)

Criteria and their relevant sub-criteria are depicted in Figure 5.1

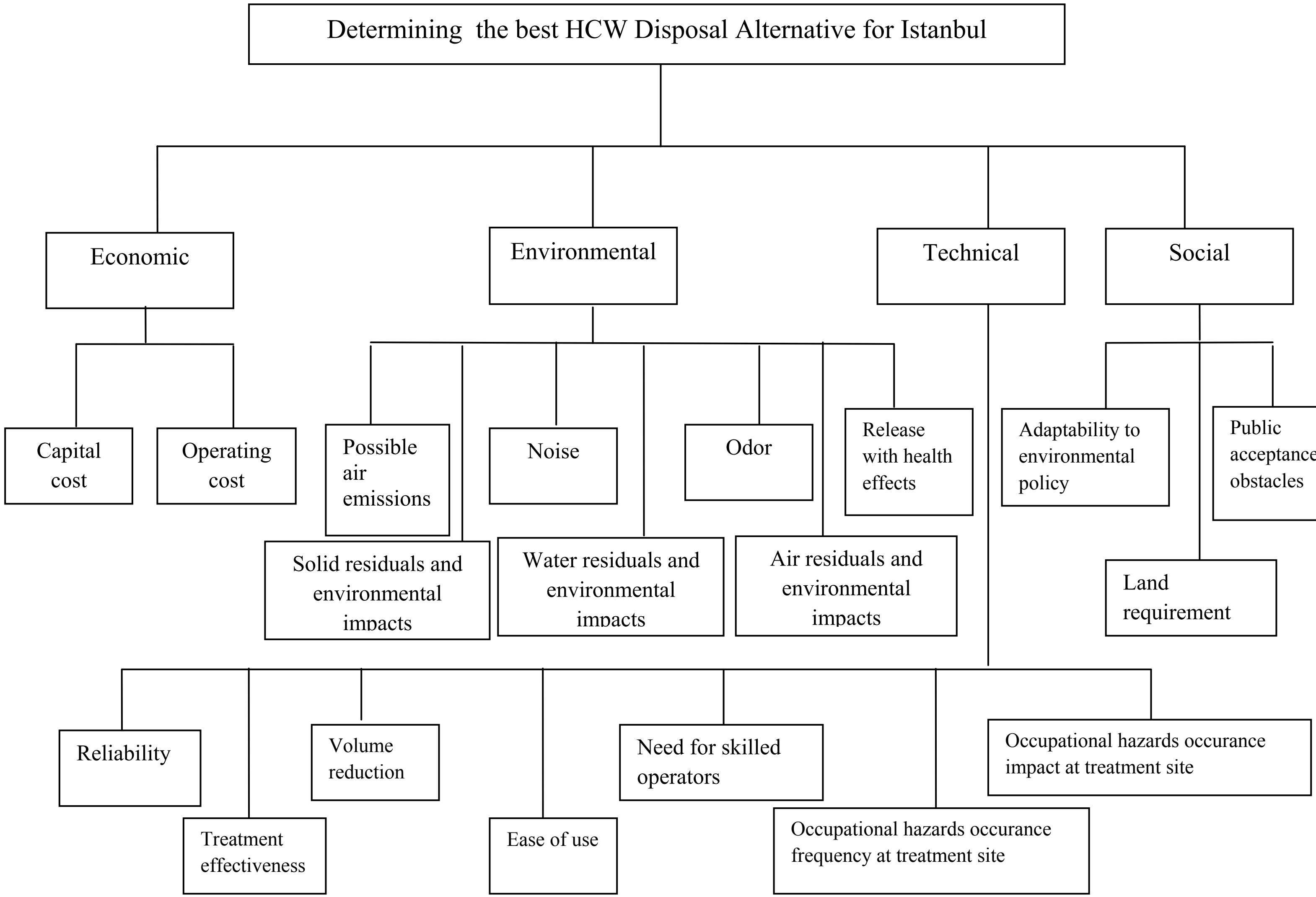

Figure 5.1 Hierarchical structure of the HCW disposal alternative evaluation problem

Detailed explanation of criteria and sub-criteria are given below.

1) Economic Factors

Capital and Operating Costs: The factor that always weighs heavily with decision makers is the system cost. Given similar risks and benefits, the cost of any system being considered must be competitive with the costs of other alternatives .

Capital costs are the sum of the cost of the treatment system, auxiliary equipment, facility improvements, system installation, and associated engineering and permitting expenses.

Direct operating cost should always include expenses for personnel salaries and benefits, utilities, supplies, and repairs and maintenance.

2) Environmental Factors

Possible Air Emissions: Possible air emissions are taken into consideration. Particulate and potentially toxic air emissions from incinerators are the primary factors that contributed to the development of alternative treatment technologies. Uncontrolled air emissions may lead to the release of potentially hazardous and/or toxic materials. If emissions are generated during the treatment cycle, they should not be hazardous or toxic; or, if these sorts of emissions are released, the treatment system should have an equipment to reduce the levels of toxic/hazardous substances. If emissions are vented to the outside, it is critical that they be:

a) colorless and free from persistent mist or droplets;
b) odorless as detectable at the boundaries of the facilities; and
c) vented, when appropriate, through High Efficiency Particulate Air (HEPA) filters.

Environmental Impacts of Treatment Technology Residuals: No waste disposal system or technology can make wastes disappear. They simple transform or store wastes,in a safer and more environmentally sound state.

Regardless of the technology selected, the facility operator will face a residuals management problem. There are three types residuals and environmental impacts to consider when analyzing medical waste treatment systems; air, water and solids. An important question, then, for the decision maker is, which technology produces the least costly and least problematic residuals. These technologies need to be evaluated more favorably than those that produce more residuals.

Noise and Odor: Reducing noise and odors are important aspects of occupational health and community relations. Technologies which are noiseless and odor-free need to be evaluated more favorably than those that are not.

Release with Health Effects: The hazards to the human health posed by medical waste justify a high level of concern with its management so it should be taken into account while evaluating the alternative treatment technologies.

3) Technical factors

Reliability: Reliability of technology can be determined from past maintenance records. For technologies that have been in operation long enough, good estimates of equipment can be obtained. For new technologies, it is necessary to find out how long the technology has been in full, continuous operation without any problems.

Treatment Effectiveness: To reduce risks a treatment system must achieve significant pathogen inactivation on a consistent, reliable, ongoing basis. The bechmark for significant pathogen reduction for a medical waste treatment system is a 6 log or 99.9999% reduction of potential pathogen populations. Systems that are unable to achieve this standard consistently and reliably should be wieved significantly less favorably than those that can because ineffectively treated medical wastes pose a number of health risks, and regulatory and public acceptance risks.

Reduction of Waste Volume : Volume reduction is important because all solid residues from treatment are eventually disposed of in landfills. To reduce cost, it is important to reduce the volume of the waste residues that will be landfilled. By selecting a technology that achieves a high reduction in waste volume, facilities can decrease landfill capacities and minimize environmental impact.

Ease of Use (Automation): A technology should be automated to minimize operator errors while allowing efficient and easy control of the process, safety interlocks, diagnostics, remote monitoring, alarms, and automatic documentation to meet record keeping requirements.

Need for Skilled Operators: With each kind of infectious waste treatment equipment there is a need for trained operators. The equipment must understand the process. It is not enough just to load the waste and push a button, because such action could result in incomplete or ineffective treatment as well as occupational exposures and environmental releases.

Occupational Hazards Occurance Frequency and Impact at Treatment Site: In this study, occupational hazards at treatment site is explained according to occurance frequency and occurance impacts of hazards.Occupational hazards must be of concern to everyone interested in reducing risk and improving reliability.Operators of infectious waste treatment equipment incur risks that are specific to each type of equipment and its operation.

4) Social Factors

Adaptability to Environmental Policy: The treatment technology that is selected must meet relevant regulatory requirements. Every type of treatment has some impact on the environment, be it on the air, the water, and the land. There are regulations to minimize most of these environmental effects. The most difficult and expensive requirement is meeting air pollution control standards.

Public Acceptance Obstacles: Public Acceptability is considered to be one of the most important criterion variables. Steps should be taken to get acceptance by the public of any particular treatment technology. To achieve this, the public should be informed and educated about the sources of medical waste, the consequences of exposure to medical waste, measures to protect themselves, awareness about the advantages and disadvantages of various available medical waste treatment technologies. All technologies are not subject to the same levels of public acceptance.

Land Requirement: The land needed to operate a technology should fit the available land in the facility. That space is not only the footprint and height of the equipment but should also include additional space needed for opening waste entry doors, access to control panels, space for hydraulic lifts, conveyors, moving bins, storage areas, etc.

5.2 Application Background of the MCDM Framework to HCW Management Problem in Istanbul

The amount of wastes collected and processed at the incineration plant steadily increased as a result of the training efforts and the effect of the regulation [47]. Even though Incineration plant has the capacity of 24 tons per day , approximately 39 tons per day health-care waste is collected .The capacity of the existing incineration plant at Kemerburgaz-Odayeri is not sufficient to incinerate all the health-care wastes generated from both sides of Istanbul. As a result of discussions with experts from ISTAC Co capacity of the alternative treatment technology is considered as 24 tones/day. We have defined four possible treatment technologies for the disposal of health-care wastes in Istanbul. Treatment systems for steam sterilization and microwaving is selected with pre-shredding component that exposes a greater surface area for treatment via utulizing a shredder to reduce the waste to a uniform and relatively small size in order to sterilize waste adequately. The alternatives can be listed as follows:

1) Incineration
2) Steam Sterilization (with pre-shredding)
3) Microwave (with pre-shredding)
4) Landfill Disposal

Alternative 1 : Incineration (existing disposal method)

The HCW is collected systematically by ISTAC Co. from health establishments.and the district municipalities. They are brought to the Storage Area in Kemerburgaz-Odayeri and discarded there by burning in the HCW Incineration Plant which is located on the European side of Istanbul. The incineration plant was constructed by Ansaldo Bolund Company in 1995 and the investment capital for the plant was 27.000.000 $ [4].

The incineration plant has been operating at its full capacity which is 24 tones/day. 85-95 per cent volume reduction and 75 per cent mass recution can be accomplished. Health-care wastes taken to the Incineration Plant in Kemerburgaz-Odayeri are firstly weighted and after loading mechanically, incinerated in the primary combustion chamber around 800-900 ^{o}C. One hour is determined as a detention time of the wastes in this unit. After primary chamber, wastes are incinerated in the secondary chamber at around 1100 – 1200^{o}C. By the secondary chamber, hazardous organic materials such as dioxin and furans are destroyed on a large scale. The high concentration of the carbon monoxide indicates the incomplete combustion. After these gases and dusts are treated by the flue-gas scrubbing system in order to reduce their concentration below the standards stated in the Regulation, they are emitted into the atmosphere through the dust-filtration system. In addtion, ashes produced by the incineration of medical wastes are carried by special medical waste collection trucks to the final disposal sites described in the Regulation. They are dumped at the sanitary landfill specially designed for the hazardous wastes and then compacted and covered by earth.

Alternative 2 : Steam Sterilization (Reference Company: Ecodas, Product: T2000)

The U.S. Environmental Protection Agency conducted an experiment to evaluate the effectiveness of a commercial autoclave for treating simulated building decontamination residue (BDR). A single standard autoclave cycle did not effectively decontaminate BDR [4] so more complex systems are needed to increase the treatment effectiveness. By that manner Ecodas with T2000 is selected as a disposal alternative technology. HCW is loaded from the top of the machine into a chamber equipped at the bottom with heavy-duty shredder. If waste contains some large unbreakable objects, like metal parts, the shredder stops automatically, and the chamber is not opened until waste is sterilised by steam. Shredded waste falls by gravity into the lower chamber. The machine is steam heated to a temperature of 138^{o} C and pressure is increased by 3.8 bar.

The fully automatic and online controlled process has a cycle time of 60 minutes, Sterile fragments (8 $\log_{10}$) are discharged from the bottom of the machine and disposed of in a conventional landfill site. The original volume of waste is reduced by 80%.

There are three different models of Ecodas. The major difference between T1000 and T300 is the height and between T2000 and T1000 the diameter. Ecodas' systems are installed in several places in France and also operated in Cyprus, Hungary, Poland, Russia, Spain , Argentina, Brazil, Mexico, Japan, Egypt, Lebanon, Guyana and Morocco.

Alternative 3 : Microwave (with pre-shredding)

(Reference Company: AMB, İmir Kimya A.Ş, Product: Ecosteryl 250)

The Ecosteryl process consists of grinding and heating wastes at the temperature of 100^{o}C. The weight of waste is automatically checked, then it is packed into 750 liters containers and automatically handled and dumped into hopper. The loading hopper includes a disinfectant spray system and a suction device to create a partial vacuum when it is opened. City water is fed through a non-return valve thereby preventing any fluid returning to the drinking water system. The liquid disinfectant is automatically dosed and pumped into the system.

Before the heat treatment phase begins, wastes are shredded by a knife mill with a grille to transfer waste into granules ranging in size from 1.5 to 2.0 cm. After grinding , wastes are handled by screws and moisturised. The ground-up wastes are conveyed through an enclosed space and sunbjected to microwaves, which ensure in-depth heating and waste decontamination. To improve disinfection level, waste is kept at a 500 liter buffer hopper for 1 hour. Disinfected wastes are then picked up under the holding hopper by an Archimedes screw and carried into a 45 liter hopper. Using the large exchange surface of the screw wastes are cooled to about 60-70^{o} C. There are several Ecosteryl medical waste decontamination units are used in France.

Alternative 4 : Landfill Disposal

In Istanbul, in instances where disposal by incineration prove impossible, medical wastes are neatly deposited for storage at a specially allocated part of dangerous waste deposition areas, a specially allocated part of domestic waste deposition areas constructed according to the requirements of Regulation or a special disposal site prepared for the medical wastes only [4].

Any landfill of HCW must be undertaken at a site licensed to accept HCW because land disposal may result in groundwater pollution if the landfill site is adequately designed.

In order to summarize the current situation Figure 5.2 indicates the amount of health-care waste collected, incinerated and landfilled at the Kemerburgaz-Odayeri incineration plant.

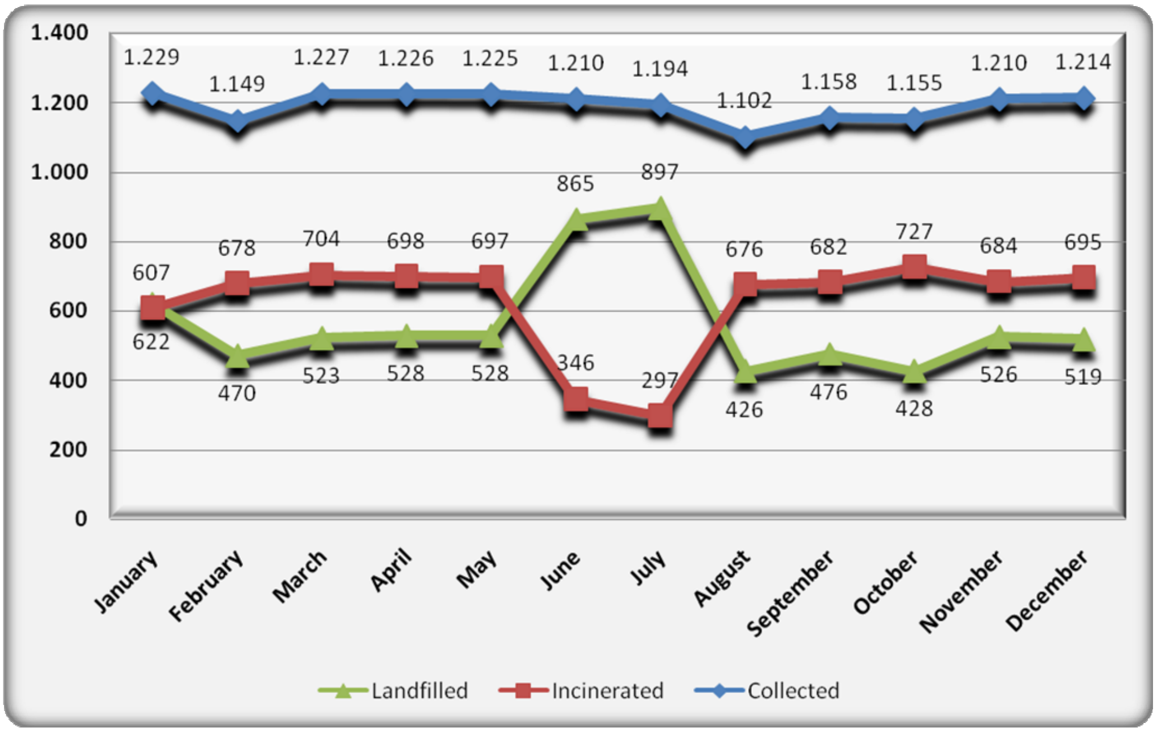

Figure 5.2 Amount of health-care collected, incinerated and lanfilled (ISTAC Co., 2008)

5.3 Application of the Hierarchical Fuzzy MCDM Method

In this study , the expert used the linguistic variables " very low (VL) ", " low (L) ", " moderate (M) ", " high (H) " and "very high (VH) " in order to assess the importance of criteria and ratings of qualitative sub-criteria. These linguistic variables can be explained via triangular fuzzy numbers as presented in Figure 5.2.

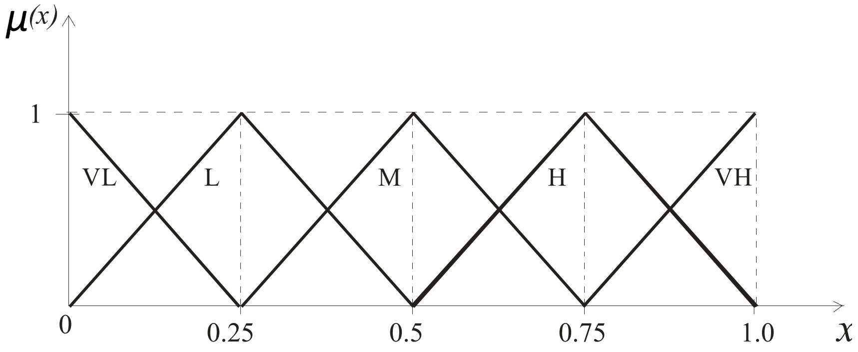

Figure 5.3 A linguistic term set where VL = (0, 0, 0.25), L = (0, 0.25, 0.5), M = (0.25, 0.5, 0.75), H = (0.5, 0.75, 1), VH = (0.75, 1, 1)

***Step* 1.** The expert used the linguistic variables “very low (VL)”, “low (L)”, “moderate (M)”, “high (H)” and “very high (VH)” to evaluate the importance of the criteria and sub-criteria, and also the ratings of alternatives with respect to various subjective criteria and sub-criteria. The evaluations are represented in Table 5.1, Table 5.2 and Table 5.3 respectively.

Table 5.1 Fuzzy importance weights of criteria

Criteria	Importance weight
Economic	H
Environmental	VH
Technical	M
Social	H

Table 5.2 Fuzzy importance weights of sub-criteria

Sub-criteria	Importance weight
Capital cost	H
Operating cost	VH
Possible air emissions	VH
Solid residuals and environmental impacts	VH
Water residuals and environmental impacts	VH
Air residuals and environmental impacts	VH
Noise	M
Odor	H
Release with health effects	VH
Reliability	H
Treatment effectiveness	VH
Volume reduction	M
Ease of use	H
Need for skilled operators	H
Occupational hazards occurance frequency	H
Occupational hazards occurance impact	H
Adaptability to Environmental Policy	VH
Public Acceptance Obstacles	H
Land Requirement	VH

Table 5.3 Data related to HCWM problem

Sub-Criteria	S_1	S_2	S_3	S_4
Capital cost	(6000000,6500000,7000000)	(2060000, 2060000, 2060000)	(3200000, 3200000, 3200000)	(335000, 430000, 535000)
Operating cost	(0.10, 0.20 , 0.30)	(0.07, 0.07, 0.07)	(0.12, 0.17, 0.22)	(0.03, 0.05, 0.06)
Possible air emissions	H	VL	VL	VL
Solid residuals and environmental impacts	L	M	M	VH
Water residuals and environmental impacts	VL	VL	VL	VH
Air residuals and environmental impacts	M	VL	VL	L
Noise	L	L	L	M
Odor	M	M	M	VH
Release with health effects	M	L	L	M
Reliability	H	H	L	H
Treatment effectiveness	VH	H	H	H
Volume reduction	(0.85, 0.90, 0.95)	(0.80, 0.80, 0.80)	(0.80, 0.80, 0.80)	(0.60, 0.65, 0.75)
Ease of use	H	H	H	M
Need for skilled operators	H	M	M	L
Occupational hazards occurance frequency	L	L	L	H
Occupational hazards occurance impact	H	H	H	M
Adaptability to environmental policy	L	M	M	L
Public acceptance obstacles	H	M	M	H

In the following steps, calculations related to alternative 1 (S_1) is given. Calculations for other alternatives (in order to determine the best disposal alternative for Istanbul) are performed in a similar manner.

Step 2 : By using Equations (4.1) and (4.2), the crisp and fuzzy data are normalized as given below.

Capital cost is a cost criterion, and $y_{11}^{*} = \max_i y_{i11} = 7000000$ and $y_{11}^{-} = \min_i y_{i11} = 335000$.

Then, we obtain

$$\tilde{y}_{111} = \left(y'_{a111}, y'_{b111}, y'_{c111}\right) = \left(\frac{7000000-7000000}{7000000-335000}, \frac{7000000-6500000}{7000000-335000}, \frac{7000000-6000000}{7000000-335000}\right)$$
$$= (0, 0.08, 0.15)$$

Operating cost is a cost criterion and $y_{12}^{*} = \max_i y_{i12} = 0.30$ and $y_{12}^{-} = \min_i y_{i12} = 0.03$.

Next, we find

$$\tilde{y}_{112} = \left(y'_{a112}, y'_{b112}, y'_{c112}\right) = \left(\frac{0.30-0.30}{0.30-0.03}, \frac{0.30-0.20}{0.30-0.03}, \frac{0.30-0.10}{0.30-0.03}\right) = (0, 0.37, 0.74)$$

Possible air emission is a cost criterion, and $y_{21}^{*} = \max_i y_{i21} = 1$ and $y_{21}^{-} = \min_i y_{i21} = 0$.

Next, we calculate

$$\tilde{y}_{121} = \left(y'_{a121}, y'_{b121}, y'_{c121}\right) = \left(\frac{1-1}{1-0}, \frac{1-0.75}{1-0}, \frac{1-0.50}{1-0}\right) = (0, 0.25, 0.50)$$

Solid residuals and environmental impact is a cost criterion, and $y_{22}^{*} = \max_i y_{i22} = 1$ and $y_{22}^{-} = \min_i y_{i22} = 0$. After that, we obtain

$$\tilde{y}_{122} = \left(y'_{a122}, y'_{b122}, y'_{c122}\right) = \left(\frac{1-0.50}{1-0}, \frac{1-0.25}{1-0}, \frac{1-0}{1-0}\right) = (0.50, 0.75, 1)$$

Water residuals and environmental impact is a cost criterion, and $y_{23}^{*} = \max_i y_{i23} = 1$ and $y_{23}^{-} = \min_i y_{i23} = 0$. Next, we find

$$\tilde{y}_{123} = (y'_{a123}, y'_{b123}, y'_{c123}) = \left(\frac{1-0.25}{1-0}, \frac{1-0}{1-0}, \frac{1-0}{1-0}\right) = (0.75, 1, 1)$$

Air residuals and environmental impact is a cost criterion, and $y_{24}^{*} = \max_i y_{i24} = 0.75$ and $y_{24}^{-} = \min_i y_{i24} = 0$. Following that, we obtain

$$\tilde{y}_{124} = (y'_{a124}, y'_{b124}, y'_{c124}) = \left(\frac{0.75-0.75}{0.75-0}, \frac{0.75-0.50}{0.75-0}, \frac{0.75-0.25}{0.75-0}\right) = (0, 0.33, 0.67)$$

Noise is a cost criterion, and $y_{25}^{*} = \max_i y_{i25} = 0.75$ and $y_{25}^{-} = \min_i y_{i25} = 0$. Then, we calculate

$$\tilde{y}_{125} = (y'_{a125}, y'_{b125}, y'_{c125}) = \left(\frac{0.75-0.50}{0.75-0}, \frac{0.75-0.25}{0.75-0}, \frac{0.75-0.75}{0.75-0}\right) = (0.33, 0.67, 1)$$

Odor is a cost criterion, and $y_{26}^{*} = \max_i y_{i26} = 1$ and $y_{26}^{-} = \min_i y_{i26} = 0.25$. Next, we obtain

$$\tilde{y}_{126} = (y'_{a126}, y'_{b126}, y'_{c126}) = \left(\frac{1-0.75}{1-0.25}, \frac{1-0.50}{1-0.25}, \frac{1-0.25}{1-0.25}\right) = (0.33, 0.67, 1)$$

Release with health effects is a cost criterion, and $y_{27}^{*} = \max_i y_{i27} = 0.75$ and $y_{27}^{-} = \min_i y_{i27} = 0$. After that, we obtain

$$\tilde{y}_{127} = (y'_{a127}, y'_{b127}, y'_{c127}) = \left(\frac{0.75-0.75}{0.75-0}, \frac{0.75-0.50}{0.75-0}, \frac{0.75-0.25}{0.75-0}\right) = (0, 0.33, 0.67)$$

Reliability is a benefit criterion, and $y_{31}^{*} = \max_i y_{i31} = 1$ and $y_{31}^{-} = \min_i y_{i31} = 0$. Following that, we find

$$\widetilde{y}_{131} = (y'_{a131}, y'_{b131}, y'_{c131}) = \left(\frac{0.50-0}{1-0}, \frac{0.75-0}{1-0}, \frac{1-0}{1-0} \right) = (0.50\,, 0.75, 1)$$

Treatment effectiveness is a benefit criterion, and $y^*_{32} = \max_i y_{i32} = 1$ and $y^-_{32} = \min_i y_{i32} = 0.50$. Then, we calculate

$$\widetilde{y}_{132} = (y'_{a132}, y'_{b132}, y'_{c132}) = \left(\frac{0.75-0.50}{1-0.50}, \frac{1-0.50}{1-0.50}, \frac{1-0.50}{1-0.50} \right) = (0.50\,, 1, 1)$$

Volume reduction is a benefit criterion, and $y^*_{33} = \max_i y_{i33} = 0.95$ and $y^-_{33} = \min_i y_{i33} = 0.60$. Next, we obtain

$$\widetilde{y}_{133} = (y'_{a133}, y'_{b133}, y'_{c133}) = \left(\frac{0.85-0.60}{0.95-0.60}, \frac{0.90-0.60}{0.95-0.60}, \frac{0.95-0.60}{0.95-0.60} \right) = (0.71\,, 0.86, 1\,)$$

Ease of use is a benefit criterion, and $y^*_{34} = \max_i y_{i34} = 1$ and $y^-_{34} = \min_i y_{i34} = 0.25$.

After that, we find

$$\widetilde{y}_{134} = (y'_{a134}, y'_{b134}, y'_{c134}) = \left(\frac{0.50-0.25}{1-0.25}, \frac{0.75-0.25}{1-0.25}, \frac{1-0.25}{1-0.25} \right) = (0.33\,, 0.67, 1)$$

Need for skilled operators is a cost criterion, and $y^*_{35} = \max_i y_{i35} = 1$ and $y^-_{35} = \min_i y_{i35} = 0$.

Then, we calculate

$$\widetilde{y}_{135} = (y'_{a135}, y'_{b135}, y'_{c135}) = \left(\frac{1-1}{1-0}, \frac{1-0.75}{1-0}, \frac{1-0.50}{1-0} \right) = (0\,, 0.25, 0.50\,)$$

Occupational hazards occurance frequency is a cost criterion, and $y^*_{36} = \max_i y_{i36} = 1$ and $y^-_{36} = \min_i y_{i36} = 0$. Next, we obtain

$$\widetilde{y}_{136} = (y'_{a136}, y'_{b136}, y'_{c136}) = \left(\frac{1-0.50}{1-0}, \frac{1-0.25}{1-0}, \frac{1-0}{1-0} \right) = (0.50\,, 0.75, 1\,)$$

Occupational hazards occurance impact is a cost criterion, and $y_{37}^{*} = \max_{i} y_{i37} = 1$ and $y_{37}^{-} = \min_{i} y_{i37} = 0.25$.

After that, we find

$$\widetilde{y}_{137} = (y'_{a137}, y'_{b137}, y'_{c137}) = \left(\frac{1-1}{1-0.25}, \frac{1-0.75}{1-0.25}, \frac{1-0.50}{1-0.25}\right) = (0, 0.33, 0.67)$$

Adaptability to environmental policy is a benefit criterion, and $y_{41}^{*} = \max_{i} y_{i41} = 0.75$ and $y_{41}^{-} = \min_{i} y_{i41} = 0$.

Following that, we calculate

$$\widetilde{y}_{141} = (y'_{a141}, y'_{b141}, y'_{c141}) = \left(\frac{0-0}{0.75-0}, \frac{0.25-0}{0.75-0}, \frac{0.50-0}{0.75-0}\right) = (0, 0.33, 0.67)$$

Public acceptance obstacles is a cost criterion, and $y_{42}^{*} = \max_{i} y_{i42} = 1$ and $y_{42}^{-} = \min_{i} y_{i42} = 0.25$.

Next, we obtain

$$\widetilde{y}_{142} = (y'_{a142}, y'_{b142}, y'_{c142}) = \left(\frac{1-1}{1-0.25}, \frac{1-0.75}{1-0.25}, \frac{1-0.50}{1-0.25}\right) = (0, 0.33, 0.67)$$

Land requirement is a cost criterion, and $y_{43}^{*} = \max_{i} y_{i43} = 1$ and $y_{43}^{-} = \min_{i} y_{i43} = 0.25$.

Then, we find

$$\widetilde{y}_{143} = (y'_{a143}, y'_{b143}, y'_{c143}) = \left(\frac{1-1}{1-0.25}, \frac{1-0.75}{1-0.25}, \frac{1-0.50}{1-0.25}\right) = (0, 0.33, 0.67)$$

Table 5.4 Normalized data related to HCWM problem

Sub-criteria	S_1	S_2	S_3	S_4
Capital cost	(0, 0.08, 0.15)	(0.74, 0.74, 0.74)	(0.57, 0.57, 0.57)	(0.97, 0.99, 1)
Operating cost	(0, 0.37, 0.74)	(0.85, 0.85, 0.85)	(0.30, 0.48, 0.67)	(0.89, 0.94, 1)
Possible air emissions	(0, 0.25, 0.50)	(0.75, 1, 1)	(0.75, 1, 1)	(0.75, 1, 1)
Solid residuals and environmental impacts	(0.50, 0.75, 1)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0,0, 0.25)
Water residuals and environmental impacts	(0.75, 1, 1)	(0.75, 1, 1)	(0.75, 1, 1)	(0,0,0.25)
Air residuals and environmental impacts	(0, 0.33, 0.67)	(0.67, 1,1)	(0.67, 1,1)	(0.33, 0.67, 1)
Noise	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0, 0.33, 0.67)
Odor	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0,0,0.33)
Release with health effects	(0, 0.33, 0.67)	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0, 0.33, 0.67)
Reliability	(0.50, 0.75, 1)	(0.50, 0.75, 1)	(0, 0.25, 0.75)	(0.50, 0.75, 1)
Treatment effectiveness	(0.50, 1, 1)	(0, 0.50, 1)	(0, 0.50, 1)	(0, 0.50, 1)
Volume reduction	(0.71, 0.86, 1)	(0.57, 0.57, 0.57)	(0.57, 0.57, 0.57)	(0, 0.14, 0.43)
Ease of use	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0, 0.33, 0.67)
Need for skilled operators	(0, 0.25, 0.50)	(0.25, 0.50, 0.75)	(0.25, 0.50, 0.75)	(0.50, 0.75, 1)
Occupational hazards occurance frequency	(0.50, 0.75, 1)	(0.50, 0.75, 1)	(0.50, 0.75, 1)	(0, 0.25, 0.50)
Occupational hazards occurance impact	(0, 0.33, 0.67)	(0, 0.33, 0.67)	(0, 0.33, 0.67)	(0.33, 0.67, 1)
Adaptability to environmental policy	(0, 0.33, 0.67)	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0, 0.33, 0.67)
Public acceptance obstacles	(0, 0.33, 0.67)	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0, 0.33, 0.67)
Land requirement	(0, 0.33, 0.67)	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0, 0, 0.33)

Step 3. Sub-criteria values are aggregated to criteria level using Equation (4.3), and are presented in Table 5.5.

$$\widetilde{x}_{11} = (x_{a11}, x_{b11}, x_{c11}) = \frac{((0.50,0.75,1)\otimes(0,0.08,0.15))\oplus((0.75,1,1)\otimes(0,0.37,0.74))}{(0.50,0.75,1)\oplus(0.75,1,1)}$$

$$=(0,0.24,0.45),$$

$$\widetilde{x}_{12} = (x_{a12}, x_{b12}, x_{c12}) =$$

$$\frac{((0.75,1,1)\otimes(0,0.25,0.50))\oplus((0.75,1,1)\otimes(0.50,0.75,1))\oplus((0.75,1,1)\otimes(0.75,1,1))}{(0.75,1,1)\oplus(0.75,1,1)\oplus(0.75,1,1)}$$

$$\oplus\frac{((0.75,1,1)\otimes(0,0.33,0.67,))\oplus((0.25,0.50,0.75)\otimes(0.33,0.67,1))}{(0.75,1,1)\oplus(0.25,0.50,0.75)}$$
$$\oplus\frac{((0.50,0.75,1)\otimes(0.33,0.67,1))\oplus((0.75,1,1)\otimes(0,0.33,0.67))}{(0.50,0.75,1)\oplus(0.75,1,1)}$$
$$=(0.26,0.56,0.83),$$

$$\widetilde{x}_{13} = (x_{a13}, x_{b13}, x_{c13}) =$$

$$\frac{((0.50,0.75,1)\otimes(0.50,0.75,1))\oplus((0.75,1,1)\otimes(0.50,1,1))\oplus((0.25,0.50,0.75)\otimes(0.71,0.86,1))}{(0.50,0.75,1)\oplus(0.75,1,1)\oplus(0.25,0.50,0.75)}$$

$$\oplus\frac{((0.50,0.75,1)\otimes(0.33,0.67,1))\oplus((0.50,0.75,1)\otimes(0,0.25,0.5))}{(0.50,0.75,1)\oplus(0.50,0.75,1)}$$
$$\oplus\frac{((0.50,0.75,1)\otimes(0.50,0.75,1))\oplus((0.50,0.75,1)\otimes(0,0.33,0,67))}{(0.50,0.75,1)\oplus(0.50,0.75,1)}$$
$$=(0.35,0.66,0.88),$$

$$\widetilde{x}_{14} = (x_{a14}, x_{b14}, x_{c14}) =$$

$$\frac{((0.75,1,1)\otimes(0,0.33,0.67))\oplus((0.50,0.75,1)\otimes(0,0.33,0.67))\oplus((0.75,1,1)\otimes(0,0.33,0.6))}{(0.75,1,1)\oplus(0.50,0.75,1)\oplus(0.75,1,1)}$$
$$=(0,0.33,0.67),$$

Table 5.5 Criteria level aggregated values

Criteria	S_1	S_2	S_3	S_4
Economic	(0, 0.24, 0.45)	(0.80, 0.80, 0.81)	(0.41, 0.52, 0.62)	(0.92, 0.96, 1)
Environmental	(0.26, 0.56, 0.83)	(0.51, 0.80, 0.96)	(0.51, 0.80, 0.96)	(0.18, 0.35, 0.59)
Technical	(0.35, 0.66, 0.88)	(0.27, 0.58, 0.87)	(0.20, 0.51, 0.79)	(0.19, 0.50, 0.81)
Social	(0, 0.33, 0.67)	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0, 0.21, 0.56)

Step 4. The normalized values of the aggregate performance ratings are calculated using Equation (4.4) and are represented in Table 5.6 , where 0 indicates the worst value and 1 indicates the best value, respectively.

$x^*_{c1} = \max_i x_{ci1} = 1$ and $x^-_{a1} = \min_i x_{ai1} = 0$. Then, we find

$$\widetilde{r}_{11} = (r_{a11}, r_{b11}, r_{c11}) = \left(\frac{0-0}{1-0.}, \frac{0.24-0}{1-0}, \frac{0.45-0}{1-0}\right) = (0, 0.24, 0.45)$$

$x^*_{c2} = \max_i x_{ci2} = 0.96$ and $x^-_{a2} = \min_i x_{ai2} = 0.18$. Then, we obtain

$$\widetilde{r}_{12} = (r_{a12}, r_{b12}, r_{c12}) = \left(\frac{0.26-0.18}{0.96-0.18}, \frac{0.56-0.18}{0.96-0.18}, \frac{0.83-0.18}{0.96-0.18}\right) = (0.11, 0.48\ , 0.83)$$

$x^*_{c3} = \max_i x_{ci3} = 0.88$ and $x^-_{a3} = \min_i x_{ai3} = 0.19$. Then, we find

$$\widetilde{r}_{13} = (r_{a13}, r_{b13}, r_{c13}) = \left(\frac{0.35-0.19}{0.88-0.19}, \frac{0.66-0.19}{0.88-0.19}, \frac{0.88-0.19}{0.88-0.19}\right) = (0.23, 0.69\ , 1)$$

$x^*_{c4} = \max_i x_{ci4} = 1$ and $x^-_{a4} = \min_i x_{ai4} = 0$. Then, we obtain

$$\widetilde{r}_{14} = (r_{a14}, r_{b14}, r_{c14}) = \left(\frac{0-0}{1-0}, \frac{0.33-0}{1-0}, \frac{0.67-0}{1-0}\right) = (0, 0.33, 0.67)$$

Table 5.6 Normalized values of aggregate performance ratings

Criteria	S_1	S_2	S_3	S_4
Economic	(0, 0.24, 0.45)	(0.80, 0.80, 0.81)	(0.41, 0.52, 0.62)	(0.92, 0.96, 1)
Environmental	(0.11, 0.48, 0.83)	(0.43, 0.79, 1)	(0.43, 0.79, 1)	(0, 0.21, 0.53)
Technical	(0.23, 0.69, 1)	(0.11, 0.57, 0.98)	(0.01, 0.46, 0.88)	(0, 0.45, 0.91)
Social	(0, 0.33, 0.67)	(0, 0.33, 0.67)	(0.33, 0.67, 1)	(0,0.21, 0.56)

Step 5. Define the ideal and the anti-ideal solutions as

$$A^* = ((1,1,1),(1,1,1),(1,1,1),(1,1,1)),$$

$$A^- = ((0,0,0),(0,0,0),(0,0,0),(0,0,0)),$$

Step 6. Calculate the weighted distances from ideal solution and anti-ideal solution (D_i^* and D_i^-) for each alternative using Equations (4.5) and (4.6), respectively, as follows:

$$\begin{aligned} D_1^* &= 1/2\{\max(0.50*|0-1|,0.75*|0.45-1|)+0.75*|0.24-1|\} \\ &+1/2\{\max(0.75*|0.11-1|,\ 1*|0.83-1|)+\ 1*|0.48-1|\} \\ &+1/2\{\max(0.25*|0.23-1|,0.75*|1-1|)+0.50*|0.69-1|\} \\ &+1/2\{\max(0.50*|0-1|,1*|0.67-1|)+0.75*|0.33-1|\} \\ &=1.83 \end{aligned}$$

$$D_2^* = 1.00$$

$$D_3^* = 1.24$$

$$D_4^* = 1.61$$

$$
\begin{aligned}
D_1^- &= 1/2\left\{\max(0.50*|0-0|, 0.75*|0.45-0|) + 0.75*|0.24-0|\right\}\\
&+ 1/2\left\{\max(0.75*|0.11-0|,\ 1*|0.83-0|) +\ 1*|0.48-0|\right\}\\
&+ 1/2\left\{\max(0.25*|0.23-0|, 0.75*|1-0|) + 0.50*|0.69-0|\right\}\\
&+ 1/2\left\{\max(0.50*|0-0|, 1*|0.67-0|) + 0.75*|0.33-0|\right\}\\
&= 1.98
\end{aligned}
$$

$$D_2^- = 2.86$$

$$D_3^- = 2.59$$

$$D_4^- = 2.04$$

Step 7. Calculate the proximity of the alternatives to the ideal solution using Equation (4.7) as follows:

$$P_1^* = \frac{1.98}{1.83 + 1.98} = 0.520$$

$$P_2^* = \frac{2.86}{1.00 + 2.86} = 0.741$$

$$P_3^* = \frac{2.59}{1.24 + 2.59} = 0.676$$

$$P_4^* = \frac{2.04}{1.61 + 2.04} = 0.559$$

***Step* 8.** The alternatives are ranked as $S_2 \succ S_3 \succ S_4 \succ S_1$. The results are illustrated in Table 5.7

Table 5.7 Ranking of the HCW disposal alternatives

S_i	P_i^*	Ranking
S_1	0.520	4
S_2	0.741	1
S_3	0.676	2
S_4	0.559	3

Table 5.7 concludes that the second alternative,"Steam Sterilization" (S_2), with the highest P_i^* value is the best HCW disposal alternative. "Microwave" as a HCW disposal technology ranks after S_2. Since "Landfill" is an economic alternative, it ranks as the third alternative. As expected, "Incineration" ranks as the last alternative because of high cost and adverse impacts on environment and health.

5.4 Application of the Hierarchical Fuzzy TOPSIS Method

***Step* 1.** The evaluations of expert are represented in Table 5.1 and Table 5.2, respectively.

Step 2. By using Equation (4.8) , we write $\tilde{I}_{MA}$.

$\tilde{I}_{MA}$ is given in Table 5.8

Table 5.8 $\tilde{I}_{MA}$ for the case study application

GOAL	
ECO	(0.5, 0.75, 1)
ENV	(0.75,1, 1)
TEC	(0.25, 0.5, 0.75)
SOC	(0.5, 0.75, 1)

Step 3.. By using Equation (4.9), we write $\tilde{I}_{SA}$. $\tilde{I}_{SA}$ for the problem is given in Table 5.9

Table 5.9 $\tilde{I}_{SA}$ for the case study application

	ECO	ENV	TEC	SOC
CC	(0.5, 0.75, 1)	0	0	0
OC	(0.75,1, 1)	0	0	0
PAE	0	(0.75,1, 1)	0	0
SREI	0	(0.75,1, 1)	0	0
WREI	0	(0.75,1, 1)	0	0
AREI	0	(0.75,1, 1)	0	0
N	0	(0.25, 0.5, 0.75)	0	0
O	0	(0.5, 0.75, 1)	0	0
RHE	0	(0.75,1, 1)	0	0
REL	0	0	(0.5, 0.75, 1)	0
TE	0	0	(0.75,1, 1)	0
VR	0	0	(0.25, 0.5, 0.75)	0
EU	0	0	(0.5, 0.75, 1)	0
NSO	0	0	(0.5, 0.75, 1)	0
OF	0	0	(0.5, 0.75, 1)	0
OI	0	0	(0.5, 0.75, 1)	0
AEP	0	0	0	(0.75,1, 1)
PAO	0	0	0	(0.5, 0.75, 1)
LR	0	0	0	(0.75,1, 1)

By using Equation (4.12), we find

$$\tilde{W}_{11} = (0.50, 0.75, 1) \otimes (0.50, 0.75, 1) = (0.25, 0.56, 1)$$

$$\tilde{W}_{12} = (0.50, 0.75, 1) \otimes (0.75, 1, 1) = (0.38, 0.75, 1)$$

$$\tilde{W}_{21} = (0.75, 1, 1) \otimes (0.75, 1, 1) = (0.56, 1, 1)$$

$$\tilde{W}_{22} = (0.75, 1, 1) \otimes (0.75, 1, 1) = (0.56, 1, 1)$$

$$\tilde{W}_{23} = (0.75, 1, 1) \otimes (0.75, 1, 1) = (0.56, 1, 1)$$

$\tilde{W}_{24} = (0.75, 1, 1) \otimes (0.75, 1, 1) = (0.56, 1, 1)$

$\tilde{W}_{25} = (0.75, 1, 1) \otimes (0.25, 0.50, 0.75) = (0.19, 0.50, 0.75)$

$\tilde{W}_{26} = (0.75, 1, 1) \otimes (0.50, 0.75, 1) = (0.38, 0.75, 1)$

$\tilde{W}_{25} = (0.75, 1, 1) \otimes (0.75, 1, 1) = (0.56, 1, 1)$

$\tilde{W}_{31} = (0.25, 0.50, 0.75) \otimes (0.50, 0.75, 1) = (0.13, 0.38, 0.75)$

$\tilde{W}_{32} = (0.25, 0.50, 0.75) \otimes (0.75, 1, 1) = (0.19, 0.50, 0.75)$

$\tilde{W}_{33} = (0.25, 0.50, 0.75) \otimes (0.25, 0.50, 0.75) = (0.06, 0.25, 0.56)$

$\tilde{W}_{34} = (0.25, 0.50, 0.75) \otimes (0.50, 0.75, 1) = (0,13, 0.38, 0.75)$

$\tilde{W}_{35} = (0.25, 0.50, 0.75) \otimes (0.50, 0.75, 1) = (0,13, 0.38, 0.75)$

$\tilde{W}_{36} = (0.25, 0.50, 0.75) \otimes (0.50, 0.75, 1) = (0,13, 0.38, 0.75)$

$\tilde{W}_{37} = (0.25, 0.50, 0.75) \otimes (0.50, 0.75, 1) = (0,13, 0.38, 0.75)$

$\tilde{W}_{41} = (0.50, 0.75, 1) \otimes (0.75, 1, 1) = (0.38, 0.75, 1)$

$\tilde{W}_{42} = (0.50, 0.75, 1) \otimes (0.50, 0.75, 1) = (0.25, 0.56, 1)$

$\tilde{W}_{43} = (0.50, 0.75, 1) \otimes (0.75, 1, 1) = (0.38, 0.75, 1)$

Step 4. Employing Equation (4.10) , we write the decision matrix. The decision matrix $\tilde{I}_A$ for the problem is given in Table 5.10

Table 5.10 The decision matrix $\tilde{I}_A$ for the case study application

	CC	OC	PAE	SREI	WREI
S_1	(6000000,6500000,7000000)	(0.10, 0.20 , 0.30)	(0.5, 0.75, 1)	(0, 0.25, 0.5)	(0, 0,0.25)
S_2	(2060000, 2060000, 2060000)	(0.07, 0.07, 0.07)	(0, 0, 0.25)	(0, 0,0.25)	(0, 0,0.25)
S_3	(3200000, 3200000, 3200000)	(0.12, 0.17, 0.22)	(0, 0, 0.25)	(0, 0,0.25)	(0, 0,0.25)
S_4	(335000, 430000, 535000)	(0.03, 0.05, 0.06)	(0, 0, 0.25)	(0.75,1, 1)	(0.75,1, 1)

Table 5.10 The decision matrix $\tilde{I}_A$ for the case study application (cont.)

	AREI	N	O	RHE	REL
S_1	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1)
S_2	(0, 0, 0.25)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.5, 0.75, 1)
S_3	(0, 0, 0.25)	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0, 0.25, 0.5)
S_4	(0, 0.25, 0.5)	(0.25, 0.5, 0.75)	(0.75,1, 1)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1)

Table 5.10 The decision matrix $\tilde{I}_A$ for the case study application (cont.)

	TE	VR	EU	NSO	OF
S_1	(0.75,1, 1)	(0.85, 0.90, 0.95)	(0.5, 0.75, 1)	(0.5, 0.75, 1)	(0, 0.25, 0.5)
S_2	(0.5, 0.75, 1)	(0.80, 0.80, 0.80)	(0.5, 0.75, 1)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)
S_3	(0.5, 0.75, 1)	(0.80, 0.80, 0.80)	(0.5, 0.75, 1)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)
S_4	(0.5, 0.75, 1)	(0.60, 0.65, 0.75)	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.5, 0.75, 1)

Table 5.10 The decision matrix $\tilde{I}_A$ for the case study application (cont.)

	OI	AEP	PAO	LR
S_1	(0.5, 0.75, 1)	(0, 0.25, 0.5)	(0.5, 0.75, 1)	(0.5, 0.75, 1)
S_2	(0.5, 0.75, 1)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)
S_3	(0.5, 0.75, 1)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)	(0.25, 0.5, 0.75)
S_4	(0.25, 0.5, 0.75)	(0, 0.25, 0.5)	(0.5, 0.75, 1)	(0.75,1, 1)

Step 5. Obtain the normalized decision matrix r_{ij} via Equations (4.1) and (4.2) .

r_{ij} is given in Table 5.11

Table 5.11 The normalized decision matrix r_{ij} for the case study application

	CC	OC	PAE	SREI	WREI
S_1	(0, 0.08, 0.15)	(0, 0.37, 0.74)	(0, 0.25, 0.5)	(0.5, 0.75, 1)	(0.75,1, 1)
S_2	(0.74, 0.74, 0.74)	(0.85, 0.85, 0.85)	(0.75,1, 1)	(0.25, 0.5, 0.75)	(0.75,1, 1)
S_3	(0.57, 0.57, 0.57)	(0.30, 0.48, 0.67)	(0.75,1, 1)	(0.25, 0.5, 0.75)	(0.75,1, 1)
S_4	(0.97, 0.99, 1)	(0.89, 0.94, 1)	(0.75,1, 1)	(0, 0, 0.25)	(0, 0, 0.25)

Table 5.11 The normalized decision matrix r_{ij} for the case study application (cont.)

	AREI	N	O	RHE	REL
S_1	(0, 0.33, 0.67)	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0, 0.33, 0.67)	(0.5, 0.75, 1)
S_2	(0.67, 1, 1)	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0.5, 0.75, 1)
S_3	(0.67, 1, 1)	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0, 0.25, 0.5)
S_4	(0.33, 0.67, 1)	(0, 0.33, 0.67)	(0,0, 0.33)	(0, 0.33, 0.67)	(0.5, 0.75, 1)

Table 5.11 The normalized decision matrix r_{ij} for the case study application (cont.)

	TE	VR	EU	NSO	OF
S_1	(0.50,1, 1)	(0.71, 0.86, 1)	(0.33, 0.67, 1)	(0, 0.25, 0.50)	(0.5, 0.75, 1)
S_2	(0, 0.50, 1)	(0.57, 0.57, 0.57)	(0.33, 0.67, 1)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1)
S_3	(0, 0.50, 1)	(0.57, 0.57, 0.57)	(0.33, 0.67, 1)	(0.25, 0.5, 0.75)	(0.5, 0.75, 1)
S_4	(0, 0.50, 1)	(0, 0.14, 0.43)	(0, 0.33, 0.67)	(0.5, 0.75, 1)	(0, 0.25, 0.50)

Table 5.11 The normalized decision matrix r_{ij} for the case study application (cont.)

	OI	AEP	PAO	LR
S_1	(0, 0.33, 0.67)	(0, 0.33, 0.67)	(0, 0.33, 0.67)	(0, 0.33, 0.67)
S_2	(0, 0.33, 0.67)	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0.33, 0.67, 1)
S_3	(0, 0.33, 0.67)	(0.33, 0.67, 1)	(0.33, 0.67, 1)	(0.33, 0.67, 1)
S_4	(0.33, 0.67, 1)	(0, 0.33, 0.67)	(0, 0.33, 0.67)	(0, 0, 0.33)

Step 6. Using Equation (4.13), the weighted normalized decision matrix v_{ij} is obtained as follows and given in Table 5.12

Here only calculations related to S_1 are shown. The remaining computations are performed in a similar manner.

$$\tilde{V}_{111} = (0, 0.08, 0.15) \otimes (0.25, 0.56, 1) = (0, 0.04, 0.15)$$

$$\tilde{V}_{112} = (0, 0.37, 0.74) \otimes (0.38, 0.75, 1) = (0, 0.28, 0.74)$$

$$\tilde{V}_{121} = (0, 0.25, 0.50) \otimes (0.56, 1, 1) = (0, 0.25, 0.50)$$

$$\tilde{V}_{122} = (0.50, 0.75, 1) \otimes (0.56, 1, 1) = (0.28, 0.75, 1)$$

$$\tilde{V}_{123} = (0.75, 1, 1) \otimes (0.56, 1, 1) = (0.42, 1, 1)$$

$$\tilde{V}_{124} = (0, 0.33, 0.67) \otimes (0.56, 1, 1) = (0, 0.33, 0.67)$$

$$\tilde{V}_{125} = (0.33, 0.67, 1) \otimes (0.19, 0.50, 0.75) = (0.06, 0.33, 0.75)$$

$$\tilde{V}_{126} = (0.33, 0.67, 1) \otimes (0.38, 0.75, 1) = (0.13, 0.50, 1)$$

$$\tilde{V}_{127} = (0, 0.33, 0.67) \otimes (0.56, 1, 1) = (0, 0.33, 0.67)$$

$$\tilde{V}_{131} = (0.50, 0.75, 1) \otimes (0.13, 0.38, 0.75) = (0.06, 0.28, 0.75)$$

$$\tilde{V}_{132} = (0.50, 1, 1) \otimes (0.19, 0.50, 0.75) = (0.09, 0.50, 0.75)$$

$$\tilde{V}_{133} = (0.71, 0.86, 1) \otimes (0.06, 0.25, 0.56) = (0.04, 0.21, 0.56)$$

$$\tilde{V}_{134} = (0.33, 0.67, 1) \otimes (0.13, 0.38, 0.75) = (0.04, 0.25, 0.75)$$

$$\tilde{V}_{135} = (0, 0.25, 0.50) \otimes (0.13, 0.38, 0.75) = (0, 0.09, 0.38)$$

$$\tilde{V}_{136} = (0.50, 0.75, 1) \otimes (0.13, 0.38, 0.75) = (0.06, 0.28, 0.75)$$

$$\tilde{V}_{137} = (0, 0.33, 0.67) \otimes (0.13, 0.38, 0.75) = (0, 0.13, 0.50)$$

$$\tilde{V}_{141} = (0, 0.33, 0.67) \otimes (0.38, 0.75, 1) = (0, 0.25, 0.67)$$

$$\tilde{V}_{142} = (0, 0.33, 0.67) \otimes (0.25, 0.56, 1) = (0, 0.19, 0.67)$$

$\tilde{V}_{143} = (0, 0.33, 0.67) \otimes (0.38, 0.75, 1) = (0, 0.25, 0.67)$

Table 5.12 The weighted normalized decision matrix v_{ij} for the case study application

	CC	OC	PAE	SREI	WREI
S_1	(0, 0.04, 0.15)	(0, 0.28, 0.74)	(0, 0.25, 0.50)	(0.28, 0.75, 1)	(0.42, 1, 1)
S_2	(0.19, 0.42, 0.74)	(0,32, 0.64, 0.85)	(0.42, 1, 1)	(0.14, 0.50, 0.75)	(0.42, 1, 1)
S_3	(0.14, 0.32, 0.57)	(0.11, 0.36, 0.67)	(0.42, 1, 1)	(0.14, 0.50, 0.75)	(0.42, 1, 1)
S_4	(0.24, 0.55, 1)	(0.33, 0.71, 1)	(0.42, 1, 1)	(0, 0, 0.25)	(0, 0, 0.25)

Table 5.12 The weighted normalized decision matrix v_{ij} for the case study application (cont.)

	AREI	N	O	RHE	REL
S_1	(0, 0.33, 0.67)	(0.06, 0.33, 0.75)	(0.13, 0.50, 1)	(0, 0.33, 0.67)	(0.06, 0.28, 0.75)
S_2	(0.38, 1, 1)	(0.06, 0.33, 0.75)	(0.13, 0.50, 1)	(0.19, 0.67, 1)	(0.06, 0.28, 0.75)
S_3	(0.38, 1, 1)	(0.06, 0.33, 0.75)	(0.13, 0.50, 1)	(0.19, 0.67, 1)	(0, 0.09, 0.38)
S_4	(0.19, 0.67, 1)	(0, 0.17, 0.50)	(0, 0, 0.33)	(0, 0.33, 0.67)	(0.06, 0.28, 0.75)

Table 5.12 The weighted normalized decision matrix v_{ij} for the case study application (cont.)

	TE	VR	EU	NSO	OF
S_1	(0.09, 0.50, 0.75)	(0.04, 0.21, 0.56)	(0.04, 0.25, 0.75)	(0, 0.09, 0.38)	(0.06, 0.28, 0.75)
S_2	(0, 0.25, 0.75)	(0.04, 0.14, 0.32)	(0.04, 0.25, 0.75)	(0, 0.09, 0.38)	(0.06, 0.28, 0.75)
S_3	(0, 0.25, 0.75)	(0.04, 0.14, 0.32)	(0.04, 0.25, 0.75)	(0, 0.09, 0.38)	(0.06, 0.28, 0.75)
S_4	(0, 0.25, 0.75)	(0, 0.04, 0.24)	(0, 0.13, 0.50)	(0.06, 0.28, 0.75)	(0, 0.09, 0.38)

Table 5.12 The weighted normalized decision matrix v_{ij} for the case study application (cont.)

	OI	AEP	PAO	LR
S_1	(0, 0.13, 0.50)	(0, 0.25, 0.67)	(0, 0.19, 0.67)	(0, 0.25, 0.67)
S_2	(0, 0.13, 0.50)	(0.13, 0.50, 1)	(0.08, 0.38, 1)	(0.13, 0.50, 1)
S_3	(0, 0.13, 0.50)	(0.13, 0.50, 1)	(0.08, 0.38, 1)	(0.13, 0.50, 1)
S_4	(0.04, 0.25, 0.75)	(0, 0.25, 0.67)	(0, 0.19, 0.67)	(0, 0, 0.33)

Step 7. We will only show the calculations related to CC, computations of the remaining sub-attributes are performed in a similar way. Table 5.13 shows the generalized mean for fuzzy number v_{ij} of all related sub-attributes.

By using Equation (4.16) , we compute

$$M(v_{111}) = \frac{-0^{2} + 0.15^{2} - (0)(0.04) + (0.04)(0.15)}{3(-0 + 0.15)} = 0.064$$

$$M(v_{211}) = \frac{-0.19^{2} + 0.74^{2} - (0.19)(0.42) + (0.42)(0.74)}{3(-0.19 + 0.74)} = 0.448$$

$$M(v_{311}) = \frac{-0.14^{2} + 0.57^{2} - (0.14)(0.32) + (0.32)(0.57)}{3(-0.14 + 0.57)} = 0.344$$

$$M(v_{411}) = \frac{-0.24^{2} + 1^{2} - (0.24)(0.55) + (0.55)(1)}{3(-0.24 + 1)} = 0.599$$

Since $\max_j v_{11} = 0.599$ and $\min_j v_{11} = 0.064$. Then, we obtain $v_1^{*} = (0.24, 0.55, 1)$ and $v_1^{-} = (0, 0.04, 0.15)$

Table 5.13 $M(v_{ij})$ values for the case study application

	CC	OC	PAE	SREI	WREI	AREI	N	O	RHE	REL
S_1	0.064	0.340	0.250	0.775	0.807	0.333	0.382	0.542	0.333	0.365
S_2	0.448	0.603	0.807	0.502	0.807	0.792	0.382	0.542	0.618	0.365
S_3	0.344	0.380	0.807	0.502	0.807	0.792	0.382	0.542	0.618	0.156
S_4	0.599	0.681	0.807	0.083	0.083	0.618	0.222	0.111	0.333	0.365

Table 5.13 $M(v_{ij})$ values for the case study application (cont.)

	TE	VR	EU	NSO	OF	OI	AEP	PAO	LR
S_1	0.448	0.274	0.306	0.156	0.365	0.208	0.306	0.285	0.306
S_2	0.333	0.167	0.542	0.156	0.365	0.208	0.542	0.486	0.542
S_3	0.333	0.167	0.542	0.156	0.365	0.208	0.542	0.486	0.542
S_4	0.333	0.092	0.111	0.365	0.156	0.347	0.306	0.285	0.111

Following that, by using Equations (4.14) and (4.15) respectively, we define the positive ideal solution A^* and negative ideal solution A^- as:

$$A^* = \begin{bmatrix} (0.24, 0.55, 1), (0.33, 0.71, 1), (0.42, 1, 1), (0.28, 0.75, 1), (0.42, 1, 1), \\ (0.38, 1, 1), (0.06, 0.33, 0.75), (0.13, 0.50, 1), (0.19, 0.67, 1), (0.06, 0.28, 0.75) \\ (0.09, 0.50, 0.75), (0.04, 0.21, 0.56), (0.04, 0.25, 0.75), (0.06, 0.28, 0.75), \\ (0.06, 0.28, 0.75), (0.04, 0.25, 0.75), (0.13, 0.50, 1), (0.08, 0.38, 1), (0.13, 0.50, 1) \end{bmatrix}$$

$$A^- = \begin{bmatrix} (0, 0.04, 0.15), (0, 0.28, 0.74), (0, 0.25, 0.5), (0, 0, 0.25), (0, 0, 0.25), \\ (0, 0.33, 0.67), (0, 0.17, 0.50), (0, 0, 0.33), (0, 0.33, 0.67), (0, 0.09, 0.38) \\ (0, 0.25, 0.75), (0, 0.04, 0.24), (0, 0.13, 0.50), (0, 0.09, 0.38), \\ (0, 0.09, 0.38), (0, 0.13, 0.50), (0, 0.25, 0.67), (0, 0.19, 0.67), (0, 0, 0.33) \end{bmatrix}$$

Step 8. We only show calculations of difference measures of sub-attributes related to CC; the remaining computations are performed similarly. Table 5.14 shows the difference measure D_{ij}^* , and Table 5.15 provides difference measure D_{ij}^- of all related sub-attributes.

Using Equation (4.21), we find

$$D_{11}^* = 1 - \frac{(0.15 - 0.24)}{(0.55 + 0.15 - 0.24 - 0.04)} = 1.220$$

Using Equation (4.22) , we obtain

$$D_{11}^- = 1 - \frac{(0.15 - 0)}{(0.04 + 0.15 - 0 - 0.04)} = 0$$

Table 5.14 D_{ij}^{*} values for the case study application

	CC	OC	PAE	SREI	WREI	AREI	N	O	RHE	REL
S_1	1.220	0.514	0.906	0	0	0.696	0	0	0.410	0
S_2	0.216	0.118	0	0.348	0	0	0	0	0	0.375
S_3	0.416	0.510	0	0.348	0	0	0	0	0	0
S_4	0	0	0	1.043	1.208	0.348	0.276	0.706	0.410	0

Table 5.14 D_{ij}^{*} values for the case study application (cont.)

	TE	VR	EU	NSO	OF	OI	AEP	PAO	LR
S_1	0	0	0	0.375	0	0.214	0.316	0.243	0.316
S_2	0.276	0.205	0	0.375	0	0.214	0	0	0
S_3	0.276	0.205	0	0.375	0	0.214	0	0	0
S_4	0.276	0.476	0.214	0	0.375	0	0.316	0.243	0.706

Table 5.15 D_{ij}^{-} values for the case study application

	CC	OC	PAE	SREI	WREI	AREI	N	O	RHE	REL
S_1	0	0	0	1.043	1.208	0	0.276	0.706	0	0.375
S_2	1.104	0.462	0.906	0.821	1.208	0.696	0.276	0.706	0.410	0.375
S_3	0.974	0.117	0.906	0.821	1.208	0.696	0.276	0.706	0.410	0
S_4	1.220	0.514	0.906	0	0	0.410	0	0	0	0.375

Table 5.15 D_{ij}^{-} values for the case study application (cont.)

	TE	VR	EU	NSO	OF	OI	AEP	PAO	LR
S_1	0.276	0.476	0.214	0	0.375	0	0	0	0.429
S_2	0	0.343	0.214	0	0.375	0	0.316	0.243	0.706
S_3	0	0.343	0.214	0	0.375	0	0.316	0.243	0.706
S_4	0	0	0	0.375	0	0.214	0	0	0

Following that, using Equations (4.17) and (4.18) respectively, we calculate the seperation measures S_i^* and S_i^- as follows:

$$S_1^* = (1.220 + 0{,}514 + 0.906 + 0 + 0 + 0.696 + 0 + 0 + 0.410 + 0 + 0 + 0 + 0 + 0.375 + 0 + 0.214 + 0.316 + 0.243 + 0.316\,) \;= 5.210$$

$$S_2^* = \; 2.127$$

$$S_3^* = \; 2.345$$

$$S_4^* = \; 6.597$$

$$S_1^- = (0 + 0 + 0 + 1.043 + 1.208 + 0 + 0.276 + 0.706 + 0 + 0.375 + 0.276 + 0.476 + 0.214 + 0 + 0.375 + 0 + 0 + 0 + 0.429) \;= 5.378$$

$$S_2^- = 9.159$$

$$S_3^- = 8.309$$

$$S_4^- = 4.015$$

Step 9. Employing Equation (4.23), we compute the relative closeness of alternatives to ideals as:

$$C_1 = 5.378 / (5.210 + 5.378\,) = 0.508$$

$$C_2 = 9.159 / (2.127 + 9.159\,) = 0.812$$

$$C_3 = 8.309 / (2.345 + 8.309\,) = 0.780$$

$$C_4 = 4.015 / (6.597 + 4.015\,) = 0.378$$

Step 10. Ranking of the alternatives are illustrated in Table 5.16.

Table 5.16 Ranking of HCW Disposal Alternatives

S_i	C_i	Ranking
S_1	0.508	3
S_2	0.812	1
S_3	0.780	2
S_4	0.378	4

Table 5.16 concludes that “Steam Sterilization”, S_2 , is the best disposal technology for Istanbul and “Microwave”, S_3, ranks as the second alternative disposal technology, which are the same results obtained using the hierarchical fuzzy MCDM method. As expected “Incineration”, S_1 , ranks as the third alternative and “Landfill”, S_4 ranks as the last alternative due to their adverse environmental and health impacts.

6. CONCLUSION

HCW management is a high priority environmental concern in developing countries of the world because poor management of HCW causes environmental pollution and health problems in terms of proliferation of diseases by viruses and micro-organism, as well as contamination of ground water by untreated medical waste in landfills. Thus, in Istanbul, the problems associated with the treatment and disposal of health-care waste, which is continuoulsy increasing day by day, should be solved in a manner that minimizes the risks to the public health and well-being of human and damage to the environment [49]. With the rising awareness of the environmental implications of waste disposal, the management and disposal of HCW are gaining more and more attention. Furthermore, selection of HCW disposal technology is very much dictated by the prevailing legislation as well as public perception.

In this study, firstly, the hierarchical fuzzy MCDM algorithm proposed by Karsak and Ahiska [6] has been employed, and secondly, the hierarchical fuzzy TOPSIS method [7] has been applied in order to evaluate health-care waste disposal alternatives for Istanbul. Both methods provide a structured hierarchical model for health-care waste disposal alternative evaluation and can handle crisp and fuzzy data expressed in linguistic terms or triangular fuzzy numbers. They also possess advantages in that they are easy to compute and to understand, and are based on a reliable distance-based methods. These abilities will facilitate the use of selected algorithms in HCW disposal alternative selection process.

In classical MCDM methods, the ratings and the weights of the criteria are assumed to be known precisely. In general, crisp data are inadequate to model real-life situations. Besides having the capability of considering numerous attributes that are structured in multi-level hierarchy, the applied decision frameworks enable the decision-makers to use linguistic terms. These approaches are able to incorporate both crisp data and fuzzy data represented as linguistic variables or fuzzy numbers into the analysis. The decision-makers' importance assessment of evaluation criteria is incorporated into the analysis by linguistic variables. In conclusion, the decision frameworks presented in this study appear to be robust decision tools due to their effectiveness in quantifying the imprecision inherent in decision-maker's assessments [50].

After the evaluation of four HCW disposal alternatives for Istanbul using two fuzzy multiple criteria decision making methods, the rankings are obtained. The ranking obtained due to the hierarchical fuzzy MCDM algorithm is $S_2 > S_3 > S_4 > S_1$, whereas the ranking found using the hierarchical fuzzy TOPSIS is $S_2 > S_3 > S_1 > S_4$. The results obtained from two MCDM methods appear to be very close. Applying both methods, we obtain that "Steam sterilization" ranks as the best alternative and it is followed by "Microwave". "Steam sterilization" is the best alternative disposal method for Istanbul since it minimizes the impact on the environment and demonstrates a commitment to public health. Non- incineration technologies take the first and second rankings as the best alternative disposal technology since they appear to emit fewer pollutants and generate non-hazardous residues. Furthermore, "Landfill" is an economic alternative compared with other alternatives; however, because of its several drawbacks for the environment and public health, it should only be used in a limited extent. It is also concluded that like landfilling, "Incineration" ranks after non-incineration alternative technologies due to its high costs, adverse environmental and health impacts. Thus, we can conclude that the Turkish Government and Municipalities should support the development of non-incineration health care waste treatment technologies in order to protect water and air quality and also public health instead of choosing to reconstruct and equip existing outdated incineration plants or supporting the construction of new ones.

REFERENCES

[1] Diaz, L.F., Savage, G.M., Eggerth,L.L, "Alternatives for the Treatment and Disposal of Healthcare Wastes in Developing Countries ", *Waste Management*, 25, 626-637, (2005).

[2] WHO, *Safe Management of Wastes from Health-care Activities*, World Health Organization, Geneva, (1999).

[3] Kılıç,M., "*Optimization of the Health-Care Waste Handling and Final Disposal of the Infectious Wastes of the Hospital-Medical Centers in the Anatolian Side of Istanbul*", M.S. Thesis, Boğaziçi University, İstanbul, (2004).

[4] Zeren,B. A., "*Health-Care Waste Management of the Hospitals In the European Side of Istanbul*", M.S. Thesis, Boğaziçi University, İstanbul, (2004).

[5] Zeren, B.A., Kocasoy, G., "Determination of the Best Appropriate Management Methods for the Health-Care Wastes in Istanbul", *Waste Management and Research*, 28, 1227-1235, (2008).

[6] Karsak, E.E., Ahiska, S.S., "Fuzzy Multi-Criteria Decision Making Approach for Transport Projects Evaluation in Istanbul", *Lecture Notes in Computer Science*, 3483, 301-311, (2005).

[7] Kahraman, C., Ateş, N., Çevik, S., Gülbay M., Erdoğan, S., "Hierarchical Fuzzy TOPSIS Model for Selection Among Logistics Information Technologies", *Journal of Enterprise Information Management*, 20 (2), 143-168, (2007).

[8] EPA, "US Environmental Protection Agency Office of Medical Waste Section" www.epa.gov/osw/nonhaz/industrial/medical/index.htm, (2009).

[9] EPA, *Guidance For Evaluating Medical Waste Treatment Technologies*, Environmental Protection Agency, Washington, (1993).

[10] Fisher, T., "*An Integrated Methodology For Assessing Medical Waste Treatment Technologies*," PhD. Thesis, Southern Methodist University, (1997).

[11] Ministry of Environment and Foresty of Turkey, *Turkish Medical Waste Control Regulation*, Offical Gazette No. 25883, Ankara, (1993).

[12] Bisson, C.L., McRae, G., Shaner, H.G. *An Ounce of Prevention: Waste Reduction Strategies for Health Care Facilities*, American Society for Healthcare Environmental Services, Chicago, (1993).

[13] Brunner, C.R., Dee, P.E., *Medical Waste Disposal*, Incinerator Consultants Incorporated, Virginia, (1996).

[14] Lee, B.K., Ellenbecker, M.J., Ersaso, R.M., "Alternatives for treatment and disposal cost reduction of regulated Medical Wastes", *Waste Management,* 24, 143-151, (2004).

[15] Bayrak, S., Karadurmuş, E., "Measuring of Bioemissions from Steam Sterilization of Medical Wastes and Selection of Bioindicator" , *Üniversite Öğrencileri 2.Çevre Sorunları Kongresi Bildiri Kitabı*, 185-197, Fatih Üniversitesi, Istanbul, (2007).

[16] Shang, H.Y., Jia, H.Q., "Present Situation and Disposal of Medical Wastes in China", *Journal of Environmental Pollution and Control,* 24, 1001-3685, (2002).

[17] Soliman, S.M., Ahmed, A.I., "Overview of Biomedical Waste Management in Selected Governorates in Egypt: A pilot study", *Waste Management*, 27, 1920- 1923, (2007).

[18] Jangsawang,W., Fungtammasan, B., Kerdsuwan, S. , "Effects of Operating Parameters on the combustion of medical wastes in a controlled air incinerator", *Energy Conversion and Management*, 46, 3137-3149, (2005).

[19] Öztürk, M., İskenderoğlu, A.U., *Istanbul'da Tıbbi Atık Yönetimi*, İSTAÇ A.Ş., İstanbul, (2002).

[20] Lee, C.C., Huffman, G.L., “Medical Waste Management / Incineration” , *Journal of Hazardous Materials*, 35, 3495-3501, (1996).

[21] Ficarella, A., Laforgia, D., “Numerical Simulation of Flow-field and Dioxins Chemistry for Incineration Plants and Experimental Investigation” , *Waste Management*, 20, (24-49), (2000).

[22] Karademir, A., “Health Risk Assessment of PCDD/F Emissions from a Hazardous and Medical Waste Incinerator in Turkey”, *Environmental International,* 30, 1027 - 1038, (2004).

[23] Alvim-Ferraz, C.M., Afanso, S.A.V., “Incineration of Different Types of Medical Wastes: Emission Factor for Gaseous Emissions ”, *Journal of Atmospheric Environment,* 37, 5415-5422, (2003)

[24] Zhao, L., Zhang, F., Wang K., Zhu, J., “Chemical Properties of Heavy Metals in Typical Hospital Waste Incinerator Ashes in China”, *Waste Management*, 29, 1114-1121, (2008).

[25] EPA, http://www.epa.gov/osw/nonhaz/industrial/medical/publications.htm, (2009).

[26] Medical Wastes , OTA-O-459. Government Printing Office Washington, DC, September, (1990).

[27] U.S. Congress, Office of Technology Assessment, F*inding the Rx for Managing Medical Wastes*, Washington, (1990).

[28] Gupta, S., Boojh, R., Mishra A., Chandra, H., “Rules and Management of biomedical waste at Vivekananda Polyclinic : A Case Study” , *Waste Management*, (2008).

[29] Batchelor, C.J., Mashapa., P., “ A Survey of Methods for the Safe Destruction and Disposal of Health-care Waste ”, *Proceedings of the Biennal Conference and Exhibition*, Somerset West, 1, 405-413, (2000).

[30] Yang, C., Peijun, L., Lupi C., Yangzhao, S., Diandou, X., Qian, F., Shasha, F., “Sustainable Management Measures for Healthcare Waste in China”, *Waste Management*, 29, 1994-2004, (2009).

[31] Chung, S.S., Poon, C.S., “Evaluating Waste Management Alternatives by the Multiple Criteria Approach ”, *Resources, Conservation and Recycling*, 17, 189-210, (1996).

[32] Hokkanen, J., Salminen, P., “Choosing A Solid Waste Management System Using A Multicriteria Decision Analysis”, *European Journal of Operational Research*, 98, 19-36, (1997).

[33] Wang, T.C., Lee, H.D., “Developing A Fuzzy TOPSIS Approach Based on Subjective Weights and Objective Weights”, *Expert Systems with Applications*, 36, 8980-8985, (2009).

[34] Karsak, E.E., “Distance-Based Fuzzy MCDM Approach for Evaluating Flexible Manufacturing System Alternatives, *International Journal of Production and Research,* 40, 3167- 3181, (2002).

[35] Hwang, C.L., Yoon, K., *Multiple Attribute Decision Making: Methods and Applications*, Springer, Heidelberg, (1981).

[36] Dağdeviren, M., Yavuz, S., Kılınç, N., “Weapon Selection Using the AHP and TOPSIS Methods Under Fuzzy Environment”, *Expert Systems with Applications*, 36, 8143-8151, (2009).

[37] Chen, S.J., Hwang, C.L., “*Fuzzy Multiple Attribute Decision Making Methods and Applications* ”, Springer, Berlin, (1992).

[38] Liang, G.S., “ Fuzzy MCDM Based on Ideal and Anti-ideal Concepts”, *European Journal of Operational Research*, 112, 682- 691, (1999).

[39] Chen, C.T., “Extensions of The TOPSIS for Group Decision Making Under Fuzzy Environment”, *Fuzzy Sets and Systems*, 114, 1-9, (2000).

[40] Tsaur, S.H., Chang, T.Y., Yen, C.H., “The Evaluation of Airline Service Quality by Fuzzy MCDM, *Tourism Management*, 23, 107-115, (2002).

[41] Chu, T.C., Lin, Y.C., “ Facility Location Selection Using Fuzzy TOPSIS Under Group Decisions ”, *International Journal of Uncertainty, Fuzziness and Knowledge – Based Systems*, 10, 687-701, (2002).

[42] Chu, T.C., Lin, Y.C., "A Fuzzy TOPSIS Method for Robot Selection", *International Journal of Advanced Manufacturing Technology*, 21, 284-290, (2003).

[43] Zhang and Lu (2003) Zhang, G., Lu, J., " An Integrated Group Decision-Making Method Dealing with Fuzzy Preferences for Alternatives and Individual Judgements for Selection Criteria", G*roup Decision and Negotiation*, 12, 501-515, (2003).

[44] Wang, J.W., Cheng, C.H., Cheng, H.K., "Fuzzy Hierarchical TOPSIS for Supplier Selection", *Applied Soft Computing ,* 9, 377-386, (2009).

[45] Kahraman, C., *Fuzzy Applications in Industrial Engineering*, Springer, Heidelberg, (2006).

[46] Health care Without Harm, *Non-Incineration Medical Waste Treatment Technologies in Europe,* Prague, (2004).

[47] Birpınar, M.E., Bilgili, M.S., Erdoğan, T., Medical waste management in Turkey: A case study of Istanbul, *Waste Management,* (2008).

[48] Lemieux,P., Sieber, R., Osborne, A., Woodard, A., "Destruction of Spores on Building Decontamination Residue in a Commercial Autoclave", *Applied and Environmental Microbiology*, 72, 7687-7693, (2006).

[49] Zeren, B.A., Kocasoy, G., "Treatment and Disposal for Health-Care Wastes in Developing Countries- A Case Study in Istanbul, Turkey", *Waste Management and Research*, 25, 83-89, (2007).

[50] Karsak, E.E., Dursun, M., "Evaluating Solid Waste Management Scenarios Using a Fuzzy Multi-Criteria Decision Making Approach", *Proceedings of the 2007 International Conference on Industry, Engineering and Management Systems*, Cocoa Beach, USA, 131-140, (2007).

BIOGRAPHICAL SKETCH

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