A FUZZY MULTIPLE CRITERIA ANALYSIS FOR THE DETERMINATION OF THE BEST WEEE MANAGEMENT SCENARIO FOR TURKEY

(TÜRKİYE İÇİN EN İYİ EEEA YÖNETİM SENARYOSUNUN BELİRLENMESİNE YÖNELİK BULANIK ÇOK ÖLÇÜTLÜ BİR ANALİZ)

by

Can ÜÇÜNCÜOĞLU, B.S.

Thesis

Submitted in Partial Fulfillment

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Supervisor : Prof. Dr. H. Ziya ULUKAN

Committee Members : Prof. Dr. E. Ertuğrul KARSAK

Prof. Dr. Cengiz KAHRAMAN

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Can ÜÇÜNCÜOĞLU
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LIST OF SYMBOLS

AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
FAHP	Fuzzy Analytic Hierarchy Process
FANP	Fuzzy Analytic Network Process
DEA	Data Envelopment Analysis
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
ELECTRE	Elimination and Choice Translating Reality
PROMETHEE	Preference Ranking Organisation Method for Enrichment Evaluations
MAUT	Multiple Attribute Utility Theory
MCDM	Multiple Criteria Decision Making
MODM	Multiple Objective Decision Making
MADM	Multiple Attribute Decision Making
MOMP	Multiple Objective Mathematical Programming
WEEE	Waste Electrical Electronic Equipment
EEE	Electrical Electronic Equipment
EEE	Elektrik Elektronik Ekipman
EEE	Equipements Electriques et Electroniques
EEEA	Eletrik Elektronik Ekipman Atığı
DEEE	Déchets des Equipements Electriques et Electroniques
RoHS	Restriction of Hazardous Substances Directive
DM	Decision Maker
EC	European Community
EU	European Union
DMT	Decision Making Team
US EPA	United States Environmental Protection Agency
IT	Information Technology

PDA	Portable Digital Assistant
CRT	Cathode ray-tube
US GAO	United States General Accounting Office
LCD	Liquid Crystal Display
EOL	End of Life
LCA	Life Cycle Assessment
PCB	Printed Circuit Board
SMD	Surface Mont Devices
CFC	Chlorofluorocarbon
HCFC	Hydrochlorofluorocarbon
PBDE	Polybrominated diphenyl ethers
TFN	Triangular Fuzzy Number
TrFN	Trapezoidal Fuzzy Number
STFN	Standardized Trapezoidal Fuzzy Number
CF	Contribution Factor
PC	Personal Computer

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ABSTRACT

The production of electrical and electronic equipment (EEE) is one of the fastest growing global manufacturing activities. This development has resulted in an increase of waste electrical and electronic equipment (WEEE). Rapid economic growth, coupled with urbanization and growing demand for consumer goods, has increased both the consumption of EEE and the production of WEEE, which can be a source of hazardous wastes that pose a risk to the environment and to sustainable economic growth.

To address potential environmental problems that could stem from improper management of WEEE, many countries and organizations have drafted national legislation to improve the reuse, recycling and other forms of material recovery from WEEE to reduce the amount and types of materials disposed in landfills. The recovery of WEEE is also important in Turkey, which is on the edge of European Community.

WEEE constitutes one of the most complicated solid waste streams in terms of its composition, and, as a result, it is difficult to be effectively managed. The selection of a technologically reliable, environmentally friendly, economically affordable and socially acceptable management scenario for WEEE is a significant question. The use of multiple attribute decision making (MADM) methods in WEEE management has the advantage of rendering subjective and implicit decision making more objective and transparent. The aim of this study is to provide an analytical tool to select the best WEEE management scenario.

Analytic Hierarchical Process (AHP) is one of the analytical tools, which can be used to handle a MADM problem. However, a shortfall of AHP is that it lacks in considering interdependencies, if any, among the selection criteria. Analytic Network Process (ANP) is a similar technique, but can capture the interdependencies between the criteria under consideration, hence allowing for a more systematic analysis. It can allow

inclusion of criteria, both tangible and intangible (difficult to quantify), which has some bearing on making the best decision. Further, many of these criteria have some level of interdependency among them, thus making ANP modeling better fit for the problem under study.

However, the ANP based decision model seems to be ineffective in dealing with the inherent fuzziness or uncertainty in judgment during the pairwise comparison process. Although the use of the discrete scale of 1–9 to represent the verbal judgment in pairwise comparisons has the advantage of simplicity, it does not take into account the uncertainty associated with the mapping of one's perception or judgment to a number. In real-life decision-making situation, the decision makers or stakeholders could be uncertain about their own level of preference, due to incomplete information or knowledge, complexity and uncertainty within the decision environment. They also tend to specify preferences in the form of natural language expressions which are most often vague and uncertain. Such conditions may occur when evaluating WEEE management scenarios.

For this reason, in this study, the usage of the fuzzy version of ANP is proposed to make a multiple attribute selection among WEEE management scenarios. In the proposed methodology, the decision makers' opinions on the relative importance of the selection criteria are determined by a fuzzy AHP procedure. To do this, Zeng et al.'s (2007) method was modified to follow a similar way to classical AHP. According to the results from the implementation of the fuzzy ANP methodology, the "Extended Producer Responsibility", scenario has been determined as the best alternative for Turkey.

RESUME

La production des équipements électriques et électroniques (EEE) est l'une des activités communes de production globale en pleine croissance. Ce développement a produit une augmentation de déchets des équipements électriques et électroniques (DEEE). Un développement économique rapide, allié à l'urbanisation et la demande croissante des biens de consommation, a augmenté en même temps la consommation de EEE et la production de DEEE, qui peuvent être une source de déchets dangereux qui forment un risque à l'environnement et au développement économique durable.

Pour s'adresser aux problèmes de l'environnement qui pourraient dériver d'une gestion erronée de DEEE, plusieurs pays et organisations ont ébauché une législation nationale pour améliorer la réutilisation, le recyclage et les autres formes de récupération des matériaux de DEEE pour réduire le montant et les types de matériaux écoulés dans les décharges. La récupération des DEEE est importante en Turquie aussi, pays qui se trouve sur la frontière de la Communauté Européenne.

Les DEEE constituent l'un des types de déchets solides les plus compliqués en ce qui concerna sa composition et, comme résultat, sa gestion est des plus difficiles. Le choix d'un scénario de gestion des DEEE qui soit technologiquement fiable, qui ne nuise pas à l'environnement, qui soit accessible du point de vue économique et socialement acceptable est une question importante. L'utilisation d'une analyse multi-critères dans la gestion (DPSG) des DEEE a l'avantage de rendre la prise de décision plus subjective et plus implicite et aussi plus transparente. Le but de cette étude est de procurer un outil analytique pour choisir le meilleur scénario de gestion des DEEE.

Le Processus Hiérarchique Analytique (PHA) est un des outils analytiques qui peut être utilisé pour savoir s'y prendre pour utiliser une DPSG. Toutefois un manque de PHA signifie que ce dernier manque dans la considération des interdépendances, si cela est le

cas, parmi les critères de sélection. Le Processus du Réseau Analytique (PRA) est une technique semblable mais elle peut capturer l'interdépendance entre les critères considérés, permettant ainsi une analyse plus systématique.

Il peut permettre l'inclusion de critères, en même temps tangibles ou intangibles (difficiles à quantifier) qui ont une influence sur la prise de la meilleure décision. En outre, plusieurs de ces critères ont un certain niveau d'interdépendance entre eux, ceci fait que le modèle de PRA est plus adapté pour le problème objet de cette étude.

Toutefois la décision basée sur le PRA a l'air de n'avoir aucun effet en ce qui concerne l'incertitude et l'indécision dans le jugement, pendant le processus de comparaison par paires. Bien que l'emploi de l'échelle distincte de 1 à 9, pour représenter le jugement oral dans les comparaisons par paires ait l'avantage de la simplicité, il ne prend pas en considération l'incertitude associée à la représentation de la perception o du jugement des gens à un nombre. Dans la situation de prises de décisions de la vie réelle, ceux qui prennent les décisions ou les intervenants pourraient être incertains en ce qui concerne leur propre niveau de préférence, à cause de l'information ou les connaissances insuffisantes, la complexité et l'incertitude dans les décisions sur l'environnement. Ils ont aussi tendance à spécifier les préférences sous la forme d'expression naturelles de langage qui sont vagues et incertaines. De telles conditions peuvent survenir lors de l'évaluation des scénarios de gestion des DEEE.

C'est pour cela que dans cette étude, l'usage d'une version floue des PHA est proposée pour pouvoir faire une sélection d'attributs multiples parmi les scénarios de gestion des DEEE. Dans la méthodologie qui est proposée les opinions des faiseurs d'opinion sur l'importance relative des critères de sélection sont déterminées par une procédure floue de PHA. Pour cela la méthode Zeng a été modifiée pour suivre une voie similaire au PHA classique.

ÖZET

Elektrikli ve elektronik ekipman (EEE) üretimi, dünyada en hızlı artan üretim faaliyetlerinden biridir. Bu gelişim, elektrikli ve elektronik ekipman atıklarının da (EEEA) hızla artmasına yol açmıştır. Şehirleşme, ekonomik düzeylerin hızla gelişimi, rekabet koşulları nedeniyle ürünlerin kalitesinin artması ve fiyatlarının düşmesi gibi çeşitli nedenlerden dolayı tüketici mallarına olan talep gün geçtikçe artmaktadır. Taleplerindeki bu hızlı artış, çevre için büyük risk meydana getirecek, tehlikeli maddelerin kaynağı olan EEE'nin tüketiminde ve EEEA'nın miktarında hızlı bir arşta sebebiyet vermektedir.

EEEA'nın doğru bir şekilde yönetimini sağlayabilmek ve yanlış yönetiminden kaynaklanabilecek potansiyel çevre sorunlarını belirlemek ve bu konuları ele almak maksadıyla, birçok ülke ve kuruluş çeşitli yasalar uygulamakta veya planlamaktadır. Bu yasalar, atık sahalarına ve atık bertaraf tesislerine gönderilecek EEEA'nın çeşit ve miktarlarını en aza indirmek amacı ile yeniden kullanım ve geri dönüşüm gibi geri kazanım seçeneklerinin geliştirilmesini ve arttırılmasını amaçlamaktadır. Avrupa Birliği'nin eşiğinde bulunan Türkiye için de EEEA'nın geri kazanımı büyük bir önem arz etmektedir.

EEEA, içeriğinde bulunan maddeler açısından en karmaşık katı atık akımlarından bir tanesidir ve bunun bir sonucu olarak EEEA'nın etkin bir şekilde yönetimi çok zordur. EEEA için çevre ile dost, teknolojik olarak elverişli, ekonomik olarak düşük maliyetli, sosyal ve politik açılardan kabul edilebilir bir senaryo seçimi büyük dikkat gerektiren önemli bir sorundur. EEEA yönetiminde çok ölçütlü karar verme yöntemlerinin kullanılması, daha objektif ve şeffaf kararların verilmesi açısından birçok avantaja sahiptir. Bu çalışmanın amacı en iyi EEEA yönetim senaryosunu seçmek için analitik bir yöntem sağlamaktır.

Analitik hiyerarşi süreci (Analytic Hierarchy Process - AHP), çok ölçütlü karar verme problemini ele almak için kullanılabilecek analitik yöntemlerden bir tanesidir. Fakat bu yöntemin seçim ölçütleri arasındaki ilişkileri ve etkileşimleri ele alamaması nedeniyle bu çalışmada Analitik Ağ Süreci (Analytic Network Process - ANP) yönteminin uygulanması kararlaştırılmıştır. ANP, çok ölçütlü bir karar verme yöntemi olup Saaty (2001) tarafından geliştirilmiştir. ANP, ikili karsılaştırmalar esasına dayanır, faktör ve alternatiflerin iç ve dış bağımlılığı temelinde analizler yapar. Ağ yapısı sayesinde, tüm etkileşimler ve geri bildirimler göz önünde bulundurulabilir. Bu özelliği, ANP'nin karmaşık karar problemlerini daha doğru ve gerçekçi olarak modellemesini sağlar. ANP en iyi kararın verilmesinde etkili olan hem maddi hem de maddi olmayan ölçütlerin kapsam içerisine alınmasına izin vermektedir. EEEA yönetim senaryosu seçimi probleminde kullanılan birçok ölçüt arasında karşılıklı bağımlılık ve etkileşim söz konusu olması nedeniyle incelenen problemin çözümünde ANP'nin uygun olduğu görülmüştür.

Bununla birlikte ANP tabanlı karar verme modeli ikili karşılaştırma süreci esnasında, karar vermenin doğasında var olan belirsizlik ile ilgilenmede yetersiz görülmektedir. ANP yönteminde, 1 ile 9 arasında numaralandırılmış ölçeklerin kullanımı basit olmasına rağmen karar verme sürecinin doğasında var olan belirsizliğin açıklanmasında yetersiz kaldığı görülmektedir. Gerçek hayattaki karar verme durumunda, karar vericiler, karar verme ortamı içerisindeki eksik bilgiye, tecrübeye, karmaşaya ve belirsizliğe bağlı olarak, kendi tercih seviyeleri hakkında kararsız olabilirler.

Bu çalışmada verilerin bulanık olarak tanımlanabildiği ortamlarda, çok ölçütlü karar verme problemlerini, ölçütlerin etkileşimini de göz önüne alarak çözmek amacıyla Bulanık ANP yöntemi kullanılmıştır. Bulanık ANP yöntemi, Türkiye için en uygun EEEA yönetim senaryosu seçimi problemi üzerinde uygulanmıştır. Tasarlanan metodolojide, karar vericilerin seçim ölçütlerinin göreceli önemi üzerindeki fikirleri bir bulanık AHP prosedürü kullanılarak belirlenmiştir. Bunu yapmak için, Zeng ve diğerlerinin (2007), geliştirdiği yöntem, klasik AHP'ye benzer bir yol takip etmek maksadıyla değiştirilmiştir. Uygulama sonucunda "genişletilmiş üretici sorumluluğu" alternatifi, en iyi alternatif olarak belirlenmiştir.

1. INTRODUCTION

In a world of finite resources and disposal capacities, recovery of used products and materials is key to supporting a growing population at an increasing level of consumption. As waste reduction is becoming a major concern in industrialized countries a concept of material cycles is gradually replacing a "one way" perception of economy. The balance between production and consumption is critical line which is have to drawn diligently. However, the consumption supported by humankind take an advantage situation whereas the resources of world exhausting rapidly. Because the resources of world already limited for the next periods; we have to produce, consume then produce and use again the one consumed. Thus the recovery of used products which could be defined as waste management is becoming the critical. It is the major concern of industrialized and densely populated countries because of the huge amount of waste produced after manufacturing or consumption [1].

The production of electrical and electronic equipment (EEE) is one of the fastest growing markets in the world. EEE have been developed, applied, and consumed world-wide at a very high speed. Subsequently, the increasing amount of waste electrical and electronic equipment (WEEE) has become a common problem facing the world. Challenges faced by WEEE management are not only consequences of growing quantities of waste but also the complexity of WEEE. WEEE constitutes one of the most complicated solid waste streams in terms of its composition, and, as a result, it is difficult to be effectively managed [2].

Businesses, governments, customers and the public are becoming increasingly interested in the alternative management of industrial products in a global scale, when those reach the end of their useful life [3]. Especially in the case of EEE, due to the fact that such products contain high-value materials, as well as toxic ones. Their environmentally sound end-of-life management has become an issue of critical importance. WEEE management is a complex and multidisciplinary problem that should be considered from environmental, social, and technical as well as economic aspects. Multiple criteria decision making (MCDM) methods can help governments and companies to evaluate alternative scenarios.

MCDM is both an approach and a set of techniques, with the goal of providing an overall ordering of options, from the most preferred to the least preferred option [4]. MCDM is divided in two groups as multiple objective decision making (MODM) and multiple attribute decision making (MADM). The intention of MCDM methods is to improve the quality of decisions by making choices more explicit, reasonable and effective. This study focuses on the detailed multiple attribute evaluation of a number of WEEE management scenarios to determine the most suitable one for Turkey.

As one of the most commonly used methods for solving MADM problems in the literature, the analytic hierarchy process (AHP) was first introduced by Thomas L. Saaty [5]. In AHP, a hierarchy considers the distribution of a goal among the elements being compared and judges which element has a greater influence on that goal. In reality, a holistic approach like an analytic network process (ANP) developed by Saaty is needed if all attributes and alternatives involved are connected in a network system that accepts various dependencies. Several MADM problems cannot be hierarchically structured as being in AHP because they involve the interactions and dependencies in higher or lower level elements. Not only does the importance of the attributes determine the importance of the alternatives as in the AHP, but the importance of alternatives themselves also influences the importance of the attributes [6]. In this study, we adopted ANP for solving the WEEE management selection problem based on the following motivations [7]:

- ANP deals with the problem of the subsystems interdependence and feedback;
- ANP has a systematic approach to set priorities and trade off among goals and criteria;
- Criteria weights or priorities established by ANP are based on the use of a ratio scale by human judgment instead of arbitrary scales;

- ANP can measure all tangible and intangible criteria in the model;
- ANP is a relatively simple, intuitive approach that can be accepted by managers and other decision-makers;
- ANP can easily be used to solve multiple criteria decision problems involving group decision making;
- ANP enables a better communication, leading to a clearer understanding and consensus among actors so that they will commit to the selected alternative more likely.

Furthermore, this application of Saaty's ANP has several shortcomings: this method is mainly used for crisp decision making problems and creates and deals with a very unbalanced scale of judgment. In addition, the ANP method does not take into account the uncertainty associated with the mapping of one's judgment to a number, and its ranking is rather imprecise. On the other hand, the subjective judgment, selection, and preference of decision-makers have a great influence on its results [8]. Due to the vagueness and uncertainty on judgments of the decision makers, the crisp pairwise comparison in the conventional ANP seems to be insufficient and imprecise to capture the right judgments of decision makers. The fuzzy set theory can model this vagueness and uncertainty. Therefore, in this study, a fuzzy ANP methodology is used.

Several researchers have attempted to use the fuzzy analytic network process (FANP) for different problems. Although crisp ANP has been applied to a large variety of decision making processes for different applications, FANP has received less attention in research. The main reason behind this is, its requirement of tremendous computational effort. Since the supermatrix priority derivation process in the ANP requires complex matrix operations on real numbers, the most practical approach to extend FAHP to the ANP framework is to derive first the crisp priorities or weights from the fuzzy comparison matrices [9]. Most of the FANP methods in the literature is an extension of FAHP approach proposed by Chang [10], which derives crisp local priorities from fuzzy comparison matrix using the extent analysis method and possibility theory. However, they used a rather simplified supermatrix calculation which appears, in our opinion, far removed from that of the original ANP. In addition, their proposed algorithm may yield a zero value of initial weights or local priorities to some elements of the decision structure. A computed zero local priority from the extent analysis could be problematic because some paths of interactions will not be considered in the supermatrix calculations. It should be noted that an unimportant element in a cluster may still be important overall because of dependence and feedback in the decision structure [11]. Thus, the extension of Chang’s extent analysis method to the ANP framework may have some drawbacks in the sense that the outcome could not capture all the possible interactions in the decision structure. There are also other fuzzy AHP methods developed by other researchers like Laarhoven and Pedrycz [12], Buckley [13]. These methods have some computational difficulties and theoretical problems indicated in the literature.

In this study, the usage of the fuzzy version of ANP is proposed to make a multiple attribute selection among WEEE management scenarios. In the proposed methodology, the decision makers' opinions on the relative importance of the selection criteria are determined by a fuzzy AHP procedure. To do this, Zeng et al.’s [14] method was modified to follow a similar way to classical AHP. Although several authors have recently applied this FAHP method, to the best of our knowledge, it has never been tested within the supermatrix framework.

The main advantage in this approach is that the user does not face complex computations to solve the problem with fuzzy data. Another advantage is that the methodology presented is very general and can be applied to many MADM problems where imprecise data can be represented by fuzzy numbers.

The rest of the study is organized as follows: In section 2, we represent the definition, the recovery process and the management of WEEE. Section 3 reviews multiple criteria decision making. The fourth section presents the basics of the fuzzy set theory. Section 5 analyzes the fuzzy decision making methodologies employed in this study for the evaluation of alternative WEEE management scenarios. Section 6 presents the application of the proposed method to Turkey’s WEEE management problem. Finally, conclusions are provided in Section 8.

2. WASTE ELECTRICAL AND ELECTRONIC EQUIPMENT

What would we do without electronics? For most of us, electronics are present in every facet of our lives. Televisions provide entertainment and bring local, national, and world news into our homes; computers connect us to the internet, and are essential to most professions. Mobile phones have revolutionized the way that we communicate, keeping us connected to family, friends, clients, and colleagues [15]. The accelerating pace of consumption of materials, energy and other resources needed to maintain the production of electric electronic products in the developed and developing countries is clearly unsustainable. Recent growth in the use of mobile phones, personal computers and flat screen TVs is spectacular [16].

As a result of the growing importance of electronics to the world economy has brought about a surge in demand for EEE [17]. According to Chui and Frossberg [18], the production of EEE is one of the fastest growing businesses in the world. In the meantime, both technological innovation and market expansion of EEE are accelerating the replacement of outdated EEE, leading to a significant increase in waste electrical and electronic equipment EEE (WEEE), which can be a source of hazardous wastes that pose a risk to the environment and to sustainable economic growth [19].

The useful life of consumer electronic products is relatively short, and decreasing as a result of rapid changes in equipment features and capabilities [20]. For example, the lifespan of a computer has steadily decreased because of continuous technological advancements in the areas of memory, speed, new operating systems, weight, and enhanced audio/visual capability. In 1992, the average first life of a computer was 4-6 years. By the year 2005 it was determined to be only 2 years [19]. Furthermore, a study by Kang and Schoeming [20] indicated that 50% of computers discarded at a collection facility were still in working condition. This same type of rapid disposal of a workable product has also been identified with one other type of e-waste product, mobile phones.

According to the European Commission (EC), the total amount of waste in Europe is expected to increase by about 45% between 1995 and 2020. As a response to that forecast, the European waste strategy has been grounded on three pillars; waste prevention, recycling and reuse and improved final disposal [21]. For the second pillar "*recycling and reuse*" several recent studies covering various types of packaging waste have reported on the sustainability of such practices. So far, all these studies have examined clearly defined and most of the time single-material types of waste such as aluminum packaging or PET bottles. The question is, however, whether similar conclusions can also be drawn for more complex types of waste such as WEEE [22].

WEEE is one of the priority streams in waste management because of its major challenges. It has in fact become an issue of concern to solid waste management professionals. Challenges faced by WEEE management are not only consequences of growing quantities of waste but also the complexity of WEEE. As a result of the variety of product models, size changes, compatibility issues, etc., the recovery of WEEE is very challenging [17].

Table 2.1: Benefits of using scrap iron and steel [18].

Benefits	Percentage
Savings in energy	74
Savings in virgin materials use	90
Reduction in air pollution	86
Reduction in water use	40
Reduction in water pollution	76
Reduction in mining wastes	97
Reduction in consumer wastes generated	105

To address potential environmental problems that could stem from improper management of WEEE, many countries and organizations have drafted national legislation to improve the reuse, recycling and other forms of material recovery from WEEE to reduce the amount and types of materials disposed in landfills. Recycling of WEEE is important not only to reduce the amount of waste requiring treatment, but also to promote the recovery of valuable materials [19].

Table 2.2: Recycled materials energy savings over virgin materials [18].

Materials	**Energy savings (%)**
Aluminum	95
Copper	85
Iron and steel	74
Lead	65
Zinc	60
Paper	64
Plastics	>80

The US Environmental Protection Agency (EPA) has identified seven major benefits when scrap iron and steel are used instead of virgin materials [18]. Using recycled materials in place of virgin materials results in significant energy savings (as shown in Tables 2.1 and 2.2).

2.1 Definition and Generation Rates of Electrical and Electronic Waste

A broad range of goods is classified as EEE, including large and small household appliances; information and technology (IT) equipment including computers, computer games and peripherals; mobile phones and other telecommunication equipment; portable electronic devices such as portable digital assistants (PDAs), video and audio equipment, including MP3 players and peripherals; and electrical tools [19].

Once these products reach the end of their useful life, they become e-waste or WEEE. WEEE has been defined as any equipment that is dependent on electric currents or electromagnetic fields in order to work properly, including equipment for the generation, transfer, and measurement of current. In response to the increasing volumes of WEEE and their potential environmental impacts through various disposal routes, the EC has published a proposal in 2002 for Directives on Waste from Electrical and Electronic Equipment. The Directive of the Parliament and European Union Council on waste electrical and electronic equipment subdivides WEEE into ten different categories Table 2.3 shows the categories of WEEE used in European Union legislations.

Table 2.3: The contents of EU legislations

Large household appliances	Refrigerators/freezers, washing machines, dishwashers
Small household appliances	Toasters, coffee makers, irons, hairdryers
Office, Information & communication equipment	Personal computers, telephones, mobile phones, laptops, printers, scanners, copiers
Entertainment & Consumer equipment	Televisions, stereo equipment, VCR/DVD/CD players, Hi-Fi sets, radios
Lighting equipment	Fluorescent tubes, sodium lamps etc.
Electrical and electronic tools	Handheld drills, saws, screwdrivers
Toys, leisure and sports equipment	Game consoles, coin slot machines
Medical equipment systems	With the exception of all implanted and infected products
Monitoring and control instruments.	
Automatic dispensers.	

As WEEE extends across a number of industry sectors and is a relatively new focus of environmental concern, accurate data and trends are difficult to ascertain. There is no uniformly accepted definition of WEEE, which has made record-keeping and accounting difficult. Worldwide, WEEE constitutes one of the fastest growing waste fractions generated, accounting for 8% of all municipal waste [23].

The disposal rate of this waste stream is accelerating because the global market for electronics is far from saturated, and the lifespan of electronic goods is becoming shorter, so that obsolete equipment disposal is increasing. In the former (before May 2004) 15 European Union member countries (EU15), the amount of WEEE produced during 1990–1999 was 3.3–3.6 kg per capita and is projected to reach 3.9–4.3 kg per capita for the period 2000– 2010. According to this study (which assessed only five appliances: refrigerators, personal computers, televisions, photocopiers, and small household appliances), these items account for only 25% of the whole WEEE stream of the EU15. Another estimate of the total per capita WEEE generation in the EU15 is 4–20 kg/year. Other estimates of total WEEE generation rates for the EU range from 14 to 20 kg per capita. The range of uncertainty relates mainly to differences in how WEEE is defined [19].

2.2 Characteristics of WEEE

Waste electrical and electronic equipment is non-homogeneous and complex in terms of materials and components. In order to develop a cost-effective, socially acceptable and environmentally friendly recycling system, it is important to identify and quantify valuable materials and hazardous substances of this waste stream [18].

2.2.1 Materials Composition

Waste electrical and electronic equipment is a complex material containing various fractions. The various elements present in WEEE are shown in Figure 2.1. It is estimated that about 66% of WEEE by weight consists of metals such as iron, copper, aluminum and gold and nonmetals, with other pollutants make up about 34% of the waste. Ferrous metal is the most common material found in electric and electronic components [19].

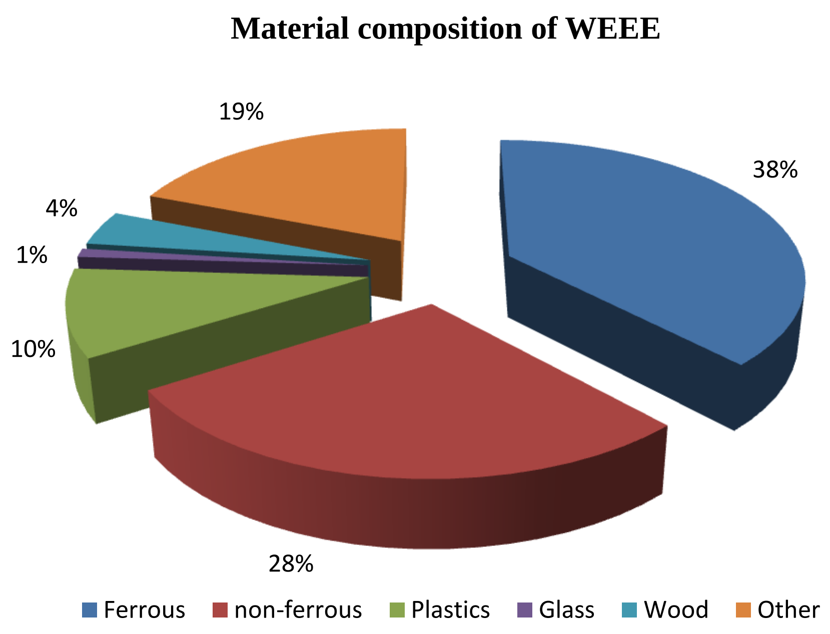


Figure 2.1: Materials found in electronic equipment [24].

The main economic driving force for the recycling of electronic scrap is the recovery of precious metals. However, the content of precious metals in WEEE is steadily decreasing. According to the U.S. General Accounting Office (GAO) (November 2005), “computers contain precious metals, such as gold, silver, and platinum, which require substantial amounts of energy and land to extract [15]. These metals can often be extracted with less environmental impact from used electronics than from the environment. The U.S. Geological Survey, for instance, reports that 1 metric ton of computer scrap contains more gold than 17 tons of ore, and much lower levels of harmful elements common to ores, such as arsenic, mercury and sulfur. A typical mobile phone consists of 40% metals, 40% plastics, and 20% ceramics and other trace materials. Much of this is recoverable, including the batteries. Wireless phones also contain a number of toxic materials, such as lead and brominated flame retardants, which are released into the environment when they are disposed of in a landfill or incinerator [15].

2.2.2 Hazardous Substances and Components

WEEE consists of a large number of components of various sizes and shapes, some of which contain hazardous components that need be removed for separate treatment. With these hazardous elements, WEEE can cause serious environmental problems during disposal if not properly pretreated. For example, the cadmium from one mobile phone battery is sufficient to pollute 600.000 lt. of water [25]. Televisions (TVs) and video and computer monitors use cathode ray-tubes (CRTs), which have significant amounts of lead. CRTs were used in all television sets until the late twentieth century. Because of the x-ray hazard in TVs, the glass envelopes of most modern CRTs are made from heavily leaded glass. The lead in this glass may represent an environmental hazard, especially in the presence of acid rain leaching through landfills. Finally, most indirectly-heated vacuum tubes (including CRTs) use various highly reactive materials to enhance their cathode emissions and performance of their getter assemblies. Printed circuit boards contain primarily plastic and copper, and most have small amounts of chromium, lead solder, nickel, and zinc. Relays and switches in electronics, especially older ones, may contain mercury [15]. Berylium has been used for thermal conductivity and can be present in connectors. Also, capacitors in some types of older and larger equipment that is now entering the waste stream may contain polychlorinated biphenyls.

Major categories of hazardous materials and components of WEEE that have to be selectively treated are shown in Table 2.4.

Table 2.4: Major hazardous components in WEEE [18].

Materials and components	**Description**
Batteries	Heavy metals such as lead, mercury and cadmium are present in batteries
Cathode ray tubes (CRTs)	Lead in the cone glass and fluorescent coating cover the inside of panel glass
Mercury containing components such as switches	Mercury is used in thermostats, sensors, relays and switches (e.g. on printed circuit boards and in measuring equipment and discharge lamps); it is also used in medical equipment, data transmission, telecommunication, and mobile phones
Asbestos waste	Asbestos waste has to be treated selectively
Toner cartridges, liquid and pasty, as well as color toner	Toner and toner cartridges have to be removed from any separately collected WEEE
Printed circuit boards (PCB)	In printed circuit boards, cadmium occurs in certain components, such as SMD chip resistors, infrared detectors and semiconductors
Polychlorinated biphenyl containing capacitors	Polychlorinatedbiphenyl containing capacitors have to be removed for safe destruction
Liquid crystal displays (LCDs)	LCDs of a surface greater them 100 cm^2 have to be removed from WEEE
Plastics containing halogenated flame retardants	During incineration/combustion of the plastics halogenated flame retardants can produce toxic components
Equipment containing CFC, HCFC	CFCs present in the foam and the refrigerating circuit must be properly extracted and destroyed; HCFC or CFCs present in the foam and refrigerating circuit must be properly extracted and destroyed or recycled
Gas discharge lamps	Mercury has to be removed

WEEE should not be combined with unsorted municipal waste destined for landfills because electronic waste can contain more than 1000 different substances, many of which are toxic, such as lead, mercury, arsenic, cadmium, selenium, and hexavalent chromium. Some of the toxic effects of the heavy metals are given below [19].

Lead: The negative effects of lead are well established and recognized. Lead causes damage to the central and peripheral nervous systems, blood systems, kidney and reproductive system in humans. The main applications of lead in computers are: glass panels and gasket (frit) in computer monitors (1–4 kg per monitor), and solder in printed circuit boards and other components.

Cadmium: Cadmium compounds are toxic, they can bioaccumulate, and they pose a risk of irreversible effects on human health. Cadmium occurs in certain components such as surface mount devices (SMD) chip resistors, infrared detectors, and semiconductor chips.

Mercury: Mercury can cause damage to various organs including the brain and kidneys. Most importantly, the developing fetus is highly susceptible through maternal exposure to mercury. Mercury is used in thermostats, sensors, relays, switches (e.g. on printed circuit boards and in measuring equipment), medical equipment, lamps, mobile phones and in batteries.

Hexavalent chromium/chromium VI: Chromium VI is still used for corrosion protection of untreated and galvanized steel plates and as a decorative or hardener for steel housings. It easily passes through cell membranes and is then absorbed (producing various toxic effects in contaminated cells)

Additional harmful substances in WEEE can include arsenic, polychlorinated biphenyls, chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), nickel, and asbestos. Even when present in small amounts, some of these chemicals can be potent pollutants and contribute to toxic landfill leachate and vapours, such as the vaporization of metallic and dimethylene mercury. Furthermore, uncontrolled fires may arise in landfills, releasing extremely toxic dioxins and furans (dioxin-like compounds) into the atmosphere.

2.3 Treatment Options of WEEE

The life cycle of a product refers to the sequence of interrelated steps of a product from the acquisition of raw materials for manufacturing to the disposal of the used product, i.e. its end-of life (EOL). At the end-of-life, the product can be either disposed of, or still in use to extend its life cycle (see Figure 2.2). The end-of-life of a product in this study refers to the time point when the product's functionality no longer satisfies the requirements of the original purchaser or the first user. End-of-life strategies describe the approaches or methods in dealing with the product at its end-of-life. EOL treatment includes the activities associated with recovering value from the product, through manual labor and/or machinery. In view of the environmental problems and high residual value of WEEE, WEEE management system should be established to extend the life cycle of EEE. This management system comprises collection, classification, pre-treatment, etc., and five conventional end-of-life treatment strategies [25].

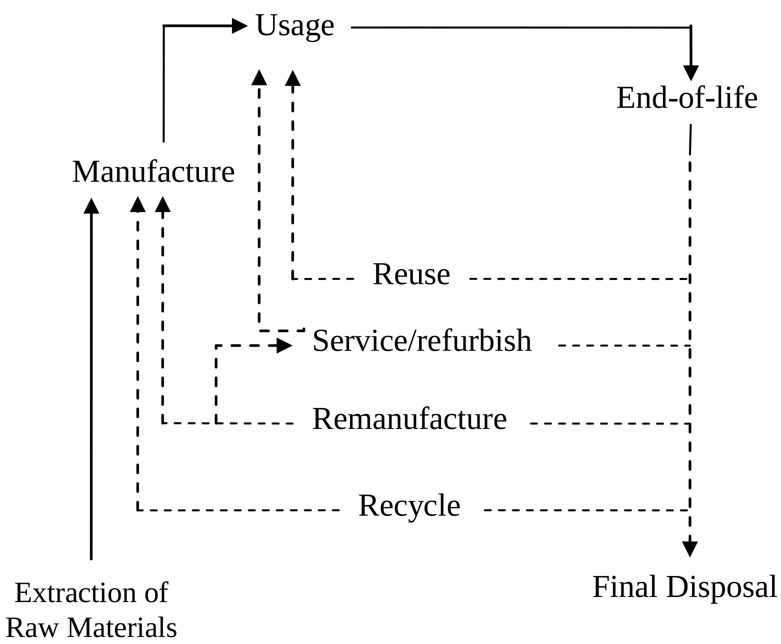


Figure 2.2: Generic Product's life cycle [25].

In accordance with the potential economic and environmental efficiency, these strategies can be categorized as follows:

1. **Reuse:** the recovery and trade of used products or their components as originally designed;
2. **Servicing:** a strategy aimed at extending the usage stage of a product by repair or maintenance;
3. **Remanufacturing:** the process of removing specific parts of the waste product for further reuse in new products;
4. **Recycling:** including the treatment, recovery, and reprocessing of materials contained in the used products or components in order to replace the virgin materials in the production of new goods;
5. **Disposal:** the processes of incineration or landfill.

2.4 Recycling of WEEE

WEEE recycling is in its infancy, and consumer recognition of the need for recycling is a critical factor in the further expansion of this industry. More than 90% of WEEE is landfilled, and a large fraction of WEEE waste from households ends up in waste incinerators. Many consumers do not immediately discard or recycle unused electronics, since they think that the products retain value. More than 70% of retired EEEs are kept in storage for 3–5 years [25]. However, with the rapid development of electronic technologies, the residual value of outdated electronic devices decreases rapidly; both the recovery value of parts and the machine resale value drop rapidly as machines and devices age. Consumers also need to be educated about the effects of such waste on the environment and health, and learn the significance of the recycling symbol that must appear on the packaging of such equipment (a crossed-out wheeled bin). Recycling of WEEE is an important step of the end-of life strategies for WEEE treatment. The maximization of valuable material recovery and the consequent minimization of disposal rely on the technologies used in the process. With the steadily decreasing of the precious metal contents in EEE, the precious metal oriented recovery techniques, such as hydrometallurgy and pyrometallurgy, are facing great challenges.

On the other hand, mechanical/physical recycling of WEEE, due to its better environmental property and easier operability, is drawing more attention. Compared with hydrometallurgy and pyrometallurgy, mechanical/physical processes can achieve full material recovery including plastics. Mechanical recycling of WEEE can be broadly divided into three major stages [18].

1. **Disassembly (dismantling):** targeting on singling out hazardous or valuable components.
2. **Upgrading:** using mechanical/physical processing to upgrade desirable materials content, i.e. preparing materials for refining process.
3. **Refining:** in the last stage, recovered materials return to their life cycle.

Disassembly and upgrading are two key processes of the mechanical recycling of WEEE.

2.4.1 Disassembly

Among the desirable alternatives for EOL processing of products are remanufacturing, reusing and recycling. Although disposal and incineration are also possible EOL alternatives, they should be kept to a minimum. In order to remanufacture, reuse or recycle, often the product has to be disassembled first [26].

Disassembly is a systematic process that removes a component or a part, or a group of parts or a subassembly from a product (i.e., partial disassembly); or splits a product into all of its parts (i.e., complete disassembly) for a given purpose.

In WEEE recycling practice, selective disassembly (dismantling) is an indispensable process, since (1) the reuse of components is of the first priority, (2) dismantling the hazardous components is essential, and (3) it is important to dismantle highly valuable components and high grade materials such as PCBs, cables, and engineering plastics in order to simplify the subsequent recovery of materials [25].

Disassembly has recently gained a lot of attention in the literature due to its role in product recovery. Even though approaching disassembly as the reverse of assembly may sound reasonable, for complex products, the operational characteristics of disassembly and assembly are quite different. Tani and Güner [27] compare assembly and disassembly and describe the identifiers of the disassembly process. According to their observations, disassembly of a product can be performed by finding natural and easier ways whereas in assembly, the process needs to be highly optimized and sequences of parts to form a product must be clearly defined. Although the actual mechanism of disassembly is simpler than that of assembly, the operational scope of disassembly is much more complex than assembly. The general operational characteristics of disassembly and assembly systems are highlighted by Brennan et al. [28] and given in Table 2.5. Both operational and physical differences between assembly and disassembly imply that the assembly planning knowledge may not be used for the disassembly planning issues. Thus, there is a need to develop new techniques and methodologies to specifically address disassembly planning [29].

Table 2.5: Comparison of assembly and disassembly [28].

System characteristic	**Assembly**	**Disassembly**
Demand	Dependent	Dependent
Demand sources	Single	Multiple
Forecasting requirements	Single end item	Multi-item
Planning horizon	Product life-cycle	Indefinite
Design orientation	Design for assembly	Design for disassembly
Facilities and capacity planning	Straightforward	Intricate
Manufacturing systems	Dynamic and constrained	Dynamic and constrained
Operations complexity	Moderate	High
Flow process	Convergent	Divergent
Direction of material flow	Forward	Reverse
Inventory by-products	None	Potentially numerous
Availability of scheduling	Numerous	None

The implementation of disassembly needs highly efficient and flexible tools. The most attractive research on disassembly process is the use of robots. Unfortunately, full (semi) application of automation disassembly for recycling of EEE is full of frustration.

Currently, there are only a few pilot projects for automated disassembly of keyboards, monitors and PCBs, and there is no (semi) automated solution for the personal computer (PC) itself. The manual disassembly aided by tools, due to its high flexibility, is currently the main dismantling process. Ragn-Sells Elektronikatervinning AB in Sweden is a typical electronics recycling company. Figure 2.3 illustrates the disassembly process utilized in the company. A variety of tools are involved in the dismantling process for removing hazardous components and recovery of reusable or valuable components and materials [18].

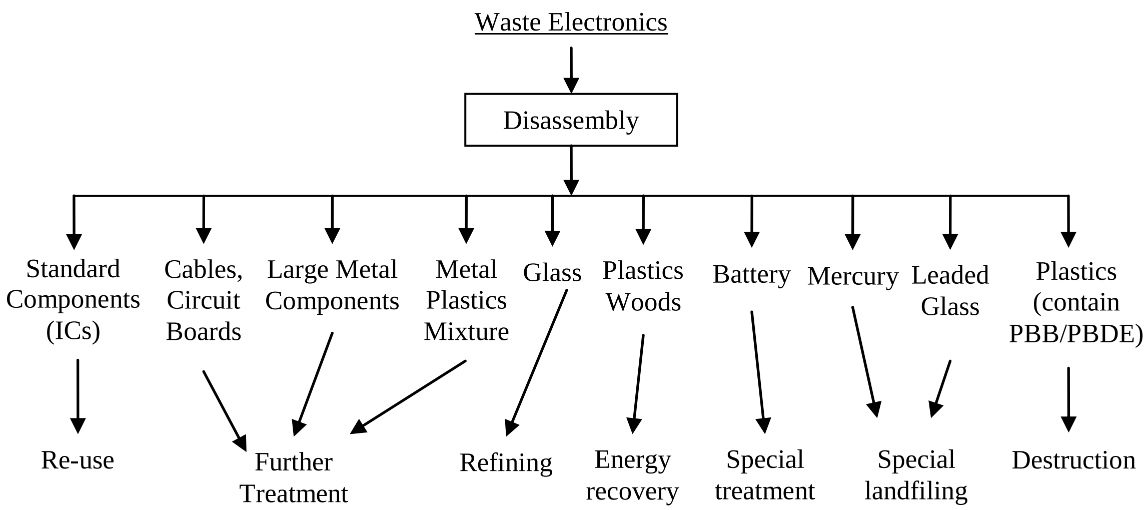


Figure 2.3: Recycling process developed by Ragn-Sells Elektronikatervinning AB [18].

The disassembled cables, PCBs and metal/plastics mixture, being a mixture of various materials, should be further treated to upgrade the materials contents of them.

2.4.2 Upgrading

WEEE can be regarded as a resource of metals, such as copper, aluminum and gold, and non-metals. Effective separation of them, based on the differences in their physical characteristics, is another crucial process for recycling of WEEE. The upgrading usually includes two stages: comminuting and separating.

Comminuting: Comminuting is the first step of the physical upgrading process. Only when the disassembled WEEE is shredded to a proper granularity, can the materials of the WEEE be liberated one another, and then be separated effectively. Basically, the materials present in EEE are attached by fastening, inserting, welding, binding, wrapping and so forth. Therefore, it does not need much intensive energy to unlock the associated materials like ceramics, glass, and metals having distinctive mechanical properties. The optimized comminuting result is that every comminuted particle is made by sole material [25].

Separation: After liberation of the materials in the disassembled WEEE through comminuting, the separation of them can then be performed by mechanical/physical methods. The differences on the physical characteristics of materials in non-homogeneous compounds, such as magnetism, electric conductivity and density, etc., are the bases of the mechanical/physical separation of them. Mechanical/physical separation processes include electromagnetic separation, electronic-conductivity based separation, density based separation and so forth. All of them have application instances in the WEEE recycling field. Magnetic separation is widely used for the recovery of ferromagnetic metals from non-ferrous metals and other nonmagnetic wastes. Over the past decade, the advances in the design and operation of high-intensity magnetic separators also make it possible to separate copper alloys from the waste matrix [25].

Electric conductivity based separation is used to separate materials of different electric conductivity (or resistivity). There are three typical electric conductivity based separation techniques: (1) eddy current separation, (2) corona electrostatic separation, and (3) triboelectric separation. With the marked density difference between metals and nonmetals in WEEE powders, the heavier metal materials can be effectively separated from non-metal materials by the density based separation methods. In the practice of recycling WEEE, according to the requirements of the task, some of the above methods can be combined together to fulfill the separation of the materials present in WEEE.

2.5 Legislative Influences on Electronics Recycling

The European Union (EU) WEEE Directive and RoHS Directive has received the greatest amount of attention in the literature in comparison to other e-waste initiatives. These directives are also important in Turkey, which is on the edge of EU.

2.5.1 Producer Responsibility Legislation

Following acknowledgment that the volumes of WEEE arising in the European Union were very large and increasing year on year, the EC introduced a range of legislation aimed directly at tackling the problem. The two key, and perhaps best known, pieces of legislation are the WEEE and RoHS Directives. After over 10 years of debate, these Directives have now become a reality and they have had a significant impact on the way manufacturers design, produce and dispose of their products. The WEEE Directive, however, is just one part of a much larger policy mechanism within the EC that is aimed at introducing Producer Responsibility. This makes the producers (in this case, of electrical and electronic equipment) legally responsible for the recovery and recycling of their products when they are finally disposed of at end of life [16].

2.5.2 The WEEE Directive

The Waste Electrical and Electronic Equipment (WEEE) Directive directly controls the disposal of end-of-life equipment and the percentage going to landfill, as well as setting targets for the percentages of a product that have to be recovered and recycled. As mentioned before the WEEE Directive specifies ten categories of types of electrical and electronic equipment and each category has a defined recycling and recovery target. All recycling and recovery targets are based on a percentage of total product weight. Although there is a huge amount of specific detail within the WEEE Directive, its broad aim is to reduce the volume of electrical and electronic waste consigned to landfill, increase the recovery and recycling of electrical and electronic waste and minimize the lifecycle environmental impact of the electrical and electronic equipment sector. The basic aims of the WEEE Directive can be summarized as follows:

- Separate collection of WEEE
- Treatment according to agreed standards
- Recovery and recycling to meet set targets
- Producer pays from collection onwards
- Option for business users to pay some or all of costs
- Retailers to offer take-back of end-of-life equipment
- Consumers to return WEEE free of charge

By introducing guidelines and requirements such as the provision of information for recycling and the design of products to aid reuse, recovery and recycling, the WEEE Directive aims to improve the environmental performance of all operators involved in the lifecycle of EEE, i.e. producers, customers and recyclers.

2.5.3 The RoHS Directive

The 'Restriction of the use of certain Hazardous Substances in electrical and electronic equipment' (RoHS) Directive was originally contained within the text of the WEEE Directive, but it has subsequently been removed and now exists as a stand-alone Directive that complements the WEEE Directive. The key objective of the RoHS Directive is the protection of human health and the environment through restrictions on the use of certain hazardous substances. Specifically, these materials are lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls and certain polybrominated diphenyl ethers. The RoHS Directive has had, and continues to have, a significant impact on manufacturers, sellers, distributors and recyclers of electrical and electronic equipment. Producers need to ensure that the products they put on the European market do not contain the proscribed materials and that they comply with the requirements of the Directive. If a producer is found to have placed products that contain these proscribed materials on the European market they may be forced to withdraw them. The RoHS Directive covers all of the products categories described in the WEEE Directive, except for the medical and monitoring and control categories. Because it is not possible to eliminate every single atom of a substance, the RoHS Directive states that a material must not be present above a specified percentage weight in what is known as an homogenous material. This figure is set at 0.1% by weight for each of the proscribed materials, except cadmium for which the level is ten times lower at 0.01%. Table 2.6 shows the materials targeted by the RoHS Directive.

Table 2.6: Materials targeted by the RoHS Directive [16].

Material	Maximum permitted level
Lead	0.1 %
Mercury	0.1 %
Hexvalent chromium	0.1 %
Cadmium	0.01 %
Polybrominated biphenyls	0.1 %
Pentabromodipenyl ether	0.1 %
Octabromodiphenyl ether	0.1 %

2.6 Waste Management Models

The tools selected to evaluate alternative scenarios are an important part of the waste management models. The type of tool selected also depends on the decision being made and on the decision-makers [30]. In some cases, the goal of the model is simple, (to optimize waste collection routes for vehicles), while in others, it is more complex (to evaluate alternative waste management scenarios). Most waste management models consider economic and environmental aspects, but very few consider social aspects. For a waste management system to be sustainable, it needs to be environmentally effective, economically affordable and socially acceptable. Rogers [31] categorizes models into two categories: those that use optimizing methods and those that use compromising methods. While Rogers's categorization is centered around engineering project appraisal, it can be applied to waste management models as well. Optimizing models assume that the different objectives of the proposal can be expressed in a common denominator or scale of measurement, whereby the loss in one objective can be directly evaluated against a gain in another. Optimization models include cost benefit analysis and present worth evaluation with the common scale of measurement usually expressed in monetary terms. In contrast, compromising methods assume that the decision maker may have limited knowledge regarding the decision situation.

A review of current waste management models shows that most can be categorized into one of three categories; those based on cost benefit analysis, those based on life cycle analysis and those based on the use of multiple criteria techniques [32].

2.6.1 Models Based on Cost Benefit Analysis

This tool enables decision-makers to assess the positive and negative effects of a set of scenarios by translating all impacts into a common measurement, usually monetary. This means that impacts, which do not have a monetary value, such as environmental impacts, must be estimated in monetary terms. There are several ways to do this, such as estimating the costs of avoiding a negative effect (e.g. the cost of pollution control on an incinerator) or to establish how much individuals are willing to pay for an environmental improvement [33]. On completion of the analysis, the scenario with the greatest benefit and least cost is the preferred scenario.

Benefits and limitations

- The results are presented in a clear manner, with all impacts summed up into one monetary figure.
- It enables decision-makers to see what scenarios are efficient in their use of resources.
- There is uncertainty involved in estimating the monetary value of several environmental and/or social impacts in monetary terms. This also raises ethical issues.
- The assumptions about prices may change during the lifetime of the waste program, changing the preferred outcome

2.6.2 Models Based on Life Cycle Analysis

Life cycle assessment is a tool that studies the environmental aspects and potential impacts throughout a product's life from raw material acquisition through production, use and final disposal. While most life cycle studies have been comparative assessments of substitutable products delivering similar functions (e.g. glass versus plastic for beverage containers), there has been a recent trend towards the use of life cycle approaches in comparing alternative production processes and this includes the use of LCA in comparing waste management scenarios.

Benefits and limitations

- Use of LCA techniques will not necessarily guarantee that one can choose which option is ‘‘environmentally superior’’ because it is not able to assess the actual environmental effects of the product, package or service system. The actual environmental effects of emissions and wastes will depend on when, where and how they are released into the environment.
- LCA is but one tool in the ‘‘environmental management toolbox’’ and should not be used in isolation to decide such issues as which waste management treatment option is to be preferred.
- A difficulty associated with LCA is establishing where the boundary is and the definition of the functional unit. The results produced by variations of LCAs (e.g. investigating the same product) differ in practice.
- LCAs are restricted to looking at environmental impacts only.

2.6.3 Models Based on Multiple Criteria Decision Making

Over the past two decades, MCDM has developed into a discipline in its own right. A common characteristic of all MCDM approaches is that taking several individual and often conflicting criteria into account in a multidimensional way leads to more robust decision making rather than optimizing a single dimensional objective function. In addition, the multiple criteria approach assists decision makers to learn about the problem and the alternative courses of action from several points of view. The normal approach is to identify several alternatives, which are then evaluated in terms of criteria that are important for the model or circumstances of the model being developed. A detailed description of the various MCDM techniques is given in chapter 3.

Benefits and limitations

- Allows a systematic approach to evaluate policy options and helps understanding of the problem.
- A mixture of quantitative and qualitative information can be incorporated. MCDM goes beyond the evaluation of purely economic consequences and allows non-economic criteria to be assessed on an equal basis.
- Account can be taken of the preferences of the various stakeholder groups with conflicting objectives.
- Multiple criteria techniques offer a level of flexibility and inclusiveness that purely economic based models tend to lack.
- There is a need for personal judgment and experience in making the decisions

Numerous applications in the literature have shown that the use of MCDM is a suitable method for making decisions in the area of waste management. Multiple criteria methods can be applied to any complex decision and can consider criteria such as risk, economics, safety, etc., Some recent MCDM studies in the field of WEEE are given in Table 2.7.

Table 2.7: WEEE management studies using MCDM methods

Year	Authors	Article Title	Methods	Ref. No.
2005	Ravi et al.	Analyzing alternatives in reverse logistics for EOL computers: ANP and balanced scorecard approach	ANP and BSC	**[34]**
2008	Rousis et al.	Multi-criteria analysis for the determination of the best WEEE management scenario in Cyprus	PROMETHE I, II	**[2]**
2008	Queiruga et al.	Evaluation of sites for the location of WEEE recycling plants in Spain	PROMETHEE	**[35]**
2009	Achillas et al.	Decision support system for the optimal location of electrical and electronic waste treatment plants. A case study in Greece	ELECTRE III	**[3]**
2009	Iakovou et al.	A methodological framework for EOL management of electronic products	Multi-criteria Matrix	**[36]**

3. DECISION MAKING PROCESS

Making decisions is a part of our daily lives. The major concern is that almost all decision problems have multiple, usually conflicting criteria. Decision making has changed over the last decades. From a single person and single criterion, decision environments have developed increasingly to become multiple person and multiple criteria [37].

Multiple criteria decision making (MCDM) is one of the most well known branches of decision making [38]. In the literature, there are two basic approaches to MCDM problems: multiple attribute decision making (MADM) and multiple objective decision making (MODM). From a practical viewpoint, MADM is associated with problems whose number of alternatives has been predetermined. The focus of MADM problems is on selecting the best or preferred alternative(s) from a finite set of alternatives. On the other hand the focus of MODM problems is to design or create an alternative when possible number of alternatives is high (or infinite) and all the alternatives are not known a priori.

When analyzing the decision making process, the context or environment of the decision to be made allows for a categorization of the decisions based on the nature of the problem or the nature of the data or both. There are two broad categories of decision problems: decision making under certainty and decision making under uncertainty. Some break decision making under uncertainty down further in terms of whether the problem can be modeled by probability distributions (risk) or not (uncertainty). Three different types of decision making environments are as follows:

a. Decision making under conditions of certainty (Deterministic)
b. Decision making under situations of risk (Stochastic)
c. Decision making under conditions of uncertainty (Fuzzy)

Another way of classifying MCDM methods is according to the number of decision makers involved in the decision process. Hence, we have single decision maker MCDM methods and group decision makers MCDM methods. The classification schema is shown in Figure 3.1.

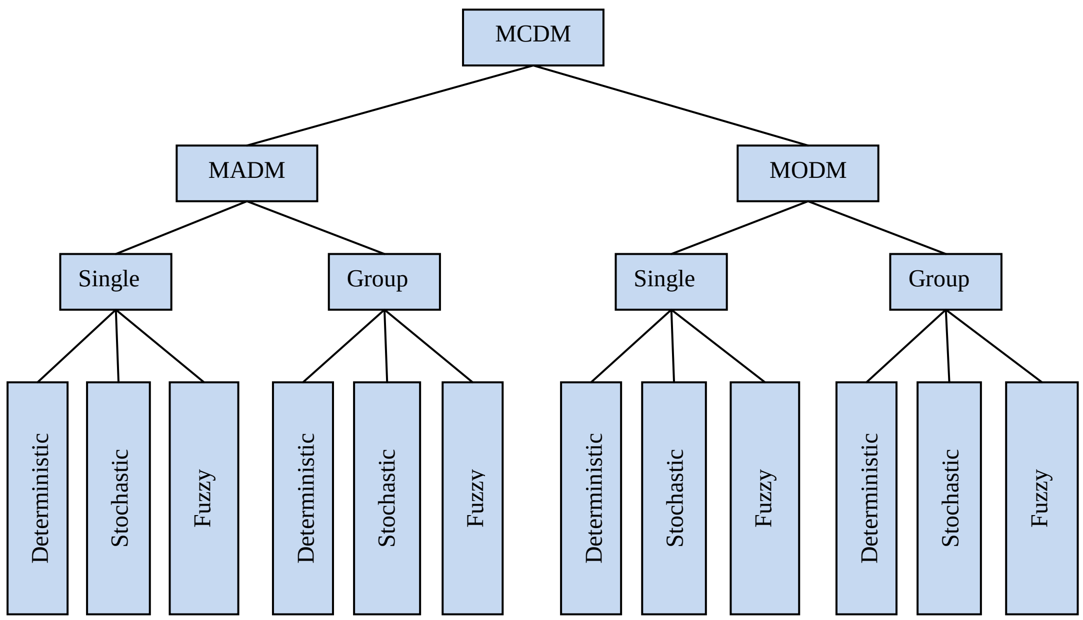


Figure 3.1: Classification scheme for MCDM methods [39].

3.1 Multiple Criteria Decision Making

MCDM refers to making decision in the presence of multiple and often conflicting criteria, where criteria means the standards of judgment or rules to test acceptability. All MCDM problems share the following common characteristics.

- ***Multiple criteria:*** Each problem has multiple criteria.
- ***Conflict among criteria:*** Multiple criteria usually conflict with each other.
- ***Design/selection:*** Solutions to an MCDM problem are either to design the best alternative(s) or to select the best one(s) among a predetermined finite set of alternatives [37].

The intention of MCDM is to improve quality of decisions by making choices more explicit, reasonable and effective. MCDM provides decision makers with powerful capabilities in analyzing, exploring and comparing a set of incompatible alternatives. It can help them gain insight on the problem as well as confidence when making a decision.

As we mentioned before, the MCDM problems is divided into two branches: MODM and MADM. The differences between MODM and MADM are systematically summarized in Table 3.1. In this study we focus on MADM under fuzziness.

Table 3.1: Comparison of MODM and MADM approaches [39].

Criteria for comparison	**MODM**	**MADM**
Criteria defined by	Objectives	Attributes
Objectives defined	Explicitly	Implicitly
Attributes defined	Implicitly	Explicitly
Constraints Define	Explicitly	Implicitly
Alternatives Defined	Implicitly	Explicitly
Number of Alternatives	Infinite (Large)	Finite (Small)
Decision Maker's Control	Significant	Limited
Decision modeling paradigm	Process-oriented	Outcome-oriented
Relevant to	Design/search	Evaluation/choice

3.1.1 Multiple Objective Decision Making

MODM models generally deal with continuous problems in which the number of variables is infinite and variables used to define the decision problem tend to be continuous. In other words, the feasible alternatives are not known a priori but are represented by a set of mathematical constraints [40]. Most of MODM methods are based on mathematical programming in which there are more than one objective to be optimized and try to obtain an appropriate compromise solution form a set of efficient solution. Generally a multiple objective mathematical programming (MOMP) model can be formulated as follows:

$$MODM \begin{cases} Max(or\ Min)\{f_1(x), f_2(x), \dots, f_k(x)\} \\ \qquad Subject\ to: g_j(x) \le b_j \end{cases} \tag{3.1}$$

Where x is the vector of the decision variables, $\{\mathrm{f}_1(\mathrm{x}), \mathrm{f}_2(\mathrm{x}), \ldots, \mathrm{f}_\mathrm{k}(\mathrm{x})\}$ are the objective functions to be maximized (or minimized), $\mathrm{g}_\mathrm{j}(\mathrm{x}) \leq \mathrm{b}_\mathrm{j}$ is a set of constraints.

A solution to MCDM problem is called a superior solution if it is feasible and maximizes (or minimizes) all the objectives simultaneously. In most MODM problems, a superior solution does not exist as the objectives conflict with one another.

3.1.2 Multiple Attribute Decision Making

MADM is the most well known branch of decision making. It is a branch of a general class of operations research models that deal with decision problems under the presence of a number of decision criteria. The MADM approach requires that the choice (selection) be made among decision alternatives described by their attributes. MADM problems are assumed to have a predetermined, limited number of decision alternatives [38]. For a given set of alternatives, MADM models try to choose the best alternative among them, rank the alternatives from the best to the worst or classify them into classes [41].

MADM approaches can be viewed as alternative methods for combining the information in a problem's decision matrix together with additional information from the decision maker to determine a final ranking, screening, or selection among the alternatives. Besides the information contained in the decision matrix, all but the simplest MADM techniques require additional information from the decision maker to arrive at a final ranking, screening, or selection [38]. A typical MADM problem is formulated as [42].

$$(MADM) \begin{cases} Select\ A_i\ from\ \ A_1, \ldots, A_m \\ using\ \ X_1, \ldots, X_n \end{cases} \tag{3.2}$$

where $\{A_1, \ldots, A_m\}$ denotes m alternatives, and $\{X_1, \ldots, X_n\}$ represents the n attributes. The selection is usually based on maximizing a multiple attribute utility function.

The problems of MADM are widely diverse. However, even with the diversity, all the problems which are considered here share the following common characteristics:

Alternatives: In general, the alternatives represent the different choices of action available to the decision maker. A finite number of alternatives are to be screened, prioritized, selected and ranked [43].

Multiple attributes: Each problem has multiple attributes. A decision maker must generate relevant attributes for each problem setting. Attributes are also referred to as "goals" or "decision criteria". Attributes represent the different dimensions from which the alternatives can be viewed. In situations where the number of attributes is large, the attributes can be classified in a hierarchical manner. In this case, certain attributes can be major ones. Each major attribute can be associated with several sub-attributes.

Conflict among Attributes: Since different attribute represent different dimensions of the alternatives, they usually conflict with each other [37].

Incommensurable Units: Different criteria may be associated with different units of measure.

Decision Weights: Most of the MADM methods require that the attribute be assigned weights of importance. Usually these weights are normalized to add up to one.

Decision Matrix: A MADM problem can be concisely expressed in a matrix format. A decision matrix D is a *(m x n)* matrix whose element x_{ij} indicates the performance rating of alternative A_i, with respect to attribute X_j $(i = 1,2, \dots, m \text{ and } j = 1,2, \dots, n)$. In other words the matrix is called the matrix of decision or performance table. Each line of this matrix expresses the performances of the action or alternative i relative to n attribute considered. Each column *j* expresses the evaluations of all the actions made by the decision maker, relative with the attribute [43].

3.2 Multiple Attribute Decision Making Methods

Among the MADM methods developed in the literature, analytical hierarchy process (AHP), analytic network process (ANP), multiple attribute utility theory (MAUT), data envelopment analysis (DEA), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and outranking methods (PROMETHEE and ELECTRE) are more frequently applied to discrete decision problems than all other methods. The following sub-sections give a brief introduction to the main concept and features of them.

3.2.1 Analytic Hierarchy Process (AHP)

The analytical hierarchy process (AHP) was developed primarily by Saaty [5]. AHP is a type of additive weighting method. It has been widely reviewed and applied in the literature, and its use is supported by several commercially available, user-friendly software packages. Decision makers often find it difficult to accurately determine cardinal importance weights for a set of attributes simultaneously. As the number of attributes increases, better results are obtained when the problem is converted to one of making a series of pairwise comparisons. AHP formalizes the conversion of the attribute weighting problem into the more tractable problem of making a series of pairwise comparisons among competing attributes [38].

The essence of the process is decomposition of a complex problem into a hierarchy with goal (objective) at the top of the hierarchy, attributes and sub-attributes at levels and sub-levels of the hierarchy, and decision alternatives at the bottom of the hierarchy. AHP summarizes the results of pairwise comparisons in a “matrix of pairwise comparisons.” The relative priorities of the elements in each level of the hierarchy are determined by pairwise comparisons using 1-9 scale [44]. Each pairwise comparison requires the decision maker to provide an answer to the question: “Attribute A is how much more important than Attribute B, relative to the overall objective?” A detailed description of the AHP method is presented in Chapter 5.1.

3.2.2 Analytic Network Process (ANP)

The ANP, also introduced by Saaty, is a generalization of the analytic hierarchy process (AHP) [45]. Whereas AHP represents a framework with a unidirectional hierarchical AHP relationship, ANP allows for complex interrelationships among decision levels and attributes. The ANP feedback approach replaces hierarchies with networks in which the relationships between levels are not easily represented as higher or lower, dominant or subordinate, direct or indirect [46]. For instance, not only does the importance of the criteria determine the importance of the alternatives, as in a hierarchy, but also the importance of the alternatives may have impact on the importance of the criteria [45].

In some practical decision problems, it seems to be the case where the local weights of criteria are different for each alternative. AHP has a difficulty in treating in such a case since AHP uses the same local weights of criteria for each alternative. ANP permits the use of different weights of criteria for alternatives [38]. A detailed description of the ANP method is presented in Chapter 5.3.

3.2.3 Multiple Attribute Utility Theory (MAUT)

Multiple attribute utility theory takes into consideration the decision maker's preferences in the form of utility functions which is defined over a set of attributes. The utility value can be determined by determination of single attribute utility functions followed by verification of preferential and utility independent conditions and derivation of multiple attribute utility functions. The utility functions can be either additively separable or multiplicatively separable with respect to single attribute utility [47].

The main steps in using a multiple attribute utility model can be counted as 1) determination of utility functions for individual attributes, 2) determination of weighting or scaling factors, 3) determination of the type of utility model, 4) the measurement of the utility values for each alternative with respect to the considered attributes, and 5) the selection of the best alternative [38].

3.2.4 Data Envelopment Analysis (DEA)

Data envelopment analysis (DEA) is a nonparametric method of measuring the efficiency of a decision making unit such as a firm or a public-sector agency, which was first introduced into the operations research literature by Charnes et al. [48]. DEA is a relative, technical efficiency measurement tool, which uses operations research techniques to automatically calculate the weights assigned to the inputs and outputs of the production units being assessed. The actual input/output data values are then multiplied with the calculated weights to determine the efficiency scores. DEA is a nonparametric multiple criteria method; no production, cost, or profit function is estimated from the data [38].

3.2.5 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

This method is developed by Huang and Yoon [49] as an alternative to ELECTRE. The basic concept of this method is that the selected alternative should have the shortest distance from the negative ideal solution in geometrical sense. The method assumes that each attribute has a monotonically increasing or decreasing utility. This makes it easy to locate the ideal and negative ideal solutions. Thus, the preference order of alternatives is yielded through comparing the Euclidean distances. A decision matrix of M alternatives and N criteria is formulated firstly. The normalized decision matrix and construction of the weighted decision matrix is carried out. This is followed by the ideal and negative-ideal solutions. For benefit criteria the decision maker wants to have maximum value among the alternatives and for cost criteria he wants minimum values amongst alternatives. This is followed by separation measure and calculating relative closeness to the ideal solution. The best alternative is one which has the shortest distance to the ideal solution and longest distance to negative ideal solution [50].

3.2.6 Elimination and Choice Translating Reality (ELECTRE)

The basic concept of the ELECTRE (ELimination Et Choix Traduisant la Réalité or Elimination and Choice Translating Reality) method is how to deal with outranking relation by using pairwise comparisons among alternatives under each criteria separately. The outranking relationship of two alternatives, denoted as $A_i \rightarrow A_j$, describes that even though two alternatives i and j do not dominate each other mathematically, the decision maker accepts the risk of regarding A_i as almost surely better than A_j. An alternative is dominated if another alternative outranks it at least in one criterion and equals it in the remaining criteria. The ELECTRE method consists of a pairwise comparison of alternatives based on the degree to which evaluation of the alternatives and preference weight confirms or contradicts the pairwise dominance relationship between the alternatives. The decision maker may declare that she/he has a strong, weak, or indifferent preference or may even be unable to express his or her preference between two compared alternatives [38].

3.2.7 Preference Ranking Organisation Method for Enrichment Evaluations (PROMETHEE)

The preference ranking organization method of enrichment evaluations (PROMETHEE) methods have been developed by Brans and Vincke [51] for solving MADM problems. Unlike ELECTRE's concept of concordance and discordance, positive and negative outranking flow concepts are used for gathering evidence about preference of alternatives and building the outranking relation. After aggregation of outranking relations, criterion wise ranking is done by using the information on the level of evidence that shows how much the alternative outranks other alternatives (positive outranking net flow) and how much the alternative is outranked by others (negative outranking net flow). PROMETHEE I relies on an ordinal aggregation of these evidence and produces a partial rank where a better ranked alternative has both a higher positive outranking net flow and a lower negative outranking net flow. PROMETHEE II aggregates these evidences cardinally and produces a complete rank [52]. There are other PROMETHEE methods which we did not discuss here. More detailed descriptions of PROMETHEE methods can be found in [53].

According to Chen and Hwang [54] classical MADM methods are easier to apply than the PROMETHEE method. The PROMETHEE method may be theoretically sound but is too costly to apply to MADM problems of any size.

3.3 Decision Making Under Certainty and Uncertainty

Everyone engages in the process of making decisions on a daily basis. Some of decisions are quite easy to make and almost automatic. Other decisions can be very difficult to make and almost debilitating. Likewise the information needed to make a good decision varies greatly [55]. As it was stated earlier, there are many MCDM methods available in the literature. Each method has its own characteristics. There are many ways one can classify MCDM methods. One way to classify them according to the type of data they use. That is, we may have deterministic, stochastic, or fuzzy MCDM methods [37].

Decision making under certainty means that the data are known deterministically or at least at an estimated level the decision maker is comfortable with in terms of variation. Likewise, the decision alternatives can be well defined and modeled [55]. In certainty, availability of complete, perfect, and crisp information leads to formulating, appropriate deterministic model and the decision making problem becomes maximizing the utility function [56]. The techniques used for these problem types are linear programming, nonlinear programming, integer programming, multiple objective optimization, goal programming, analytic hierarchy process, and others [40].

It is not surprising to see that uncertainty exists in the human world. Research that attempt to model uncertainty into decision analysis is done basically through probability theory and/or the fuzzy set theory. The former presents the stochastic nature of decision analysis while the latter captures the subjectivity of human behavior.

Decision making under risk means that there is uncertainty in the data, but this uncertainty can be modeled probabilistically [40]. In the case of decision making under risk, there is possibility of allocating probability values to each state of nature, therefore, the problem can be considered as maximizing the expected utility function.

It is suggested by Efstathiou [57] and Dubois and Prade [58] that a stochastic decision method such as statistical decision analysis does not measure the imprecision in human behavior; rater, this method is away to model incomplete knowledge about the external environment surrounding human beings. The fuzzy set theory, on the other hand, is a perfect means for modeling uncertainty (or imprecision) arising from mental phenomena which are neither random nor stochastic.

Decision makers face many problems with incomplete and vague information in MCDM problems since the characteristic of these problems often require this kind of information. Fuzzy set approaches are suitable to use when modeling human knowledge is necessary and when human evaluations are needed.

It has been widely recognized that most decisions made in the real world take place in an environment in which the goals and constraints, because of their complexity, are not known precisely, and thus, the problem cannot be exactly defined or precisely represented in a crisp value [59]. To deal with the kind of qualitative, imprecise information or even ill-structured decision problems, Zadeh [60] suggested employing the fuzzy set theory as a modeling tool for complex systems that can be controlled by humans but are hard to define exactly.

Fuzzy logic is a branch of mathematics that allows a computer to model the real world the same way that people do. It provides a simple way to reason with vague, ambiguous, and imprecise input or knowledge. In Boolean logic, every statement is true or false; i.e., it has a truth value 1 or 0. Boolean sets impose rigid membership requirements. In contrast, fuzzy sets have more flexible membership requirements that allow for partial membership in a set. Everything is a matter of degree, and exact reasoning is viewed as a limiting case of approximate reasoning. Hence, Boolean logic is a subset of fuzzy logic [38]. Human beings are heavily involved in the process of decision analysis. A rational approach toward decision making should take into account human subjectivity, rather than employing only objective probability measures. This attitude towards the uncertainty of human behavior led to the study of a new decision analysis field, fuzzy decision making [54].

3.4 MADM Problems and Fuzzy Sets

Problems dealing with multiple attribute decision making are common occurrences in everyday life. A MADM problem can be concisely expressed in matrix format as:

$$D = \begin{matrix} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{matrix} \begin{matrix} X_1 & X_2 & \cdots & X_n \\ \left[\begin{matrix} x_{11} \\ x_{21} \\ \vdots \\ x_{m1} \end{matrix}\right. & \begin{matrix} x_{12} \\ x_{22} \\ \vdots \\ x_{m2} \end{matrix} & \begin{matrix} \cdots \\ \cdots \\ \ddots \\ \cdots \end{matrix} & \left.\begin{matrix} x_{1n} \\ x_{2n} \\ \vdots \\ x_{mn} \end{matrix}\right] \end{matrix} \tag{3.3}$$

where $A_i,\ i = 1, \dots, m$ are possible course of actions (referred to as alternatives) ; X_j, $j = 1, \dots, n$ are attributes with which alternative performances are measured; x_{ij} is the performance (or rating) of alternative A_i with respect to attribute X_j.

It is not uncommon that, at times, the x_{ij} value (or rating) connot be assessed precisely. The imprecision may come from different sources [54]:

Unquantifiable information: The price of a new car can be easily determined while the safety or comfort of a car is not quantifiable. Safety and comfort of a car are usually expressed in linguistic terms such as good, fair, poor, etc. They are qualitative data.

Incomplete information: The speed of a fast moving object can be measured by some equipment as "about 90 kmph" but not "exactly 90 kmph." The fuzzy set theory is helpful for such cases.

Non-obtainable information: Sometimes crisp data is obtainable but the cost is too high, and the decision maker (DM) may wish to get an "*approximation*" of that crisp data. When the data is very sensitive "*approximated*" data or linguistic descriptions are used. The information is fuzzy because of its unavailability.

Partial ignorance: Some fuzziness is attributed to partial ignorance of the phenomenon since one knows only a part of the facts.

The classic MADM methods generally assume that all criteria and their respective weights are expressed in crisp values and, thus, that the rating and the ranking of the alternatives can be carried out without any problem. In a realworld decision situation, the application of the classic MADM method may face serious practical constraints from the criteria perhaps containing imprecision or vagueness inherent in the information. In many cases, performance of the criteria can only be expressed qualitatively or by using linguistic terms, which certainly demands a more appropriate method.

The most preferable situation for a MADM problem is when all ratings of the criteria and their degree of importance are known precisely, which makes it possible to arrange them in a crisp ranking. However, many of the decision making problems in the real world take place in an environment in which the goals, the constraints, and the consequences of possible actions are not known precisely [59]. These situations imply that a real decision problem is very complicated and thus often seems to be little suited to mathematical modeling because there is no crisp definition [61]. Consequently, the ideal condition for a classic MADM problem may not be satisfied, in particular when the decision situation involves both fuzzy and crisp data. In general, the term “fuzzy” commonly refers to a situation in which the attribute or goal cannot be defined crisply, because of the absence of well-defined boundaries of the set of observation to which the description applies.

A similar situation is when the available information is not enough to judge or when the crisp value is inadequate to model real situations. Unfortunately, the classic MADM methods cannot handle such problems effectively, because they are only suitable for dealing with problems in which all performances of the criteria are assumed to be known and, thus, can be represented by crisp numbers. The application of the fuzzy set theory in the field of MADM is justified when the intended goals or their attainment cannot be defined or judged crisply but only as fuzzy sets [62]. The presence of fuzziness or imprecision in a MADM problem will obviously increase the complexity of the decision situation in many ways. Fuzzy or qualitative data are operationally more difficult to manipulate than crisp data, and they certainly increase the computational requirements in particular during the process of ranking when searching for the preferred alternatives [54].

Having to use crisp values is one of the problematic points in the crisp evaluation process. As some criteria are difficult to measure by crisp values, they are usually neglected during the evaluation. Another reason is about mathematical models that are based on crisp values. These methods cannot deal with decision makers' ambiguities, uncertainties, and vagueness that cannot be handled by crisp values. The use of fuzzy set theory allows us to incorporate unquantifiable information, incomplete information, non obtainable information, and partially ignorant facts into the decision model. When decision data are precisely known, they should not be placed into a fuzzy format in the decision analysis. Applications of fuzzy sets within the field of decision making have, for the most part, consisted of extensions or "fuzzifications" of the classic theories of decision making. Decisions to be made in complex contexts, characterized by the presence of multiple evaluation aspects, are normally affected by uncertainty, which is essentially from the insufficient and/or imprecise nature of input data as well as the subjective and evaluative preferences of the decision maker. Fuzzy sets have powerful features to be incorporated into many optimization techniques.

4. THE FUZZY SET THEORY

The boundaries of classical sets are required to be drawn precisely and, therefore, set membership is determined with complete certainty. An individual is either definitely a member of the set or definitely not a member of it. This sharp distinction is also reflected in classical logic, where each proposition is treated as either true or false. However, most sets and propositions are not so neatly characterized. It is not surprising that uncertainty exists in the human world. To survive in our world, we are engaged in making decisions, managing and analyzing information, as well as predicting future events.

As stated in earlier chapters, WEEE management scenario selection is a multiple attribute decision making (MADM) problem that involve multiple and conflicting criteria.

Due to the uncertainty of information and the vagueness of human feeling and recognition, it is difficult to provide exact numerical values for the criteria and to make evaluations which exactly convey the feeling and recognition of objects for decision makers. Therefore, most of the selection parameters cannot be given precisely.

In such cases, the WEEE management scenario selection problems that can be tackled by MADM or MODM methods become fuzzy MADM and fuzzy MODM problems, respectively, and the classical models cannot be used any longer.

The fuzzy set theory is developed for solving problems in which descriptions of activities and observations are imprecise, vague, and uncertain. The term “fuzzy” refers to the situation in which there are no well-defined boundaries of the set of the activities or observations to which the descriptions apply. In fuzzy sets, the characteristic function allows various degrees of membership for the elements of a given set [63].

4.1 Fuzzy Sets

To deal with vagueness of human thought, Zadeh [60] first introduced the the fuzzy set theory, which was based on the rationality of uncertainty due to imprecision or vagueness. A major contribution of the fuzzy set theory is its capability of representing vague knowledge. The theory also allows mathematical operators and programming to apply to the fuzzy domain [64]

The fuzzy set theory is composed of an organized body of mathematical tools particularly well-suited for handling incomplete information, the unhappiness of classes of objects or situations, or gradualness of preference profiles, in a flexible way. It offers a unifying framework for modeling various types of information ranging from precise numerical, interval-valued data, to symbolic and linguistic knowledge, with a stress on semantics rather than syntax [65].

A tilde will be placed above a symbol if the symbol represents a fuzzy set. The membership functions for a fuzzy set $\tilde{A}$ will be denoted by $\mu_{\tilde{A}}(x)$ or $\mu(x|\tilde{A})$ interchangeably in the rest of this study.
Let X be a classical (or ordinary) set of objects, called the universe, whose generic elements are denoted by x, $X = \{x\}$. A fuzzy set $\tilde{A}$ in X is characterized by membership function $\mu_{\tilde{A}}(x)$ which associates with each element in X a real number in the interval $[0,1]$. The fuzzy set, $\tilde{A}$, is usually denoted by the set of pairs [54]:

$$\tilde{A} = \{(x, \mu_{\tilde{A}}(x)) | x \in X\} \tag{4.1}$$

A notation convention for fuzzy sets when the universe of discourse, X, is discrete and finite, is as follows for fuzzy set $\tilde{A}$:

$$\tilde{A} = \left\{\frac{\mu_{\tilde{A}}(x_1)}{x_1} + \frac{\mu_{\tilde{A}}(x_2)}{x_2} + \cdots\right\} = \left\{\sum_i \frac{\mu_{\tilde{A}}(x_i)}{x_i}\right\} \tag{4.2}$$

When the universe, X, is continuous and infinite, the fuzzy set $\tilde{A}$ is denoted by:

$$\tilde{A} = \left\{\int \frac{\mu_{\tilde{A}}(x)}{x}\right\} \tag{4.3}$$

In both notations, the horizontal bar is not a quotient but rather a delimiter. The numerator in each term is the membership value in set $\tilde{A}$ associated with the element of the universe indicated in the denominator. In the first notation, the summation symbol is not for the algebraic summation but rather denotes the collection or aggregation of each element; hence the "+" signs in Equation (4.2) are not the algebraic "add" but are the function-theoretic union. In Equation (4.3) the integral sign is not an algebraic integral but a continuous function theoretic union notation for continuous variables [66].

Before defining fuzzy numbers and basic fuzzy arithmetic operations, we briefly review some basic concepts of fuzzy sets. These basic definitions and notations below will be used in the following paragraphs, unless otherwise stated [54].

Complement of a fuzzy set: The complement of fuzzy set $\tilde{A}$, denoted by $\bar{\tilde{A}}$, is defined as:

$$\mu_{\bar{\tilde{A}}}(x) = 1 - \mu_{\tilde{A}}(x)\,,\ \forall x\ \in X \tag{4.4}$$

Support of fuzzy a set: It is often necessary to consider those elements in a fuzzy set which have nonzero membership grades. These elements are the support of that fuzzy set. The support of a fuzzy set $\tilde{A}$, is an ordinary set on X defined as:

$$S(A) = \{x \in X \mid \mu_{\tilde{A}}(x) > 0\} \tag{4.5}$$

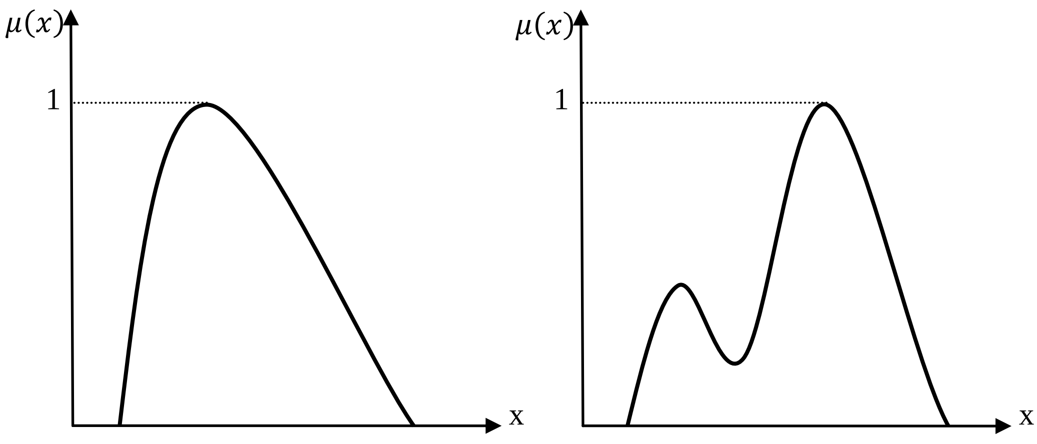
α-cut of a fuzzy set: The α-cut of a fuzzy set $\tilde{A}$ is an ordinary set whose elements belong to fuzzy set $\tilde{A}$ at least to the degree α. α-cut of a fuzzy set $\tilde{A}$ is defined as:

$$A_\alpha = \{x \in X \mid \mu_{\tilde{A}} \geq \alpha\} \tag{4.6}$$

Convexity of a fuzzy set: The convexity of a fuzzy set is an important property from the application aspect. A fuzzy set $\tilde{A}$ is convex if

$$\mu_{\tilde{A}}(\lambda x_1 + (1-\lambda)x_2) \geq \min\big(\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2)\big) \tag{4.7}$$

Where $x_1, x_2 \in X$, and $\lambda \in [0,1]$. Figure 4.1 gives a convex fuzzy set and a non-convex fuzzy set. Unless otherwise stated, all the fuzzy sets in the following chapters are assumed convex.



a) Convex b) Nonconvex

Figure 4.1: Convex and non-convex fuzzy sets [54].

Normality of a fuzzy set: A fuzzy set $\tilde{A}$ is normal if and ony if there exists at least one x value such that $\mu_{\tilde{A}}(x) = 1$. This property guarantees that at least one element in a fuzzy set fully satisfies the phenomenon that the fuzzy applies to [54]. The height of a fuzzy set $\tilde{A}$ is the maximum value of the membership function. If the height of a fuzzy set is less than unity, the fuzzy set is said to be sub normal. Figure 4.2 illustrates typical normal and subnormal fuzzy sets. Unless otherwise stated, all the fuzzy sets in the following chapters are assumed normal [66].

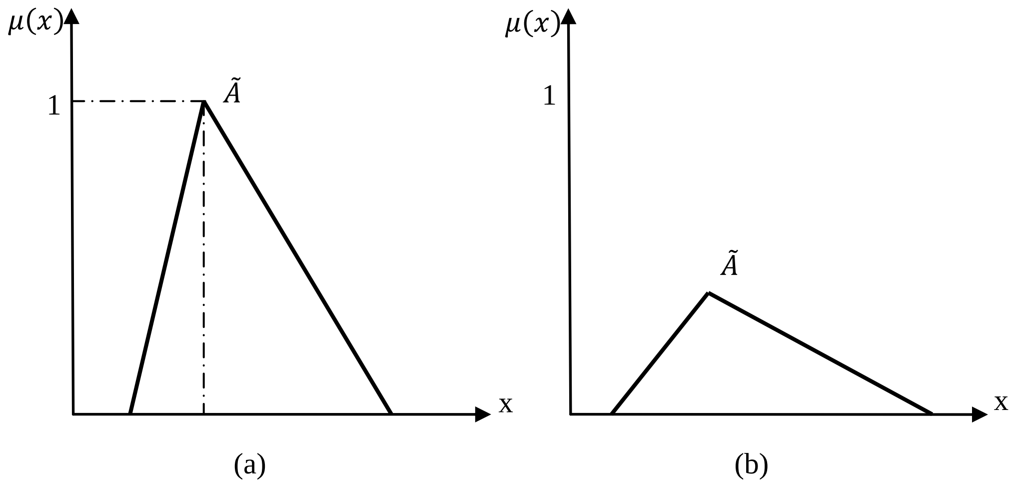


Figure 4.2: Fuzzy sets that are normal (a) and subnormal (b) [66].

If $\tilde{A}$ is a convex single-point normal fuzzy set defined on the real line, then $\tilde{A}$ is often termed a fuzzy number.

4.2 Fuzzy Numbers

A fuzzy number is a special fuzzy subset of the real numbers. Fuzzy numbers are used to characterize imprecise numerical information such as "*about 5*" or "*approximately less than 5*". A fuzzy number can be expressed in some membership function forms. Two important and widely used membership functions are linear triangular and linear trapezoidal. So far triangular numbers [12], and trapezoidal numbers [13], have been applied to various decision models. A triangular fuzzy number (TFN) is shown in Figure 4.3.

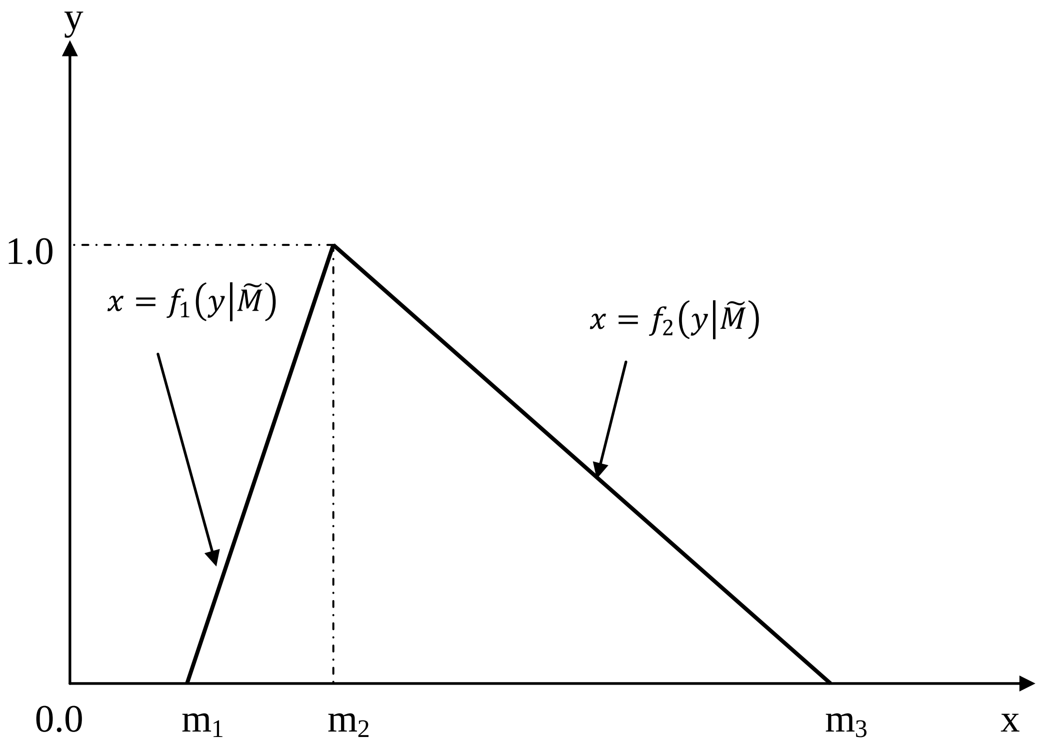


Figure 4.3: A Triangular Fuzzy Number, $\widetilde{M}$ [67]

The membership function of a TFN $(\widetilde{M})$ is defined by [67]:

$$\mu(x|\widetilde{M}) = (m_1, f_1(y|\widetilde{M})/m_2, m_2/f_2(y|\widetilde{M}), m_3) \quad (4.8)$$

Where $m_1 < m_2 < m_3$, $f_1(y|\widetilde{M})$ is a continuous monotone increasing function of y for $0 \le y \le 1$ with $f_1(0|\widetilde{M}) = m_1$ and $f_1(1|\widetilde{M}) = m_2$ and $f_2(y|\widetilde{M})$ is continuous monotone decreasing function of y for $0 \le y \le 1$ with $f_2(1|\widetilde{M}) = m_2$ and $f_2(0|\widetilde{M}) = m_3$. $\mu(x|\widetilde{M})$ is denoted simply as $(m_1/m_2, m_2/m_3)$.

The membership function of a TFN is given by Equation (4.9):

$$\mu(x) = \begin{cases} 0, & x < m_1 \\ \frac{x-m_1}{m_2-m_1}, & m_1 \le x \le m_2 \\ \frac{m_3-x}{m_3-m_2}, & m_2 \le x \le m_3 \\ 0, & x > m_3 \end{cases} \quad (4.9)$$

A flat (trapezoidal) fuzzy number (TrFN) is shown in Figure 4.4. The membership function of an TrFN, $\tilde{V}$, is defined by:

$$\mu(x|\tilde{V}) = (m_1, f_1(y|\tilde{V})/m_2, m_3/f_2(y|\tilde{V}), m_4) \quad (4.10)$$

Where $m_1 < m_2 < m_3 < m_4$, $f_1(y|\tilde{V})$ is a continuous monotone increasing function of y for $0 \le y \le 1$ with $f_1(0|\tilde{V}) = m_1$ and $f_1(1|\tilde{V}) = m_2$ and $f_2(y|\tilde{V})$ is continuous monotone decreasing function of y for $0 \le y \le 1$ with $f_2(1|\tilde{V}) = m_3$ and $f_2(0|\tilde{V}) = m_4$. $\mu(x|\tilde{V})$ is denoted simply as $(m_1/m_2, m_3/m_4)$.

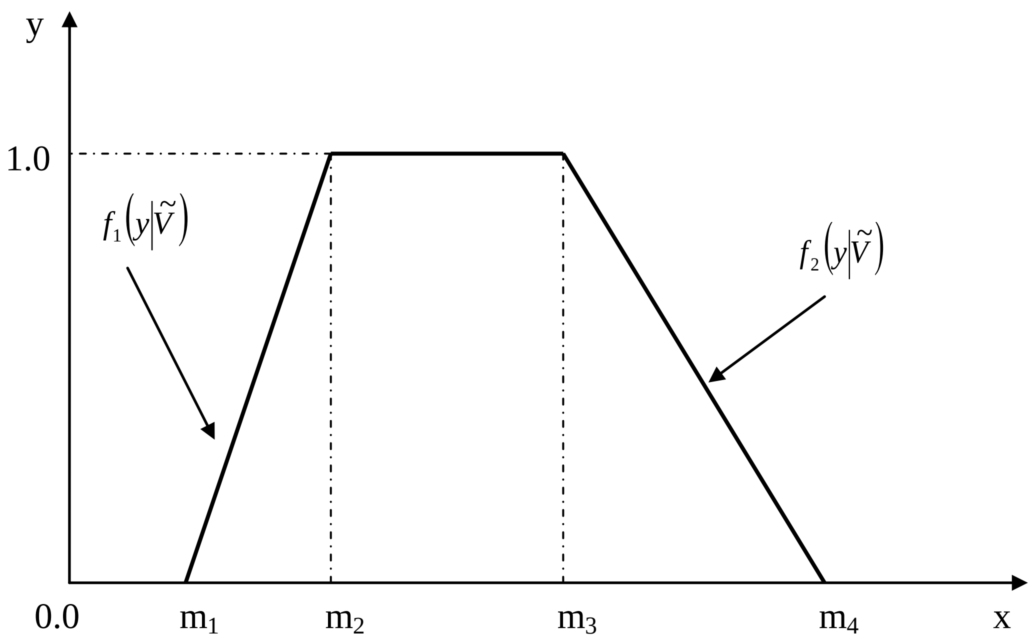


Figure 4.4: A Trapezoidal (flat) Fuzzy Number, $\tilde{V}$ [67]

The membership function of a TrFN is given by Equation (4.11)

$$\mu(x) = \begin{cases} 0, & x < m_1 \\ \frac{x-m_1}{m_2-m_1}, & x \geq 0 \\ 1, & m_2 \leq x \leq m_3 \\ \frac{m_4-x}{m_4-m_3}, & m_3 \leq x \leq m_4 \\ 0, & x > m_4 \end{cases} \qquad (4.11)$$

4.3 Fuzzy Arithmetic

One of the most basic concepts of the fuzzy set theory which can be used to generalize crisp mathematical concepts to fuzzy sets is the extension principle. Let X be a Cartesian product of universes $X = X_1, \dots ,X_r,$ and $\tilde{A}_1, \dots, \tilde{A}_r$ be r fuzzy sets in $X_1, \dots, X_r$, respectively. f is a mapping from X to universe Y, $y = f(x_1, \dots, x_r)$. Then the extension principle allows us to define a fuzzy set $\tilde{B}$ in Y by.

$$\tilde{B} = \{(y, \mu_{\tilde{B}}(y)) | y = f(x_1, \dots, x_r), (x_1, \dots, x_r) \in X\}, \qquad (4.12)$$

where

$$\mu_{\tilde{B}}(y) = \begin{cases} \sup\limits_{(x_1,\dots,x_r) \in f^{-1}(y)} \min\{\mu_{\tilde{A}_1}(x_1), \dots, \mu_{\tilde{A}_r}(x_r) \in X\}, & \textit{if } f^{-1}(y) \neq \varnothing \\ 0, & \textit{otherwise} \end{cases} \qquad (4.13)$$

where f^{-1} is the inverse of f.

Consider two triangular fuzzy numbers $\tilde{P}$ and $\tilde{Q}$, $\tilde{P} = (a,b,c)$ and $\tilde{Q} = (d,e,f)$. With this notation and by the extension principle, some of the extended algebraic operations of triangular fuzzy numbers are expressed in Table 4.1.

Table 4.1: Fuzzy arithmetic operations for $\tilde{P} = (a,b,c)$, $\tilde{Q} = (d,e,f)$ [54].

Image of $\tilde{P}$	$-\tilde{P} = (-c,-b,-a)$
Inverse of $\tilde{P}$	$\tilde{P}^{-1} = \left(\frac{1}{c},\frac{1}{b},\frac{1}{a}\right)$
Addition	$\tilde{P} \oplus \tilde{Q} = (a+d, b+e, c+f)$
Subtraction	$\tilde{P} \ominus \tilde{Q} = (a-f, b-e, c-d)$
Scalar Multiplication	
$\forall\ k > 0, k \in R$	$k \otimes \tilde{P} = (ka, kb, kc)$
$\forall\ k < 0, k \in R$	$k \otimes \tilde{P} = (kc, kb, ka)$
Multiplication	
$\tilde{P} > 0, \tilde{Q} > 0$	$\tilde{P} \otimes \tilde{Q} \cong (ad, be, cf)$
$\tilde{P} < 0, \tilde{Q} > 0$	$\tilde{P} \otimes \tilde{Q} \cong (af, be, cd)$
$\tilde{P} < 0, \tilde{Q} < 0$	$\tilde{P} \otimes \tilde{Q} \cong (cf, be, ad)$
Division	
$\tilde{P} > 0, \tilde{Q} > 0$	$\tilde{P} \oslash \tilde{Q} \cong (a/f, b/e, c/d)$
$\tilde{P} < 0, \tilde{Q} > 0$	$\tilde{P} \oslash \tilde{Q} \cong (c/f, b/e, a/d)$
$\tilde{P} < 0, \tilde{Q} < 0$	$\tilde{P} \oslash \tilde{Q} \cong (c/d, b/e, a/f)$

The arithmetic operations for two trapezoidal (flat) fuzzy numbers are given in Table 4.2. Let $\tilde{D} = (a, b, c, d)$ and $\tilde{H} = (e, f, g, h)$ be two trapezoidal fuzzy numbers [54].

Table 4.2: Fuzzy arithmetic operations for $\tilde{D} = (a, b, c, d)$, $\tilde{H} = (e, f, g, h)$

Image of $\tilde{D}$	$-\tilde{D} = (-d, -c, -b, -a)$
Inverse of $\tilde{D}$	$\tilde{D}^{-1} = \left(\frac{1}{d}, \frac{1}{c}, \frac{1}{b}, \frac{1}{a}\right)$
Addition	$\tilde{D} \oplus \tilde{H} = (a + e, b + f, c + g, d + h)$
Subtraction	$\tilde{D} \ominus \tilde{H} = (a - h, b - g, c - f, d - e)$
Scalar Multiplication	
$\forall\, k > 0, k \in R$	$k \otimes \tilde{D} = (ka, kb, kc, kd)$
$\forall\, k < 0, k \in R$	$k \otimes \tilde{D} = (kd, kc, kb, ka)$
Multiplication	
$\tilde{D} > 0, \tilde{H} > 0$	$\tilde{D} \otimes \tilde{H} \cong (ae, bf, cg, dh)$
$\tilde{D} < 0, \tilde{H} > 0$	$\tilde{D} \otimes \tilde{H} \cong (ed, fc, gb, ha)$
$\tilde{D} < 0, \tilde{H} < 0$	$\tilde{D} \otimes \tilde{H} \cong (dh, cg, bf, ae)$
Division	
$\tilde{D} > 0, \tilde{H} > 0$	$\tilde{D} \oslash \tilde{H} \cong (a/h, b/g, c/f, d/e)$
$\tilde{D} < 0, \tilde{H} > 0$	$\tilde{Q} \oslash \tilde{H} \cong (d/h, c/q, b/f, a/e)$
$\tilde{D} < 0, \tilde{H} < 0$	$\tilde{Q} \oslash \tilde{H} \cong (d/e, c/f, b/g, a/h)$

4.4 Defuzzifying Fuzzy Numbers

The final step is to defuzzify the new fuzzy set to obtain a crisp number (quantitative value) that can be communicated easily. Defuzzification is the conversion of a fuzzy quantity to a precise quantity, just as fuzzification is the conversion of a precise quantity to a fuzzy quantity. The output of a fuzzy process can be the logical union of two or more fuzzy membership functions defined on the universe of discourse of the output variable [66]. In the literature there are various defuzzification methods like max membership principle, centroid method, weighted average method, mean max membership, center of sums method. In this study the following defuzzification equation is used:

For TrFN = (a,b,c,d)

$$z^{*} = \frac{a + 2(b + c) + d}{6} \tag{4.14}$$

5. PROPOSED METHODOLOGY: A FUZZY ANP METHOD

There are a number of variables affecting the WEEE management scenario selection problem, some of these are interdependent among each other. Analytic Hierarchy Process (AHP) is one of the analytical tools, which can be used to handle multiple attribute decision making problem [45]. However, a shortfall of AHP is that it lacks in considering interdependencies, if any, among the selection criteria. Analytic Network Process (ANP) is a similar technique, but can capture the interdependencies between the criteria under consideration, hence allowing for a more systemic analysis. It can allow inclusion of criteria, both tangible and intangible, which has some bearing on making the best decision [45]. Further, many of these factors have some level of interdependency among them, thus making ANP modeling better fit for the problem under study

In order to get the best result in analysis it is, necessary to work with more than one expert and use the right analysis tools. Due to the uncertainty of information and the vagueness of human feeling and recognition, it is difficult to provide exact numerical values for the criteria and to make evaluations which exactly convey the feeling and recognition of objects for decision makers. Therefore, most of the selection parameters cannot be given precisely. For this reason, in this study, the usage of the fuzzy version of ANP is proposed to make a multiple attribute selection among WEEE management scenarios. In the proposed methodology, the decision makers' opinions on the relative importance of the selection criteria are determined by a fuzzy AHP procedure. To do this, Zeng et al.’s [14] method was modified to follow a similar way to classical AHP.

5.1 Analytic Hierarchy Process

The analytic hierarchy process (AHP), originally developed by Thomas Saaty in 1980 is a process designed for solving complex problems involving multiple criteria. It is a popular technique often used to model subjective decision making processes because it is conceptually simple, easy to understand.

The analytic hierarchy process has been used in many different fields as a multiple attribute decision analysis tool with multiple alternatives and criteria. An extensive literature review on AHP can be found in Vaidya and Kumar's [68] study. AHP uses "pairwise comparisons" and matrix algebra to weigh criteria. The decision is made by using the derived weights of the evaluative criteria [5].

Using the AHP modeling in solving decision problems includes five steps:

Step 1: Construct the hierarchical structure,
Step 2: Obtain the input values by pairwise comparisons of each level,
Step 3: Estimate the relative weights of criteria with respect to the goal, and each alternative with respect to each criterion,
Step 4: Check for consistency,
Step 5: Combine the relative weights to determine the most preferred alternative.

A decision problem centered around measuring contributions to an overall goal, is structured and decomposed into its constituent parts using a hierarchy. The concepts of a system are used to build a hierarchy for deciding the belonged relation at various levels. Each level includes several independent elements. In general, the AHP divides a complicated problem into three levels: the overall goal of the problem; the evaluation criteria (objectives) used; and the decision alternatives considered. Figure 5.1 shows a basic hierarchical decision model in AHP. The criteria for the performance evaluation for each dimension should be mutually independent.

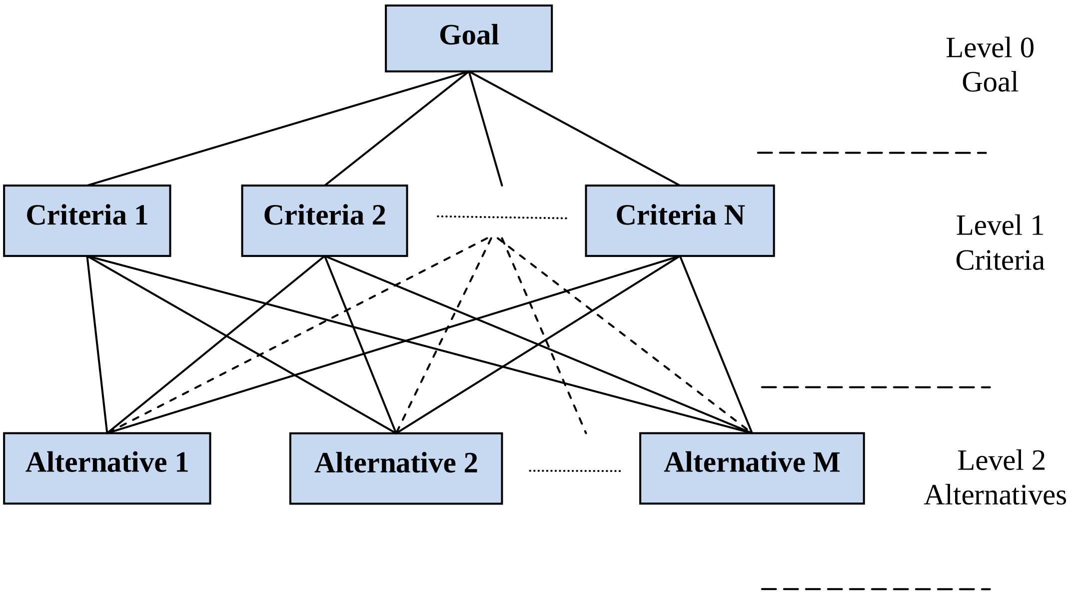


Figure 5.1: Analytic Hierarchy Process Design

After the hierarchy of the problem is constructed, the matrices of pairwise comparisons are obtained. In this matrix, the element $a_{ij} = 1/a_{ij}$, and thus, when $i = j$, $a_{ij} = 1$. The value of w_i may vary from 1 to 9, and 1 indicates equal importance, whereas 9 indicates extreme or absolute importance. The scale is shown in the Table 5.1.

Table 5.1: Saaty's 1-9 Scale for Pairwise Comparisons

Intensity of Importance	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favour one over another
5	Strong importance	Experience and judgment strongly favour one over another
7	Very strong importance	An activity is strongly favoured and its dominance is demonstrated in practice
9	Absolute importance	The importance of one over another affirmed on the highest possible order
2,4,6,8	Intermediate values	Used to represent compromise between the priorities listed above

$$A = (a_{ij}) = \begin{bmatrix} 1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & 1 & \cdots & w_2/w_n \\ \vdots & \vdots & \cdots & \vdots \\ w_n/w_1 & w_n/w_2 & \cdots & 1 \end{bmatrix} \quad (5.1)$$

In the comparisons, some inconsistencies can be expected and accepted. When *A* contains inconsistencies, the estimated priorities can be obtained by using the *A* matrix as the input using the eigenvalue technique.

$$(A - \lambda_{max} I)q = 0 \quad (5.2)$$

where λ_{max} is the largest eigenfactor of matrix *A* of size *n*, *q* is its correct eigenfactor and *I* is the identity matrix of size *n*. The correct eigenfactor, *q*, constitutes the estimation of relative priorities. Each eigenfactor is scaled to sum up to one to obtain the priorities. Saaty [69] demonstrated that $\lambda_{max} = n$ is a necessary and sufficient condition for consistency. Inconsistency may occur when λ_{max} deviates from *n* due to inconsistent responses in pairwise comparisons. Therefore, the matrix *A* should be tested for consistency using index, *CI*, which has been constructed.

$$CI = (\lambda_{max} - n)/(n - 1) \quad (5.3)$$

CI estimates the level of consistency with respect to a comparison matrix. Then, because *CI* is dependent on *n*, a consistency ratio *CR* is calculated, which is dependent of *n* as shown below.

$$CR = CI/RI \quad (5.4)$$

where *CI* is the consistency index, *RI* is random index *(RI)* generated for a random matrix of order *n*, and *CR* is the consistency ratio [70]. The general rule is that $CR \leq 0.1$ should be maintained for the matrix to be consistent. Otherwise, all or some comparisons must be repeated in order to resolve the inconsistencies of the pairwise comparisons.

5.2 Fuzzy Analytic Hierarchy Process

There are many fuzzy AHP methods proposed by various authors. These methods are systematic approaches to the alternative selection and justification problem by using the concepts of the fuzzy set theory and hierarchical structure analysis. Decision makers usually find that it is more certain to give interval judgments than fixed value judgments. This is because usually he/she is unable to be explicit about his/her preferences due to the fuzzy nature of the comparison process [71].

The earliest work in fuzzy AHP appeared in van Laarhoven and Pedrycz [12], which compared fuzzy ratios described by triangular membership functions. Buckley [13] determines fuzzy priorities of comparison ratios trapezoidal membership functions. Cheng & Mon [72] proposed a new algorithm for evaluating weapon systems by Analytical Hierarchy Process (AHP) based on fuzzy scales, which is a multiple criteria decision making approach in a fuzzy environment. Chang [10] introduces a new approach for handling fuzzy AHP, with the use of triangular fuzzy numbers for pairwise comparison scale off fuzzy AHP and the use of the extent analysis method for the synthetic extent values of the pairwise comparisons. Cheng [73] proposes a new algorithm for evaluating naval tactical missile systems by the fuzzy analytical hierarchy process based on grade value of membership function. Deng [74] presents a fuzzy approach for tackling qualitative multiple criteria analysis problems in a simple and straightforward manner. Csutora and Buckley [75] came up with a Lambda-max method, which is the direct fuzzification of the well-known λ_{max} method. Mikhailov [76] proposed a fuzzy preference programming method to derive optimal crisp priorities, which are obtained from fuzzy pairwise comparison judgments based on α-cuts decomposition of the fuzzy judgments into a series of interval comparisons. However, although fuzzy preference programming method claimed its superiority over some of the existing fuzzy prioritization methods the mathematical complexity involved may restrict its practicability. Zeng et al. [14] presented a modified AHP to structure and prioritize diverse risk factors, which also derives crisp weights from fuzzy comparison matrices. In their research, Tüysüz and Kahraman [77] and Büyüközkan et al. [78] reviewed fuzzy AHP approaches in detail.

Some of the fuzzy AHP methods mentioned above have some clear disadvantages. They require heavy computations, may result in unacceptable final fuzzy scores, and need additional fuzzy ranking procedures [76].

Table 5.2 gives a comparison of the fuzzy AHP methods in the literature that have important differences in their theoretical structures. The comparison includes the advantages and disadvantages of each method.

Table 5.2: The comparison of different fuzzy AHP methods

Sources	**The main characteristics**	**Advantages (A) and disadvantages (D)**
Van Laarhoven and Pedrycz [12]	• Direct extension of Saaty's AHP method with triangular fuzzy numbers. • Lootsma's logarithmic least square method is used to derive fuzzy weights and fuzzy performances scores.	**(A)** The opinion of multiple decision makers can be modeled in the reciprocal matrix. **(D)** There is not always a solution to the linear equations **(D)**The computational requirements are tremendous, even for a small problem. **(D)** It allows only triangular fuzzy numbers to be used
Buckley [13]	• Extension of Saaty's AHP method with trapezoidal fuzzy numbers. • Uses the geometric mean method to derive fuzzy weights and performance scores	**(A)** It is easy to extend to the fuzzy case **(A)** It guarantees a unique solution to the reciprocal comparison matrix. **(D)** The computational requirement is tremendous
Chang [10]	• Synthetical degree values • Layer simple sequencing • Composite total sequencing	**(A)**The computational requirement is relatively low **(A)** It follows the steps of crisp AHP. It does not involve additional operations. **(D)** It allows only triangular fuzzy numbers to be used
Cheng [73]	• Builds fuzzy standards • Represents performance scores by membership functions • Uses entropy concept to calculate aggregate weights	**(A)** The computational requirement is not tremendous **(D)** Entropy is used when probability distribution is known. The method is based on both probability and possibility measures.
Zeng [14]	• Fuzzy aggregation is used to create group decisions. • Lets any kind of scoring data to be used in the method	**(A)** The computational requirement is relatively low **(A)** It follows the steps of crisp AHP. It does not involve additional operations.

Among the above approaches, the extent analysis method has been employed in quite a number of applications due to its computational simplicity. However, such a method is found unable to derive the true weights from a fuzzy or crisp comparison matrix. The weights determined by the extent analysis method do not represent the relative importance of decision criteria or alternatives at all. Therefore, it should not be used as a method for estimating priorities from a fuzzy pairwise comparison matrix. In their paper Wang et al. [79] showed by examples that the priority vectors determined by the extent analysis method do not represent the relative importance of decision criteria or alternatives and that the misapplication of the extent analysis method to fuzzy AHP problems may lead to a wrong decision to be made and some useful decision information such as decision criteria and fuzzy comparison matrices not to be considered.

In their research the extent analysis method on fuzzy AHP was re-examined with three numerical examples. It was shown that;

- The extent analysis method might assign an irrational zero weight to some useful decision criteria and sub-criteria, leading to them not to be considered in decision analysis.
- The extent analysis method could not make full use of all the fuzzy comparison matrices information and might cause some useful fuzzy comparison matrices information to be wasted when it assigns an irrational zero weight to some useful decision criteria or sub-criteria.
- The weights determined by the extent analysis method do not represent the relative importance of decision criteria or alternatives and could not be used as their priorities.
- The extent analysis method might make a wrong decision and select the worst decision alternative as the best one when it was misused for solving a fuzzy AHP problem.

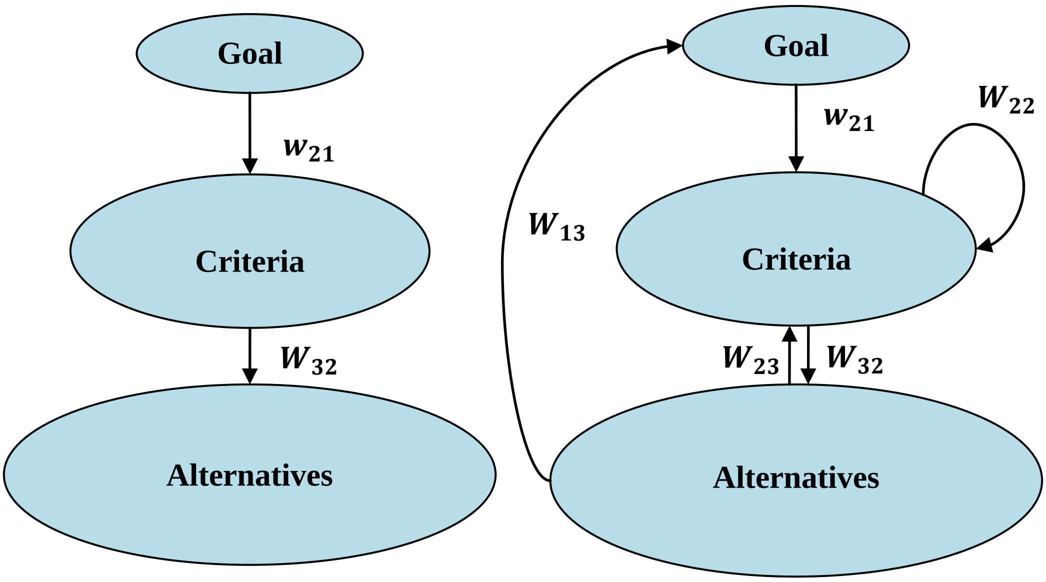
Because of its simplicity and similarity to crisp AHP we prefer using Zeng et al.'s [14] fuzzy AHP.

5.3 Analytic Network Process

ANP is a comprehensive decision-making technique that has the capability to include all the relevant criteria which have some bearing on arriving at a decision. Analytic hierarchy process (AHP) serves as the starting point of ANP. The ANP provides a general frame-work to deal with decisions without making assumptions about the interdependence of the elements within a level. In fact, ANP uses a network without needing to specify levels as in a hierarchy. Influence is a central concept in the ANP. The ANP is a useful tool for prediction and for representing the interactions among the network components in making a decision. The main reason for choosing the ANP as our methodology for selecting the best WEEE management scenario is due to its suitability in offering solutions in a complex multiple criteria decision environment. Some of the fundamental ideas in support of ANP are [80]:

- ANP is built on the widely used AHP technique,
- ANP allows for interdependency, therefore ANP goes beyond AHP,
- the ANP technique deals with dependence within a set of elements (inner dependence) and among different sets of elements (outer dependence),
- the looser network structure of the ANP makes possible the representation of any decision problem without concern for what criteria comes first and what comes next as in a hierarchy,
- the ANP is a non-linear structure that deals with sources, cycles and sinks having a hierarchy of linear form with goals in the top level and the alternatives in the bottom level,
- ANP portrays a real world representation of the problem under consideration by prioritizing not only just the elements but also groups or clusters of elements as is often necessary

The structural difference between a hierarchy and a network is depicted in Figure 5.2. The elements in a node may influence some or all the elements of any other node. In a network, there can be source nodes, intermediate nodes and sink nodes. Relationships in a network are represented by arcs, and the directions of arcs signify dependence [45]. Interdependency between two nodes, termed outer dependence, is represented by a two-way arrow, and inner dependencies among elements in a node are represented by a looped arc.



$$W_h = \begin{bmatrix} 0 & 0 & 0 \\ w_{21} & 0 & 0 \\ 0 & W_{32} & I \end{bmatrix}$$

(a) A hierarchy

$$W_n = \begin{bmatrix} 0 & 0 & W_{13} \\ w_{21} & W_{22} & W_{23} \\ 0 & W_{32} & I \end{bmatrix}$$

(b) A network

Figure 5.2: (a) Linear hierarchy (b) nonlinear network. W_{ij} refers to influence matrix of cluster *i* on cluster *j* [81].

Although all the arcs in a network have the same meaning mathematically, the interpretations differ according to whether they are between the clusters or within a cluster. Arcs emanating from an element indicate relative importance, influence or feedback. For example, the blue arcs in Figure 5.3 refer to relative priorities of the criteria with respect to the main goal while the red ones refer to the influences between the criteria and the black ones are the feedbacks from criteria to main goal. The corresponding values of the arcs are measured on a ratio scale similar to AHP. ANP approach is capable of handling interdependency among elements by obtaining the composite weights through the development of a supermatrix. The supermatrix is the combination of individual square matrices that correspond to each cluster. All in all, the supermatrix is a single matrix showing all the elements in all clusters.

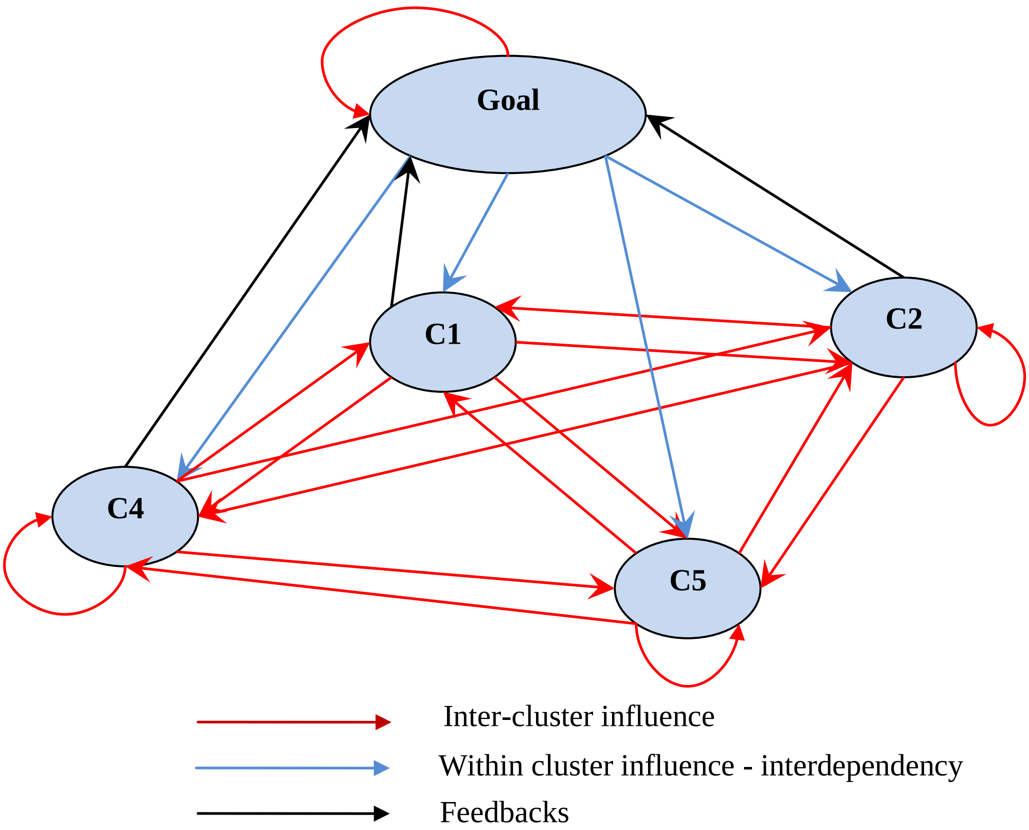


Figure 5.3: Illustration of an ANP network [82].

The priorities derived from pairwise comparison matrices are entered as parts of the columns of a supermatrix. The supermatrix represents the influence priority of an element on the left of the matrix on an element at the top of the matrix with respect to a particular control criterion. A supermatrix along with an example of one of its general entry matrices is shown in Equations (5.5 - 5.6).

$$\boldsymbol{W} = \begin{array}{cc} & \begin{array}{ccccccccc} & C_1 & & & C_2 & & \cdots & C_N & \\ e_{11} & \cdots & e_{1n_1} & e_{21} & \cdots & e_{2n_2} & \cdots\ e_{N1} & \cdots & e_{Nn_N} \end{array} \\ \begin{array}{cc} C_1 & \begin{array}{c} e_{11} \\ \vdots \\ e_{1n_1} \end{array} \\ C_2 & \begin{array}{c} e_{21} \\ \vdots \\ e_{2n_1} \end{array} \\ \vdots & \vdots \\ C_N & \begin{array}{c} e_{N1} \\ \vdots \\ e_{Nn_N} \end{array} \end{array} & \begin{bmatrix} \boldsymbol{W}_{11} & \boldsymbol{W}_{12} & \cdots & \boldsymbol{W}_{1N} \\ \boldsymbol{W}_{21} & \boldsymbol{W}_{22} & \cdots & \boldsymbol{W}_{2N} \\ \vdots & \vdots & \vdots & \vdots \\ \boldsymbol{W}_{N1} & \boldsymbol{W}_{N2} & \cdots & \boldsymbol{W}_{NN} \end{bmatrix} \end{array} \tag{5.5}$$

$$W_{ij} = \begin{bmatrix} W_{i1}^{(j1)} & W_{i1}^{(j2)} & \cdots & W_{i1}^{(jn_j)} \\ W_{i2}^{(j1)} & W_{i2}^{(j2)} & \cdots & W_{i2}^{(jn_j)} \\ \vdots & \vdots & \vdots & \vdots \\ W_{in_i}^{(j1)} & W_{in_i}^{(j2)} & \cdots & W_{in_i}^{(jn_j)} \end{bmatrix} \tag{5.6}$$

The component C_1 in the supermatrix includes all the priority vectors derived for nodes that are parent nodes in the C_1 cluster. In the ANP steady state priorities is looked for from a limit super matrix. In order to obtain the limit the matrix is raised to powers. Each power of the matrix captures all transitivity of an order that is equal to that power [83]

To summarize, ANP comprises four main steps [84]:

Step 1: Conducting pairwise comparisons on the elements at the cluster and sub-cluster levels;
Step 2: Placing the resulting relative importance weights in sub matrices within the Supermatrix.
Step 3: Adjusting the values in the supermatrix so that the supermatrix can achieve column stochastic.
Step 4: Raising the supermatrix to limiting powers until the weights have converged and remain stable.

5.4 Advantages of ANP

- ANP is a comprehensive technique that allows for the inclusion of all the relevant criteria; tangible as well as intangible, which have some bearing on decision-making process [80].
- AHP models a decision-making framework that assumes unidirectional hierarchical relationship among decision levels, whereas ANP allows for more complex relationship among the decision levels and attributes as it does not require a strict hierarchical structure.

- In decision-making problems, it is very important to consider the interdependent relationship among criteria because of the characteristics of interdependence that exists in real life problems. The ANP methodology allows for the consideration of interdependencies among and between levels of criteria and thus is an attractive multiple criteria decision-making tool. This feature makes it superior from AHP which fails to capture interdependencies among different enablers, criteria, and sub criteria [85].
- ANP methodology is beneficial in considering both qualitative as well as quantitative characteristics which need to be considered, as well as taking non-linear interdependent relationship among the attributes into consideration [86].
- ANP is unique in the sense that it provides synthetic scores, which is an indicator of the relative ranking of different alternatives available to the decision maker.

5.5 Fuzzy Analytic Network Process

In some cases, if there is vagueness for the decision problem, utilizing fuzzy sets is a useful way. For this reason, in this study, the usage of the fuzzy version of ANP is preferred. FANP has some additional advantages according to the conventional ANP method. It gives more practical results in pairwise comparison process. Therefore the method uses a linguistic scale which helps the decision maker or the expert and provides a more flexible approach in reaching a conclusion. FANP method gives better elucidation and learning in decision-making process. Below main advantages of the FANP against classical ANP are given [9].

- It better models the ambiguity and imprecision associated with the pairwise comparison process.
- It successfully derives priorities from both consistent and inconsistent judgments.
- It is cognitively less demanding for the decision makers.
- It is an adequate reflection of the decision-makers' attitude toward risk and their degree of confidence in the subjective assessments.

Although it is not popular so much as fuzzy AHP, Fuzzy ANP has been applied to many cases. Table 5.3 gives a list of various applications of FANP in the literature.

Table 5.3: Fuzzy Analytic Network Process (FANP) Studies

Year	Author(s)	Article Title	Approach	Ref. No.
2004	Büyüközkan et al.	Determining the Importance Weights for the Design Requirements in the House of Quality Using the Fuzzy Analytic Network Approach	Chang's extent analysis	[87]
2005	MOHANTY et al.	A fuzzy ANP-based approach to R&D project selection: a case study	Chang's extent analysis	[88]
2006	Kahraman et al.	A fuzzy optimization model for QFD planning process using analytic network approach	Chang's extent analysis	[89]
2007	Ayağ and Özdemir	An intelligent approach to ERP software selection through fuzzy ANP	Cheng and Mon	[6]
2008	Dağdeviren et al.	A fuzzy analytic network process (ANP) model to identify faulty behavior risk (FBR) in work system	Chang's extent analysis	[90]
2008	Promentilla et al.	A fuzzy analytic network process for multi-criteria evaluation of contaminated site remedial countermeasures	Cheng and Mon	[11]
2008	Sun and Bi	A Fuzzy ANP-based Approach to Evaluate Medical Organizational Performance	Chang's extent analysis	[91]
2009	Demirel et al.	Multi-Criteria Evaluation of Land Cover Policies Using Fuzzy AHP and Fuzzy ANP: The Case of Turkey	Deng in FAHP Chang in FANP	[92]
2009	Güneri and Şeker	A fuzzy ANP approach to shipyard location selection	Chang's extent analysis	[93]
2009	Lin et al.	Optimizing a marketing expert decision process for the private hotel	Chang's extent analysis	[94]
2009	Ramzi et al.	Developing a practical framework for ERP readiness assessment using fuzzy ANP	Chang's extent analysis	[95]
2009	Tuzkaya et al.	An integrated fuzzy multi-criteria decision making methodology for material handling equipment selection problem and an application	Chang's extent analysis	[96]
2009	Wei and Wang	A novel approach - fuzzy ANP for distribution center location	Chang's extent analysis	[97]
2009	Yüksel and Dağdeviren	Using the fuzzy analytic network process (ANP) for Balanced Scorecard (BSC): A case study for a manufacturing firm	Chang's extent analysis	[98]
2010	Boran and Göztepe	Development of a fuzzy decision support system for commodity acquisition using fuzzy analytic network process	Chang's extent analysis	[99]
2010	Dağdeviren and Yüksel	A fuzzy analytic network process (ANP) model for measurement of the sectoral competition level (SCL)	Mikhailov	[100]
2010	Liu and Wang	An advanced quality function deployment model using fuzzy analytic network process	Csutora and Buckley	[101]

While there are many proposed FAHP methods with notable differences in their theoretical foundation, only a handful of these methods are being applied in real-life problems because of computational complexity or counterintuitive results. Many attempted to 'fuzzify' AHP but limited studies had been done to investigate the fuzzy extension of ANP including its practical application to real-life decision problems. Since the supermatrix priority derivation process in the ANP requires complex matrix operations on real numbers, the most practical approach to extend FAHP to the ANP framework is to derive first the crisp priorities or weights from the fuzzy comparison matrices [9].

In this study, Zeng et al.'s [14] method was modified. The proposed method includes simplified fuzzy operations and similar steps to classical AHP. In this method, fuzzy aggregation is used to create group decisions, and then defuzzication is employed to transform the fuzzy scales into crisp scales for the computation of priority weights. The group preference of each factor is then calculated by applying fuzzy aggregation operators, i.e. fuzzy multiplication and addition operators. We partially use Zeng et al.'s [14] approach to obtain the weights from pairwise comparison matrices. Here are the steps of the methodology.

Step 1: Compare factors using pairwise comparisons. The experts are required to provide their judgments on the basis of their knowledge and expertise for each factor in the network. The experts can provide a precise numerical value, a range of numerical values, a linguistic term or a fuzzy number.

Step 2: Convert preferences into standardized trapezoidal fuzzy numbers (STFNs). Because the values of factors provided by experts are crisp numbers, range of numerical values, linguistic terms or fuzzy numbers, STFNs are employed to convert these experts' judgments into a universal format for the composition of group preferences. Let U be the universe of discourse, $U = [0, u]$. A STFN can be defined as $A = (a, b, c, d)$, where $0 \leq a \leq b \leq c \leq d$ and its membership function is as follows

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{(x-a)}{(b-a)}, & for \ a \leq x \leq b \\ 1, & for \ b \leq x \leq c \\ \frac{(d-x)}{(d-c)}, & for \ c \leq x \leq d \\ 0, & for \ otherwise \end{cases} \tag{5.7}$$

Step 3: Aggregate individual STFNs into group STFNs. The aggregation of STFN scales is defined as

$$\tilde{a}_{ij\,1} = \tilde{a}_{ij\,1}^{c_1} \otimes \tilde{a}_{ij\,2}^{c_2} \otimes \ \dots \ \otimes \tilde{a}_{ijm}^{c_m} \tag{5.8}$$

Where $\otimes$ denotes the fuzzy multiplication operator and $c_1, c_2, \dots, c_m$ are contribution factors (CFs) allocated to experts, $E_1, E_2, \dots, E_m$ and $c_1 + c_2 + \cdots + c_m = 1$.
$\tilde{a}_{ij}$ is the aggregated fuzzy scale of F_i comparing to F_j; $i, j = 1,2, \dots, n$; $\tilde{a}_{ij\,1}, \tilde{a}_{ij\,2}, \dots, \tilde{a}_{ijm}$ are the corresponding STFN scales of F_i comparing to F_j measured by experts $E_1, E_2, \dots, E_m$, respectively.

Zeng et al. [14] use arithmetic average to aggregate expert preferences. We made a modification in this step by using geometric average since arithmetic average may cause some inaccurate reciprocals to be obtained.

Step 4: Defuzzify the STFN scales. In order to convert the aggregated STFN scales into matching crisp values that can adequately represent the group preferences, a proper defuzzification is needed. Assume an aggregated STFN scale $\tilde{a}_{ij} = (a_{ij}^l, a_{ij}^m, a_{ij}^n, a_{ij}^u)$, the matching crisp value a_{ij} can be obtained

$$a_{ij} = \frac{a_{ij}^l + 2\left(a_{ij}^m + a_{ij}^n\right) + a_{ij}^u}{6} \tag{5.9}$$

where $a_{ii} = 1, a_{ji} = 1/a_{ij}$.

Consequently, all the aggregated fuzzy scales $a_{ij}\,(i, j = 1,2, \dots, n)$ are transferred into crisp scales a_{ij} within the range of [0, 9].

Let $F_1, F_2, \dots, F_n$ be a set of factors in one section, a_{ij} is the defuzzified scale representing the quantified judgment on F_i comparing to F_j. Pairwise comparisons between F_i and F_j in the same section thus yields a n-by-n matrix defined as follows:

$$A = a_{ij} = \begin{matrix} \\ F_1 \\ F_2 \\ \vdots \\ F_n \end{matrix} \begin{matrix} \begin{matrix} F_1 & F_2 & \cdots & F_n \end{matrix} \\ \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix} \end{matrix}, \quad i, j = 1,2, \dots, n \qquad (5.10)$$

where $a_{ii} = 1, a_{ji} = 1/a_{ij}$.

5.6 Steps of the Methodology

Preliminary phase

WEEE management is a complex and multidisciplinary problem that should be considered from environmental, social, and technical as well as economic aspects. The solution to this problem starts with the establishment of a decision making team in which involves a range of experts with different background/discipline and essential experience regarding the WEEE problem under consideration. Alternatives and decision criteria are determined with the help of the decision making team. As different experts have different impacts on the final decision, CF is therefore introduced into the model to distinguish experts' competence. CFs will be allocated to experts on the basis of their experience, knowledge and expertise.

Model construction and problem structuring: The problem should be stated clearly and decomposed into a rational system like a network. The structure can be obtained by the opinion of decision makers through brainstorming or other appropriate methods. An example of the format of a network is as shown in Figure 5.3.

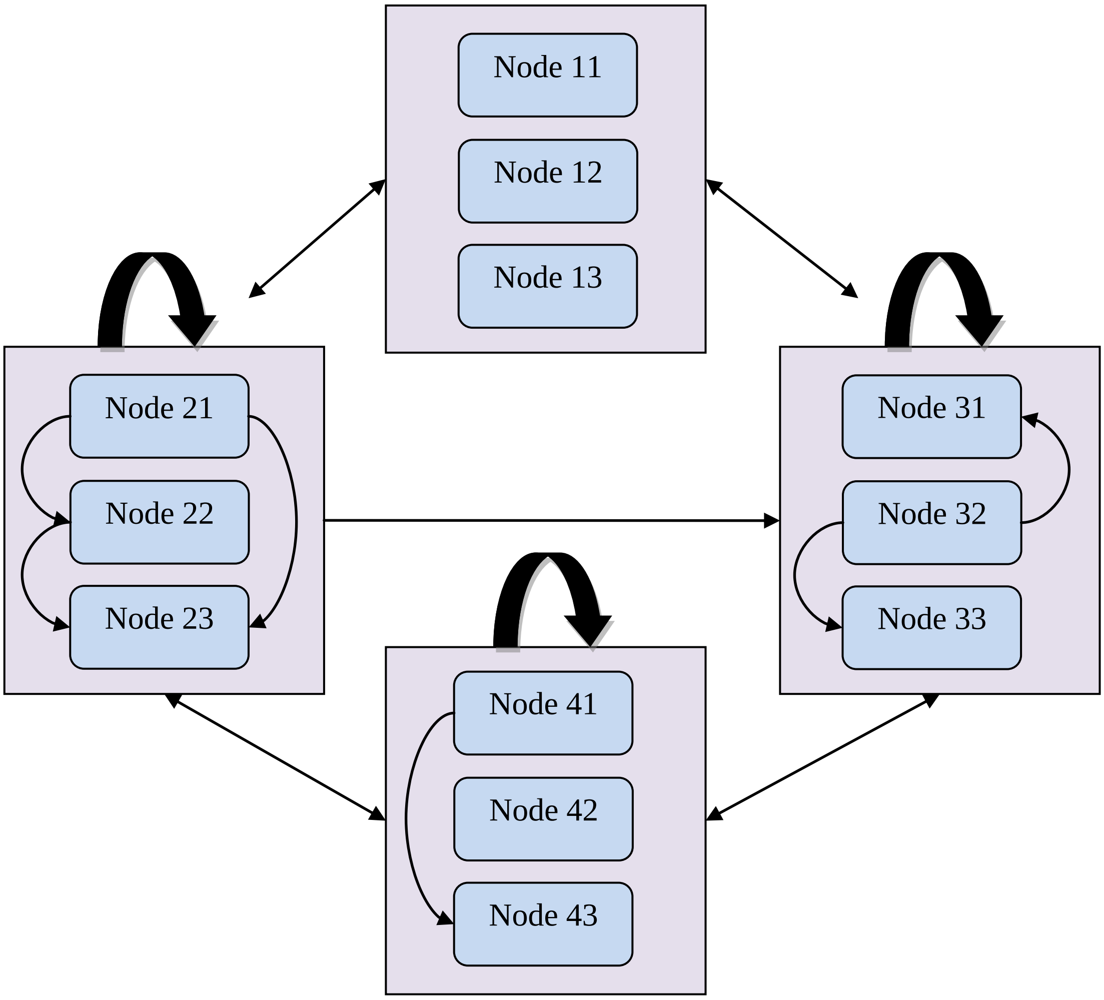


Figure 5.4: Illustration of a network design in super decisions software package.

After the clusters have been developed and the network has constructed through analysis of interrelations and feedbacks, fuzzy pairwise comparisons on the elements at the cluster and sub-cluster levels are conducted. Modified Zeng et al.'s [14] approach is used to obtain the relative importance weights as mentioned in chapter 5.5.

Supermatrix formation: After obtaining crisp relative importance weights, Super Decisions software package is used for the ANP computations. Figure 5.5 presents WEEE management scenario selection process with a wider perspective.

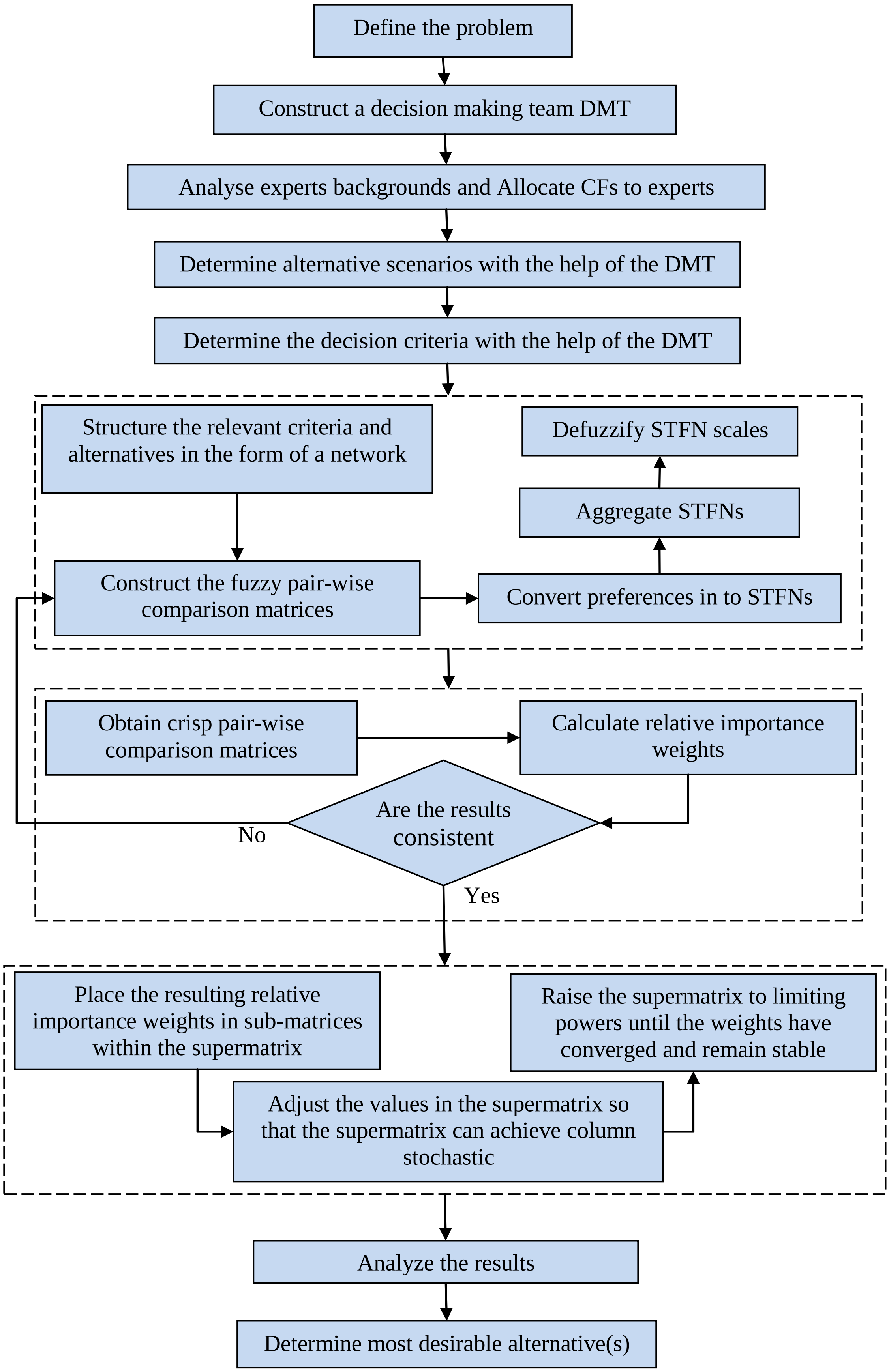


Figure 5.5: WEEE management scenario selection process

6. APPLICATION

6.1 Problem Definition

One of the fastest growing wastes in the world is the waste of electrical and electronic equipment (WEEE). In Europe, for per inhabitant 14 kg WEEE arises annually. This makes 5 million tons of WEEE in Europe. 90 percent of this WEEE is land filled, incinerated or tried to be recovered without pretreatment. For this reason, European community wants to prevent this with the WEEE directive. Within this directive, instead of disposal and landfill, EC wants to add value to the WEEE by reusing, recycling and recovering with other options on an environmental basis.

The recovery of WEEE is also important for Turkey, which is on the edge of European Community. Unlike some of the European countries, Turkey does not have a recycling infrastructure but wants to construct its infrastructure as quickly as possible. With its approximately 72 million population Turkey is a great market for electrical & electronic industry. A huge amount of EEEs are sold annually in Turkey. There are almost no studies about the quantity of the WEEE that arise annually and there is no activity for the separate collection of WEEE by the municipalities. There are also no professional facilities for the recovery of the WEEE in Turkey. By some producers, low quantities of WEEE are dismantled manually.

In this section a case study of WEEE management scenario evaluation is presented to demonstrate the application of the proposed fuzzy ANP methodology. In this case study fuzzy ANP is used to determine the most appropriate WEEE management scenario for Turkey. Super Decisions software package is used for the ANP computations.

6.2 Solution of the Problem

In this study, the decision problem is structured into its important components. The relevant criteria and alternatives are chosen on the basis of the review of literature and discussions with both from industry and academia. The relevant criteria and alternatives are structured in the form of a network. The alternative scenarios for WEEE management in Turkey are determined as;

(A1) Scenario 1 - Extended producers responsibility: Local authorities collect electric electronic equipments at the end of their useful life and private de-manufacturers recycle the collected equipment. In this scenario with the establishment of contemporary recycling plants can yield full material recovery including plastics. Producers of EEE will finance the recovery of WEEE according to their market share. However, new products purchased will include a user fee for their proper management after the end of their useful life.

(A2) Scenario 2 - Municipal scenario: The municipalities are responsible for the proper management of WEEE. Collected equipment is taken to recycling facilities where partial disassembly and shredding take place. In this scenario most of the WEEE will be disposed or incinerated after pretreatment for the hazardous substances, only metal is recycled. Citizens pay for the proper disposal through an increase in taxation.

(A3) Scenario 3 - Take-Back Scenario: OEMs are responsible to manage their own products at the end of their useful life. The customers give back an obsolete appliance while they purchase a new one of the same type. They pay a deposit when buying the product, which is refunded when they dispose the product to an authorized de-manufacturer/recycler.

(A4) Scenario 4 - Do nothing scenario: WEEE is disposed to landfills.

In this study we are going to evaluate first three alternative scenarios for WEEE management in Turkey. Because alternative four is not an option because electronic equipment contains some very serious contaminants such as lead, cadmium, beryllium and brominated flame retardants.

After alternatives are defined then next step is to determine the evaluation criteria. In order to proceed with the successful application of multiple attribute analysis, it is essential on one hand to determine and examine an adequate number of criteria that will give a representative and complete picture of alternative scenarios that are investigated. The purpose is to find a comprehensive, operational, nun-redundant and minimal set of criteria that would represent various objectives. So after determining the objectives preliminary as economic, technical environmental and socio-political we determined the evaluation criteria from the literature. The performance dimensions and related criteria and sample references about the criteria are listed in table 6.1

Table 6.1: WEEE management scenario evaluation criteria

Dimension	**Criteria**	**References**
Economic	Availability of Funds (Ec1)	[102]
	Benefits from Recycling (Ec2)	[103]
	Cost of Operations and Maintenance (Ec3)	[2]
	Implementation Cost (Ec4)	[104]
Technological	Continuity and Predictability (T1)	[105]
	Technical feasibility (T2)	[106]
	Technical reliability (T3)	[2]
	Local technical know how (T4)	[102]
	Technical flexibility (T5)	[2]
Environmental	Air emission (En1)	[2]
	Noise pollution (En2)	[2]
	Generation of Hazardous waste (En3)	[103]
	Generation of solid waste (En4)	[103]
	Waste recovery (En5)	[107]
Socio-Political	Compatibility with legislative and administrative situation (SP1)	[2]
	Political acceptance (SP2)	[102]
	Social Acceptance (SP3)	[102]
	Potential for creation of new jobs (SP4)	[2]

After determining the evaluation criteria and the alternative set convenient for Turkey, the steps of the modified fuzzy ANP algorithm is executed. The first step in any ANP approach is the development of a network decision framework. Super Decisions software package is used for the ANP computations. Figure 6.1 gives the network structure of the model built using Super Decisions software. And the schematic representation of the relationship among sub-criteria is presented in Figure 6.2

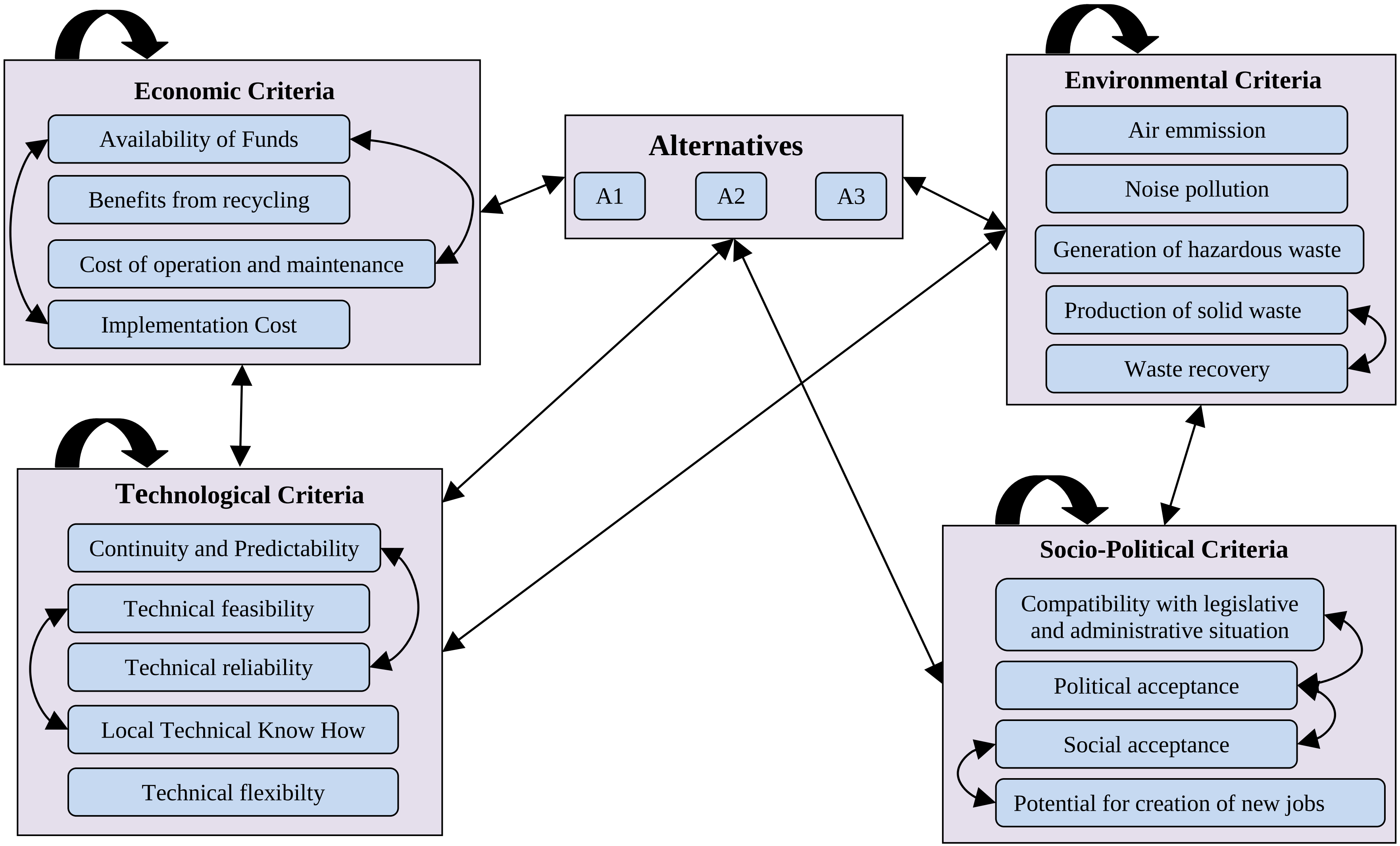


Figure 6.1: Network structure of the WEEE management scenario evaluation problem.

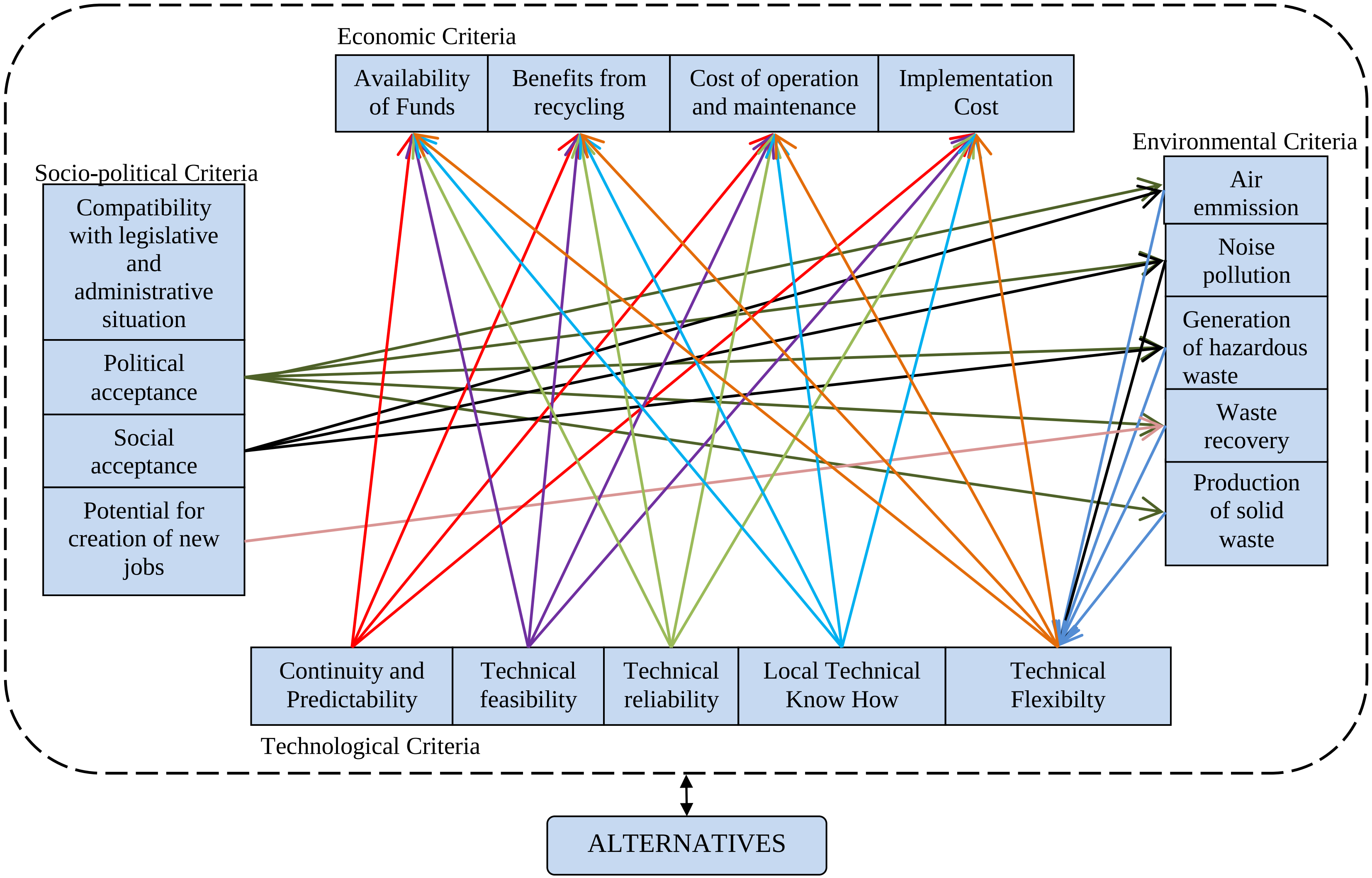


Figure 6.2: Graphical representation of Inter-cluster influences (outer dependencies)

As mentioned before Super Decisions software package is used for the ANP computations. “Super Decisions” program does not have a solution in terms of fuzzy logic. For this reason, the fuzzy data are defuzzified before inputting them into Super Decisions. An interdisciplinary decision group composed of four experts is formed. Each expert provides a decision about his/her judgment as a precise numerical value, a possible range of numerical value, a linguistic term, or a fuzzy number. Then these evaluations are converted into STFNs as defined in chapter 5.5 and aggregated STFNs are defuzzified. A scoring system is shown in Table 6.2.

Table 6.2: Fuzzy evaluation scale.

Linguistic terms	**Fuzzy scale**	**Fuzzy reciprocal scale**
Equal (E)	(1,1,1)	Equal (E)
Slightly Strong (SS)	(1,1,3)	Slightly Weak (SW)
Fairly Strong (FS)	(1,3,5)	Fairly Weak (FW)
Very Strong (VS)	(3,5,7)	Very Weak (VW)
Absolutely Strong (AS)	(5,7,9)	Absolutely Weak (AW)

The pairwise comparisons of alternatives with respect to “*benefits from recycling*” and corresponding STFNs are shown in Table 6.3.

Table 6.3: Pairwise comparison of alternatives with respect to benefit from recycling

	A1			**A2**		**A3**	
	Experts	**Score**	**STFNs**	**Score**	**STFNs**	**Score**	**STFNs**
A1	**E1**			SS	1, 1, 1, 3	FS	1, 3, 3, 5
	E2			3	3, 3, 3, 3	AS	5, 7, 7, 9
	E3			2-3	2, 2, 3, 3	5-6	5, 5, 6, 6
	E4			Ab. 3	2, 3, 3, 4	Ab. 5	4, 5, 5, 6
	Aggregation		1.000	1.86, 2.06, 2.28, 3.22		3.16, 4.79, 5.01, 6.34	
	Defuzzyified V.			2.294		4.850	
A2	**E1**					FS	1, 3, 3, 5
	E2					SS	1, 1, 1, 3
	E3					FS	1, 3, 3, 5
	E4					3-4	3, 3, 4, 4
	Aggregation				1.000	1.32, 2.28, 2.45, 4.16	
	Defuzzyified V.					2.489	
A3	**E1**						
	E2						
	E3						
	E4						
	Aggregation					1.000	

The aggregation of STFN scales can be calculated by Equation. (5.8). For example, the STFN scale of comparing Alternative A1 with Alternative A2 can be aggregated by

$$a_{12}^* = (1,1,1,3)^{0,25} \otimes (3,3,3,3)^{0.25} \otimes (2,2,3,3)^{0,25} \otimes (2,3,3,4)^{0.25}$$
$$= (1.861, 2.060, 2.280, 3.224)$$

By using Equation (5.9), the STFN scale of comparing alternative A1 with alternative A2 can be defuzzified as

$$a_{ij} = \frac{1.861 + 2(2.060 + 2.280) + 3.224}{6} = 2.294$$

These defuzzified values are entered into the ANP model using the interface provided by Super Decisions package. An example of these comparison matrixes is given in Figure 6.3

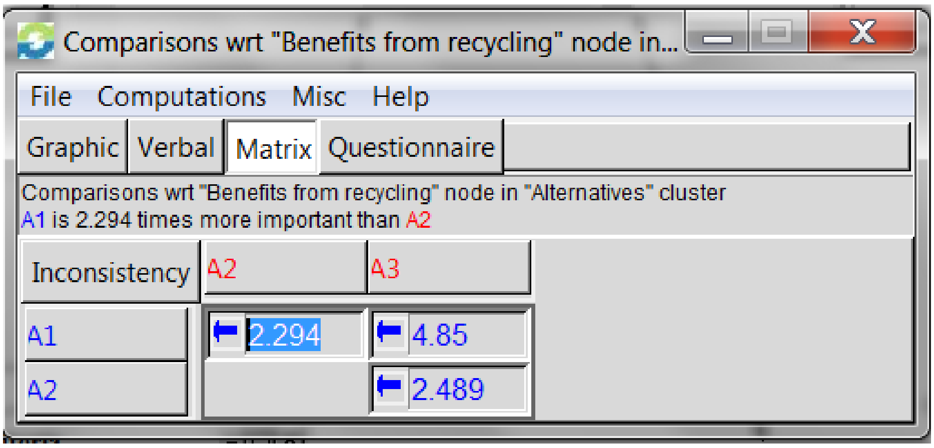


Figure 6.3: Matrix interface provided by Super Decisions package.

There are three alternatives considered in this study and alternative A1 is selected since it has the largest weight of 0.422. For demonstration, the unweighted supermatrix, weighted supermatrix, and the limiting supermatrix are illustrated in Table 6.4-6.6 respectively. Other pairwise comparison matrices can be viewed in Appendix A.

Table 6.4: Unweighted supermatrix

	A1	A2	A3	AF	BR	COM	IC	AE	GHW	NP	PSW	WR	CLAS	PA	PCNJ	SA	CaP	LAT	TKH	TF	TR
A1	0,000	0,000	0,000	0,146	0,604	0,430	0,122	0,203	0,563	0,495	0,537	0,586	0,501	0,476	0,131	0,380	0,593	0,677	0,121	0,122	0,602
A2	0,000	0,000	0,000	0,291	0,278	0,380	0,304	0,317	0,285	0,351	0,322	0,285	0,355	0,287	0,244	0,392	0,296	0,239	0,202	0,251	0,280
A3	0,000	0,000	0,000	0,563	0,118	0,190	0,574	0,480	0,152	0,154	0,141	0,129	0,144	0,237	0,625	0,228	0,111	0,084	0,676	0,627	0,118
AF	0,219	0,263	0,129	0,000	0,000	1,000	1,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,196	0,247	0,118	0,295	0,296
BR	0,466	0,415	0,485	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,423	0,292	0,470	0,219	0,216
COM	0,084	0,105	0,287	0,223	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,278	0,123	0,257	0,103	0,108
IC	0,230	0,216	0,099	0,777	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,104	0,338	0,155	0,383	0,380
AE	0,163	0,124	0,143	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,196	0,000	0,289	0,000	0,000	0,000	0,000	0,000
GHW	0,304	0,261	0,283	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,291	0,000	0,534	0,000	0,000	0,000	0,000	0,000
NP	0,094	0,085	0,085	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,075	0,000	0,177	0,000	0,000	0,000	0,000	0,000
PSW	0,167	0,185	0,182	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	1,000	0,000	0,140	0,000	0,000	0,000	0,000	0,000	0,000	0,000
WR	0,272	0,345	0,307	0,000	0,000	0,000	0,000	0,000	0,000	0,000	1,000	0,000	0,000	0,298	1,000	0,000	0,000	0,000	0,000	0,000	0,000
CLAS	0,184	0,162	0,135	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,448	0,000	0,000	0,000	0,000	0,000	0,000	0,000
PA	0,217	0,218	0,234	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	1,000	0,000	0,000	0,230	0,000	0,000	0,000	0,000	0,000
PCNJ	0,246	0,316	0,235	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,770	0,000	0,000	0,000	0,000	0,000
SA	0,353	0,304	0,396	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,552	1,000	0,000	0,000	0,000	0,000	0,000	0,000
CaP	0,135	0,145	0,294	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	1,000
LAT	0,365	0,252	0,124	0,000	0,000	0,000	0,000	1,000	1,000	1,000	1,000	1,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
LKH	0,084	0,089	0,169	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	1,000	0,000
TF	0,190	0,175	0,206	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	1,000	0,000	0,000
TR	0,225	0,338	0,208	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0.000	1,000	0,000	0,000	0,000	0,000

Table 6.5: Weighted supermatrix

	A1	A2	A3	AF	BR	COM	IC	AE	GHW	NP	PSW	WR	CLAS	PA	PCNJ	SA	CP	LAT	TKH	TF	TR
A1	0,000	0,000	0,000	0,055	0,604	0,162	0,046	0,134	0,371	0,327	0,270	0,295	0,181	0,106	0,029	0,085	0,217	0,292	0,044	0,044	0,220
A2	0,000	0,000	0,000	0,110	0,278	0,144	0,115	0,209	0,188	0,232	0,162	0,144	0,128	0,064	0,055	0,088	0,108	0,103	0,074	0,092	0,103
A3	0,000	0,000	0,000	0,213	0,118	0,072	0,217	0,317	0,100	0,102	0,071	0,065	0,052	0,053	0,140	0,051	0,041	0,036	0,248	0,230	0,043
AF	0,086	0,103	0,050	0,000	0,000	0,622	0,622	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,094	0,140	0,057	0,142	0,142
BR	0,182	0,162	0,189	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,204	0,166	0,226	0,105	0,104
COM	0,033	0,041	0,112	0,139	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,134	0,070	0,124	0,050	0,052
IC	0,090	0,084	0,039	0,483	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,050	0,192	0,075	0,184	0,183
AE	0,052	0,039	0,046	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,075	0,000	0,110	0,000	0,000	0,000	0,000	0,000
GHW	0,096	0,083	0,090	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,111	0,000	0,203	0,000	0,000	0,000	0,000	0,000
NP	0,030	0,027	0,027	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,028	0,000	0,067	0,000	0,000	0,000	0,000	0,000
PSW	0,053	0,059	0,058	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,237	0,000	0,053	0,000	0,000	0,000	0,000	0,000	0,000	0,000
WR	0,086	0,110	0,097	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,237	0,000	0,000	0,114	0,381	0,000	0,000	0,000	0,000	0,000	0,000
CLAS	0,026	0,023	0,019	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,177	0,000	0,000	0,000	0,000	0,000	0,000	0,000
PA	0,031	0,031	0,034	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,638	0,000	0,000	0,091	0,000	0,000	0,000	0,000	0,000
PCNJ	0,035	0,045	0,034	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,304	0,000	0,000	0,000	0,000	0,000
SA	0,051	0,044	0,057	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,218	0,395	0,000	0,000	0,000	0,000	0,000	0,000
CP	0,020	0,022	0,044	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,152
LAT	0,054	0,037	0,018	0,000	0,000	0,000	0,000	0,340	0,340	0,340	0,259	0,259	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
LKH	0,012	0,013	0,025	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,152	0,000
TF	0,028	0,026	0,031	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,152	0,000	0,000
TR	0,033	0,050	0,031	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,152	0,000	0,000	0,000	0,000

Table 6.6: Limit supermatrix

	A1	A2	A3	AF	BfR	COM	IC	AE	GHW	NP	PSW	WR	CLAS	PA	PCNJ	SA	CaP	LAT	TKH	TF	TR
A1	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,136	0,136
A2	0,095	0,095	0,095	0,095	0,095	0,095	0,095	0,095	0,095	0,095	0,095	0,095	0,095	0,095	0,095	0,095	0,095	0,095	0,095	0,095	0,095
A3	0,092	0,092	0,092	0,092	0,092	0,092	0,092	0,092	0,092	0,092	0,092	0,092	0,092	0,092	0,092	0,092	0,092	0,092	0,092	0,092	0,092
AF	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130	0,130
BfR	0,073	0,073	0,073	0,073	0,073	0,073	0,073	0,073	0,073	0,073	0,073	0,073	0,073	0,073	0,073	0,073	0,073	0,073	0,073	0,073	0,073
COM	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044	0,044
IC	0,103	0,103	0,103	0,103	0,103	0,103	0,103	0,103	0,103	0,103	0,103	0,103	0,103	0,103	0,103	0,103	0,103	0,103	0,103	0,103	0,103
AE	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020
GHW	0,037	0,037	0,037	0,037	0,037	0,037	0,037	0,037	0,037	0,037	0,037	0,037	0,037	0,037	0,037	0,037	0,037	0,037	0,037	0,037	0,037
NP	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012	0,012
PSW	0,031	0,031	0,031	0,031	0,031	0,031	0,031	0,031	0,031	0,031	0,031	0,031	0,031	0,031	0,031	0,031	0,031	0,031	0,031	0,031	0,031
WR	0,049	0,049	0,049	0,049	0,049	0,049	0,049	0,049	0,049	0,049	0,049	0,049	0,049	0,049	0,049	0,049	0,049	0,049	0,049	0,049	0,049
CLAS	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011
PA	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020
PCNJ	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021	0,021
SA	0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,029	0,029
CaP	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011	0,011
LAT	0,056	0,056	0,056	0,056	0,056	0,056	0,056	0,056	0,056	0,056	0,056	0,056	0,056	0,056	0,056	0,056	0,056	0,056	0,056	0,056	0,056
LKH	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007	0,007
TF	0,010	0,010	0,010	0,010	0,010	0,010	0,010	0,010	0,010	0,010	0,010	0,010	0,010	0,010	0,010	0,010	0,010	0,010	0,010	0,010	0,010
TR	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014	0,014

7. CONCLUSIONS

Our environment has limited resources, i.e. the materials we convert into products, energy, water and air supply and the places where we dispose of old products, are limited. Our society uses these resources to improve the living standard. However, we also need to provide for a sustainable environment for the next generation. To this end, we need to identify the extent of the problem and take corrective actions.

In recent years there has been growing concern about the negative impacts that industry and its products are having on both society and the environment in which we live. The concept of sustainability and the need to behave in a more sustainable manner has therefore received increasing attention. With the world's population growing rapidly and generally improving wealth, the consumption of materials, energy and other resources has been accelerating in a way that cannot be sustained. With issues such as global warming also now more openly acknowledged as being significantly influenced by our activities, there is a clear need to address the way society uses, and often wastes, valuable resources. In short, we have to behave more sustainably.

One area in which there has been much concern about the lack of sustainable behavior is in the manufacture, use and disposal of electrical and electronic products. The electronics industry provides us with the devices that have become so essential to our modern way of life and yet it also represents an area where the opportunities to operate in a sustainable way have not yet been properly realized. In fact, much electrical and electronic equipment (EEE) is typically characterized by a number of factors, including improved performance and reduced cost in each new generation of product, that actually encourage unsustainable behavior. Products such as mobile phones are often treated as fashion items and are replaced long before their design lifetimes have expired. With products increasingly having short lifecycles, using hazardous materials and processes, and generating waste at the end of their useful life, management of WEEE have become a critical issue.

WEEE management is a complex and multidisciplinary problem that should be considered from environmental, social, and technical as well as economic aspects. Multiple attribute decision making (MADM) methods can help governments and companies to evaluate alternative scenarios.

In this study we have selected the best WEEE management scenario using a MADM method. In order to get the best result in analysis it is necessary to work with more than one expert and use the right analysis tools. Due to the uncertainty of information and the vagueness of human feeling and recognition, it is difficult to provide exact numerical values for the criteria and to make evaluations which exactly convey the feeling and recognition of objects for decision makers. Therefore, most of the selection parameters cannot be given precisely. For this reason, in this study, the usage of the fuzzy version of ANP has been proposed to make a multiple attribute selection among WEEE management scenarios. In the proposed methodology, the decision makers' opinions on the relative importance of the selection criteria have been determined by a fuzzy AHP procedure. To do this, Zeng et al.'s [14] method was modified to follow a similar way to classical AHP. This is the first attempt to extend the algorithm introduced by Zeng et al. [14] within the supermatrix framework. The proposed fuzzy ANP methodology determines the most appropriate alternative based on pairwise comparisons and flexible evaluations by experts. The main feature of the proposed method is the availability of using any kind of scoring data.

The main reason for choosing the FANP as our methodology for selecting the best WEEE management scenario to its suitability in offering solutions in a complex multiple criteria decision environment. Fuzzy ANP can be viewed as an extension of ANP to accommodate explicitly the 'fuzziness' in the evaluation process. When compared with the conventional ANP, some additional advantages of fuzzy ANP can be identified. First, it could better model the vagueness and imprecision associated with the pairwise comparison process. Thus, it may be cognitively less demanding and more intuitive for the DMs. Second, it may allow an adequate reflection of the DMs' attitude toward 'fuzziness' and their degree of confidence in the subjective assessments. Fuzzy ANP, as being applied in the evaluation of WEEE management scenarios, could improve the decision process through better learning, clarification and transparency. Hence, this study demonstrates the effectiveness of the fuzzy ANP to handle not only the complexity of the problem structure at hand, but also the inherent uncertainty associated with the subjectivity of human judgment.

The presented methodological framework provides DMs' with an easy-to-use tool that could be employed either by producers of EEE or governments. The methodology has been successfully implemented for the case of Turkey. However, the procedure could be easily adopted (with slight modifications) in order to solve similar problems in countries other than Turkey, since waste management of certain waste streams is considered as significant environmental issue for many countries.

After scoring the scenarios, according to the results from the implementation of the fuzzy ANP methodology, the ranking of the scenarios is derived. Hence, the overall best scenario is the one of "Extended Producer Responsibility", described earlier.

However this does not mean that the producers of EEE are the only one responsible for the proper management of WEEE. In order to move towards a sustainable EOL plan for managing WEEE all stakeholders have to take responsibilities. With the support of Turkish government, municipalities, consumers and producers; positive changes can occur in the management of EOL EEEs in Turkey.

For the better management of WEEE scenarios, changes in manufacturing design and consumer behaviors needs to happen. Manufacturers have to start designing EE products that do not generate waste but rather can continuously be used in the same state. Consumers have to refuse to buy new EEE just because they do not have the latest and greatest. For a sustainable EOL plan to be created and to succeed, requires commitment, communication, and collaboration by all stakeholders. Commitment for a common purpose will lead to success if all stakeholders are devoted to the same cause. Currently, each manufacturer, government, residents, and processors independently decides how to handle WEEE. Consequently, manufacturers build products that are cheap and toxic; municipalities decide whether or not they want to participate in WEEE collection; residents chose where (reuse, recycle, or landfill) to dispose of unwanted EEEs. Commitment towards a sustainable EOL plan for EEE requires all stakeholders to be dedicated to the same cause which requires communicate and collaborate.

Thus, we can conclude that the Turkish Government and municipalities have to put special emphasis on waste recovery techniques and separate collection of WEEE. With the legal arrangements, they have to compel the producers to fabricate their products by recoverable materials. Stronger and clearer governmental guidelines should be in place to prevent misunderstanding and provide accountability and uniformity amongst all affected parties; Residents should be educated on the dangers of WEEE so they understand the importance of sending EOL products for reuse or recycling. Furthermore, they have to encourage the citizens to use recoverable materials.

Industry should design electronic products with less environmental impact; develop recycling technologies; setup recycling capacity; setup financing schemes for collection and sorting; provide take-back or recycling guarantee for used EEE; and communication to consumers.

It may be beneficial for the manufacturing industry and EOL processors to collaboratively work with one another to improve the design of products and it may be useful to create uniformity among all manufacturers when it comes to the types of screws, power connectors, battery, and input and output connectors used and their placement in products. And Eco-labeling programs should be implemented and they should push for the implementation of the extended producer responsibility, green productivity and cleaner production and various recycling activities.

For further research, we suggest that other multiple criteria methods to be used and compared with those results and ours. The proposed methodological approach is also not limited only to support the specific decision; it can be also used for the evaluation of management scenarios and strategies in other environmental sectors in Turkey (management of hazardous waste, used oils, used tires, etc.).

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APPENDIX A

Cluster Comparisons

Table A.1: Pairwise comparison of clusters with respect to alternatives

	Environmental Criteria			Socio-Political		Technological Criteria	
	Experts	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs
Economic Criteria	E1	SS	1,1,1,3	FS	1,3,3,5	FS	1,3,3,5
	E2	Ab. 3	2,3,3,4	Ab. 4	3,4,4,5	FS	1,3,3,5
	E3	SW	1/3,1,1,1	3	3,3,3,3	SS	1,1,1,3
	E4	2-3	2,2,3,3	SS	1,1,1,3	SS	1,1,1,3
	Aggr.	1.075, 1.565, 1.732, 2.449		1.732, 2.449, 2.449, 3.873		1, 1.732, 1.732, 3.873	
	Def. V.	1.686		2.567		1.967	
Environmental Criteria	E1			FS	1,3,3,5	3	3,3,3,3
	E2			3-4	3,3,4,4	SS	1,1,1,3
	E3			Ab. 3	2,3,3,4	FS	1,3,3,5
	E4			SS	1,1,1,3	Ab. 4	3,4,4,5
	Aggr			1.565, 2.280, 2.449, 3.936		1.732, 2.449, 2.449, 3.873	
	Def.V.			2.493		2.567	
Socio-Political Criteria	E1					SS	1,1,1,3
	E2					FW	1/5,1/3,1/3,1
	E3					Ab. 3	2,3,3,4
	E4					SW	1/3,1,1,1
	Aggr.					0.604, 1, 1, 1.861	
	Def.V.					1.078	

Table A.2: Pairwise comparison of clusters with respect to economic criteria

	Economic Criteria		
	Experts	Score	Converted STFNs
Alternatives	E1	SW	1/3, 1, 1, 1
	E2	FW	1/5, 1/3, 1/3, 1
	E3	E	1, 1, 1, 1
	E4	FW	1/5, 1/3, 1/3, 1
	Aggregation	0.340, 0.577, 0.577, 1	
	Defuzzyified V.	0.608	

Table A.3: Pairwise comparison of clusters with respect to environmental criteria

	Environmental Criteria			Technological Criteria	
	Experts	Score	Converted STFNs	Score	Converted STFNs
Alternatives	E1	FS	1, 3, 3, 5	FS	1, 3, 3, 5
	E2	2-3	2, 2, 3, 3	FS	1, 3, 3, 5
	E3	Ab. 2	1, 2, 2, 3	SS	1, 1, 1, 3
	E4	SW	1/3, 1, 1, 1	Ab. 2	1, 2, 2, 3
	Aggregation	0.904, 1.861, 2.060, 2.590		1, 2.060, 2.060, 3.873	
	Defuzzyified V.	1.889		2.185	
Environmental Criteria	E1			SW	1/3, 1, 1, 1
	E2			FW	1/5, 1/3, 1/3, 1
	E3			E	1, 1, 1, 1
	E4			SS	1, 1, 1, 3
	Aggregation			0.508, 0.760, 0.760, 1.316	
	Defuzzyified V.			0.811	

Table A.4: Pairwise comparison of clusters with respect to socio-political criteria

	Environmental Criteria			Socio-Political	
	Experts	Score	Converted STFNs	Score	Converted STFNs
Alternatives	E1	FW	1/5, 1/3, 1/3, 1	FW	1/5, 1/3, 1/3, 1
	E2	SW	1/3, 1, 1, 1	SW	1/3, 1, 1, 1
	E3	SW	1/3, 1, 1, 1	SW	1/3, 1, 1, 1
	E4	FW	1/5, 1/3, 1/3, 1	1/3	1/3, 1/3, 1/3, 1/3
	Aggregation	0.258, 0.577, 0.577, 1		0.293, 0.577, 0.577, 0.760	
	Defuzzyified V.	0.595		0.560	
Environmental Criteria	E1			SW	1/3, 1, 1, 1
	E2			SS	1, 1, 1, 3
	E3			FW	1/5, 1/3, 1/3, 1
	E4			Ab.2	1, 2, 2, 3
	Aggregation			0.508, 0.904, 0.904, 1.732	
	Defuzzyified V.			0.976	

Table A.5: Pairwise comparison of clusters with respect to technological criteria

	Economic Criteria			Technological Criteria	
	Experts	Score	Converted STFNs		
Alternatives	E1	SW	1/3, 1, 1, 1	FS	1, 3, 3, 5
	E2	FW	1/5, 1/3, 1/3, 1	SS	1, 1, 1, 3
	E3	FW	1/5, 1/3, 1/3, 1	Ab. 3	2, 3, 3, 4
	E4	Ab. 2	1, 2, 2, 3	3-4	3, 3, 4, 4
	Aggregation	0.340, 0.687, 0.687, 1.316		1.565, 2.280, 2.449, 3.936	
	Defuzzyified V.	0.734		2.493	
Economic Criteria	E1			FS	1, 3, 3, 5
	E2			FS	1, 3, 3, 5
	E3			3-4	3, 3, 4, 4
	E4			3	3, 3, 3, 3
	Aggregation			1.732, 3, 3.224, 4.162	
	Defuzzyified V.			3.057	

Node Comparisons

Table A.6: Pairwise comparison of Economic Criteria with respect to Alternative 1

	Benefits from Recycling			Cost of Operation and Maintenance		Implementation Cost	
	Experts	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs
Availability of Funds	E1	FW	1/5, 1/3, 1/3, 1	FS	1, 3, 3, 5	SS	1, 1, 1, 3
	E2	SW	1/3, 1, 1, 1	Ab. 3	2, 3 ,3 ,4	FW	1/5, 1/3, 1/3, 1
	E3	SW	1/3, 1, 1, 1	2-3	2, 2, 3, 3	SW	1/3, 1, 1, 1
	E4	FW	1/5, 1/3, 1/3, 1	4	4, 4, 4, 4	FW	1/5, 1/3, 1/3, 1
	Aggr.	0.258, 0.577, 0.577, 1		2, 2.913, 3.224, 3.936		0.340, 0.577, 0.577, 1.316	
	Def. V.	0.595		3.035		0.661	
Benefits from Recycling	E1			VS	3, 5, 5, 7	FS	1, 3, 3, 5
	E2			Ab. 5	4, 5, 5, 6	FS	1, 3, 3, 5
	E3			4-5	4, 4, 5, 5	Ab. 4	3, 4, 4, 5
	E4			FS	1, 3, 3, 5	3	3, 3, 3, 3
	Aggr.			2.632, 4.162, 4.401, 5.692		1.732, 3.224, 3.224, 4.401	
	Def. V.			4.242		3.171	
Cost of Operation and Maintenance	E1					FW	1/5, 1/3, 1/3, 1
	E2					FW	1/5, 1/3, 1/3, 1
	E3					VW	1/7, 1/5, 1/5, 1/3
	E4					FW	1/5, 1/3, 1/3, 1
	Aggr.					0.184, 0.293, 0.293, 0.760	
	Def. V.					0.353	

Table A.7: Pairwise comparison of Socio-Politic Criteria with respect to Alternative 1

	Political Acceptance			Potential for Creation of New Jobs		Social Acceptance	
	Experts	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs
Com.with Leg.and adm. situation	E1	SW	1/3, 1, 1, 1	FW	1/5, 1/3, 1/3, 1	FW	1/5, 1/3, 1/3, 1
	E2	2	2, 2, 2, 2	SW	1/3, 1, 1, 1	1/3	1/3, 1/3, 1/3, 1/3
	E3	Ab. 2	1, 2, 2, 3	SS	1, 1, 1, 3	VW	1/7, 1/5, 1/5, 1/3
	E4	SW	1/3, 1, 1, 1	1/3	1/3, 1/3, 1/3, 1/3	SW	1/3, 1, 1, 1
	Aggr.	0.687, 1.414, 1.414, 1.565		0.386, 0.577, 0.577, 1		0.237,0.386,0.386,0.577	
	Def.V.	1.318		0.616		0,393	
Political Acceptance	E1			1/2	1/2, 1/2, 1/2 , 1/2	SW	1/3, 1, 1, 1
	E2			1/2-3	1/3, 1/3, 1/2, 1/2	1/2	1/2, 1/2, 1/2, 1/2
	E3			FS	1, 3, 3, 5	Ab. 2	1, 2, 2, 3
	E4			SW	1/3, 1, 1, 1	SW	1/3, 1, 1, 1
	Aggr.			0.485, 0.841, 0.931, 1.057		0.485, 1, 1, 1.107	
	Def. V.			0.848		0.932	
Potential for Creation of New Jobs	E1					SW	1/3, 1, 1, 1
	E2					FW	1/5, 1/3, 1/3, 1
	E3					FW	1/5, 1/3, 1/3, 1
	E4					E	1, 1, 1, 1
	Aggr.					0.340, 0.577, 0.577, 1	
	Def.V.					0.608	

Table A.8: Pairwise comparison of Environmental Criteria with respect to Alternative 1

	Generation of Hazardous Waste			Noise Pollution		Production of Solid Waste		Waste recovery	
	Experts	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs
Air Emmission	E1	SW	1/3, 1, 1, 1	SS	1, 1, 1, 3	SS	1, 1, 1, 3	FW	1/5, 1/3, 1/3, 1
	E2	FW	1/5,1/3, 1/3, 1	FS	1, 3, 3, 5	SW	1/3, 1, 1, 1	VW	1/7, 1/5, 1/5 , 1/3
	E3	SW	1/3, 1, 1, 1	3	3, 3, 3, 3	FW	1/5, 1/3, 1/3, 1	SW	1/3, 1, 1, 1
	E4	FW	1/5,1/3, 1/3, 1	Ab. 3	2, 3, 3, 4	Ab. 2	1, 2, 2, 3	FW	1/5, 1/3, 1/3, 1
	Aggregation	0.258, 0.577, 0.577, 1		1.565,2.280,2.280,3.663		0.508,0.904,0.904,1.732		0.209, 0386, 0.386, 0.760	
	Defuzzyified V.	0.595		2.391		0.976		0.419	
Generation of Hazardous Waste	E1			FS	1, 3, 3, 5	SS	1, 1, 1, 3	SS	1, 1, 1, 3
	E2			SS	1, 1, 1, 3	FW	1/5, 1/3, 1/3, 1	SS	1, 1, 1, 3
	E3			3-4	3, 3, 4, 4	2-3	2, 2, 3, 3	Ab. 3	2, 3, 3, 4
	E4			Ab. 3	2, 3, 3, 4	2	2, 2, 2, 2	3-4	3, 3, 4, 4
	Aggregation			1.565,2.280,2.449,3.936		0.946,1.075,1.189,2.060		1.565, 1.732, 1.861, 3.464	
	Defuzzyified V.			2.493		1.256		2.036	
Noise Pollution	E1					FW	1/5, 1/3, 1/3, 1	FW	1/5, 1/3, 1/3, 1
	E2					SW	1/3, 1, 1, 1	VW	1/7, 1/5, 1/5 , 1/3
	E3					SW	1/3, 1, 1, 1	VW	1/7, 1/5, 1/5 , 1/3
	E4					SW	1/3, 1, 1, 1	FW	1/5, 1/3, 1/3, 1
	Aggregation					0.293, 0.760, 0.760, 1		0.169, 0.258, 0.258, 0.577	
	Defuzzyified V.					0.722		0.297	
Production of Solid Waste	E1							FW	1/5, 1/3, 1/3, 1
	E2							SW	1/3, 1, 1, 1
	E3							1/Ab.3	1/4, 1/3, 1/3, 1/2
	E4							E	1, 1, 1, 1
	Aggregation							0.359, 0.577, 0.577, 0.841	
	Defuzzyified V.							0.585	

Table A.9: Pairwise comparison of Technological Criteria with respect to Alternative 1

	Level of AdvancedTechnology			Local Tech. Know How		Technical Feasibilty		Technical Reliability	
	Experts	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs
Continuity and Predictability	E1	FW	1/5, 1/3, 1/3, 1	FS	1, 3, 3, 5	SW	1/3, 1, 1, 1	FW	1/5, 1/3, 1/3, 1
	E2	FW	1/5, 1/3, 1/3, 1	SS	1, 1, 1, 3	FW	1/5, 1/3, 1/3, 1	SW	1/3, 1, 1, 1
	E3	SW	1/3, 1, 1, 1	2	2, 2, 2, 2	1/4	1/4, 1/4, 1/4, 1/4	1/2	1/2, 1/2, 1/2, 1/2
	E4	1/3	1/3, 1/3, 1/3, 1/3	FS	1, 3, 3, 5	1/3-4	1/4, 1/4, 1/3, 1/3	E	1, 1, 1, 1
	Aggregation	0.258, 0.439, 0.439, 0.760		1.189, 2.060, 2.060, 3.5		0.254, 0.380, 0.408, 0.537		0.427, 0.639, 0.639, 0.841	
	Defuzzyified V.	0.462		2.155		0.395		0.637	
Technical Flexibility	E1			FS	1, 3, 3, 5	FS	1, 3, 3, 5	SS	1, 1, 1, 3
	E2			FS	1, 3, 3, 5	SS	1, 1, 1, 3	FS	1, 3, 3, 5
	E3			FS	1, 3, 3, 5	3-4	3, 3, 4, 4	2-3	2, 2, 3, 3
	E4			FS	1, 3, 3, 5	3	3, 3, 3, 3	Ab. 3	2, 3, 3, 4
	Aggregation			1, 3 , 3, 5		1.732, 2.280, 2.449, 3.663		1.414, 2.060, 2.280, 3.663	
	Defuzzyified V.			3		2.475		2.293	
Local Technical Know How	E1					FW	1/5, 1/3, 1/3, 1	FW	1/5, 1/3, 1/3, 1
	E2					SW	1/3, 1, 1, 1	FW	1/5, 1/3, 1/3, 1
	E3					1/3	1/3, 1/3, 1/3, 1/3	1/3-4	1/4, 1/4, 1/3, 1/3
	E4					1/2	1/2, 1/2, 1/2, 1/2	1/Ab. 4	1/5, 1/4, 1/4, 1/3
	Aggregation					0.325, 0.485, 0.485, 0.639		0.211, 0.289, 0.310, 0.577	
	Defuzzyified V.					0.484		0.331	
Technical Feasibilty	E1							SW	1/3, 1, 1, 1
	E2							FW	1/5, 1/3, 1/3, 1
	E3							FW	1/5, 1/3, 1/3, 1
	E4							SW	1/3, 1, 1, 1
	Aggregation							0.258, 0.577, 0.577, 1	
	Defuzzyified V.							0.595	

Table A.10: Pairwise comparison of Economic Criteria with respect to Alternative 2

		Benefits from Recycling		Cost of Operation and Maintenance		Implementation Cost	
	Experts	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs
Availability of Funds	E1	SW	1/3, 1, 1, 1	FS	1, 3, 3, 5	SS	1, 1, 1, 3
	E2	SW	1/3, 1, 1, 1	Ab. 4	3, 4, 4, 5	SW	1/3, 1, 1, 1
	E3	1/2	1/2, 1/2, 1/2, 1/2	2-3	2, 2, 3, 3	SW	1/3, 1, 1, 1
	E4	1/Ab.2	1/3, 1/2, 1/2, 1	4-5	4, 4, 5, 5	1/2	1/2, 1/2, 1/2, 1/2
	Aggr.	0.369, 0.707, 0.707, 0.841		2.213,3.130,3.663,4.401		0.485, 0.841, 0.841, 1.107	
	Def.V.	0.673		3.367		0.826	
Benefits from Recycling	E1			FS	1, 3, 3, 5	FS	1, 3, 3, 5
	E2			Ab. 4	3, 4, 4, 5	FS	1, 3, 3, 5
	E3			FS	1, 3, 3, 5	Ab. 3	2, 3, 3, 4
	E4			4-5	4, 4, 5, 5	SS	1, 1, 1, 3
	Aggr.			1.861, 3.464, 3.663, 5		1.189, 2.280, 2.280, 4.162	
	Def.V.			3.519		2.412	
Cost of Operation and Maintenance	E1					FW	1/5, 1/3, 1/3, 1
	E2					SW	1/3, 1, 1, 1
	E3					FW	1/5, 1/3, 1/3, 1
	E4					SW	1/3, 1, 1, 1
	Aggr.					0.258, 0.577, 0.577, 1	
	Def.V.					0.595	

Table A.11: Pairwise comparison of Socio-Politic Criteria with respect to Alternative 2

		Political Acceptance		Potential for Creation of New Jobs		Social Acceptance	
	Experts	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs
Com.with Leg.and adm. situation	E1	SW	1/3, 1, 1, 1	FW	1/5, 1/3, 1/3, 1	FW	1/5, 1/3, 1/3, 1
	E2	SS	1, 1, 1, 3	SW	1/3, 1, 1, 1	1/Ab. 3	1/4, 1/3, 1/3, 1/2
	E3	2-3	2, 2, 3, 3	1/2	1/2, 1/2, 1/2, 1/2	1/Ab. 5	1/6, 1/5, 1/5, 1/4
	E4	SW	1/3, 1, 1, 1	FW	1/5, 1/3, 1/3, 1	1/3-4	1/4,1/4, 1/3, 1/3
	Aggr.	0.687,1.189,1.316, 1.732		0.286, 0.485, 0.485, 0.841		0.214, 0.273, 0.293, 0.452	
	Def.V.	1.238		0.511		0.300	
Political Acceptance	E1			1/3	1/3,1/3, 1/3, 1/3	SW	1/3, 1, 1, 1
	E2			1/2-3	1/3, 1/3, 1/2, 1/2	1/Ab.2	1/3, 1/2, 1/2, 1
	E3			Ab. 4	3, 4, 4, 5	2-3	2, 2, 3, 3
	E4			SW	1/3, 1, 1, 1	SW	1/3, 1, 1, 1
	Aggr.			0.577, 0.816, 0.904, 0.955		0.522, 1, 1.107, 1.316	
	Def. V.			0.829		1.009	
Potential for Creation of New Jobs	E1					SW	1/3, 1, 1, 1
	E2					SS	1, 1, 1, 3
	E3					SS	1, 1, 1, 3
	E4					FS	1, 3, 3, 5
	Aggr.					0.760, 1.316, 1.316, 2.590	
	Def.V.					1.436	

Table A.12: Pairwise comparison of Environmental Criteria with respect to Alternative 2

		Generation of Hazardous Waste		Noise Pollution		Production of Solid Waste		Waste recovery	
	Experts	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs
Air Emmission	E1	SW	1/3, 1, 1, 1	SS	1, 1, 1, 3	SW	1/3, 1, 1, 1	FW	1/5, 1/3, 1/3, 1
	E2	1/Ab. 3	1/4, 1/3, 1/3, 1/2	SS	1, 1, 1, 3	SW	1/3, 1, 1, 1	FW	1/5, 1/3, 1/3, 1
	E3	FW	1/5, 1/3, 1/3, 1	Ab. 2	1, 2, 2, 3	1/Ab. 2	1/3, 1/2, 1/2, 1	1/Ab. 3	1/4, 1/3, 1/3, 1/2
	E4	FW	1/5, 1/3, 1/3, 1	2-3	2, 2, 3, 3	1/2-3	1/3, 1/3, 1/2, 1/2	VW	1/7, 1/5, 1/5 , 1/3
	Aggr.	0.240, 0.439, 0.439, 0.841		1.189, 1.414, 1.565, 3		0.333, 0.639, 0.707, 0.841		0.194, 0.293, 0.293, 0.639	
	Def. V.	0.473		1.691		0.644		0.334	
Generation of Hazardous Waste	E1			FS	1, 3, 3, 5	SS	1, 1, 1, 3	SW	1/3, 1, 1, 1
	E2			3-4	3, 3, 4, 4	SS	1, 1, 1, 3	E	1, 1, 1, 1
	E3			4	4, 4, 4, 4	FS	1, 3, 3, 5	FW	1/5, 1/3, 1/3, 1
	E4			Ab. 4	3, 4, 4, 5	SS	1, 1, 1, 3	1/3	1/3, 1/3, 1/3, 1/3
	Aggr.			2.449, 3.464, 3.722, 4.472		1, 1.316, 1.316, 3.409		0.386, 0.577, 0.577, 0.760	
	Def. V.			3.549		1.612		0.576	
Noise Pollution	E1					FW	1/5, 1/3, 1/3, 1	FW	1/5, 1/3, 1/3, 1
	E2					SW	1/3, 1, 1, 1	VW	1/7, 1/5, 1/5 , 1/3
	E3					SW	1/3, 1, 1, 1	VW	1/7, 1/5, 1/5 , 1/3
	E4					FW	1/5, 1/3, 1/3, 1	1/4	1/4, 1/4, 1/4, 1/4
	Aggr.					0.258, 0.577, 0.577, 1		0.179, 0.240, 0.240, 0.408	
	Def. V.					0.595		0.258	
Production of Solid Waste	E1							SW	1/3, 1, 1, 1
	E2							SW	1/3, 1, 1, 1
	E3							E	1, 1, 1, 1
	E4							FW	1/5, 1/3, 1/3, 1
	Aggr.							0.386, 0.760, 0.760, 1	
	Def. V.							0.738	

Table A.13: Pairwise comparison of Technological Criteria with respect to Alternative 2

	Level of AdvancedTechnology			Local Tech. Know How		Technical Feasibilty		Technical Reliability	
	Experts	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs
Continuity and Predictability	E1	FW	1/5, 1/3, 1/3, 1	FS	1, 3, 3, 5	SW	1/3, 1, 1, 1	1/3-4	1/4, 1/4, 1/3, 1/3
	E2	1/Ab. 3	1/4, 1/3, 1/3, 1/2	FS	1, 3, 3, 5	FW	1/5, 1/3, 1/3, 1	FW	1/5, 1/3, 1/3, 1
	E3	SW	1/3, 1, 1, 1	3	3, 3, 3, 3	E	1, 1, 1, 1	1/3	1/3, 1/3, 1/3, 1/3
	E4	1/2	1/2, 1/2, 1/2, 1/2	Ab. 3	2, 3, 3, 4	1/3	1/3, 1/3, 1/3, 1/3	FW	1/5, 1/3, 1/3, 1
	Aggregation	0.302, 0.485, 0.485, 0.707		1.565, 3, 3, 4.162		0.386, 0.577, 0.577, 0.760		0.240, 0.310, 0.333, 0.577	
	Def.V.	0.492		2.954		0.576		0.351	
Technical Flexibility	E1			FS	1, 3, 3, 5	SS	1, 1, 1, 3	SW	1/3, 1, 1, 1
	E2			FS	1, 3, 3, 5	SS	1, 1, 1, 3	1/2	1/2, 1/2, 1/2, 1/2
	E3			SS	1, 1, 1, 3	FS	1, 3, 3, 5	1/3	1/3, 1/3, 1/3, 1/3
	E4			3	3, 3, 3, 3	Ab. 3	2, 3, 3, 4	SW	1/3, 1, 1, 1
	Aggregation			1.316, 2.280, 2.280, 3.873		1.189, 1.732, 1.732, 3.663		0.369, 0.639, 0.639, 0.639	
	Def.V.			2.385		1.963		0.594	
Local Technical Know How	E1					SW	1/3, 1, 1, 1	1/4	1/4, 1/4, 1/4, 1/4
	E2					1/2	1/2, 1/2, 1/2, 1/2	SW	1/3, 1, 1, 1
	E3					FW	1/5, 1/3, 1/3, 1	FW	1/5, 1/3, 1/3, 1
	E4					FW	1/5, 1/3, 1/3, 1	1/Ab. 4	1/5, 1/4, 1/4, 1/3
	Aggregation					0.286, 0.485, 0.485, 0.841		0.240, 0.380, 0.380, 0.537	
	Def. V.					0.511		0.383	
Technical Feasibilty	E1							SW	1/3, 1, 1, 1
	E2							1/2	1/2, 1/2, 1/2, 1/2
	E3							1/2-3	1/3, 1/3, 1/2, 1/2
	E4							FW	1/5, 1/3, 1/3, 1
	Aggregation							0.325, 0.485, 0.537, 0.707	
	Def. V.							0.513	

Table A.14: Pairwise comparison of Economic Criteria with respect to Alternative 3

	Benefits from Recycling			Cost of Op. and Maintenance		Imp. Cost	
	Experts	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs
Availability of Funds	E1	FW	1/5, 1/3, 1/3, 1	FW	1/5, 1/3, 1/3, 1	SS	1, 1, 1, 3
	E2	SW	1/3, 1, 1, 1	1/Ab.4	1/5, 1/4, 1/4, 1/3	SS	1, 1, 1, 3
	E3	FW	1/5, 1/3, 1/3, 1	1/4-5	1/5, 1/5, 1/4, 1/4	SS	1, 1, 1, 3
	E4	1/4	1/4, 1/4, 1/4, 1/4	FW	1/5, 1/3, 1/3, 1	E	1, 1, 1, 1
	Aggr.	0.240,0.408,0.408,0.707		0.2, 0.273, 0.289, 0.537		1, 1, 1, 2.028	
	Def.V.	0.430		0.310		1.213	
Benefits from Recycling	E1			FS	1, 3, 3, 5	FS	1, 3, 3, 5
	E2			3	3, 3, 3, 3	4	4, 4, 4, 4
	E3			Ab. 4	3, 4, 4, 5	FS	1, 3, 3, 5
	E4			FS	1, 3, 3, 5	VS	3, 5, 5, 7
	Aggr.			1.732, 3.224, 3.224, 4.401		1.861,3.663,3.663,5.144	
	Def.V.			3.171		3.609	
Potential for Creation of New Jobs	E1					FS	1, 3, 3, 5
	E2					FS	1, 3, 3, 5
	E3					4	4, 4, 4, 4
	E4					Ab. 5	4, 5, 5, 6
	Aggr.					2, 3.663, 3.663, 4.949	
	Def.V.					3.6	

Table A.15: Pairwise comparison of Socio-Political Criteria with respect to Alternative 3

	Political Acceptance			Potential for Creation of New Jobs		Social Acceptance	
	Experts	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs
Com.with Leg.and adm. situation	E1	FW	1/5, 1/3, 1/3, 1	FW	1/5, 1/3, 1/3, 1	FW	1/5, 1/3, 1/3, 1
	E2	SW	1/3, 1, 1, 1	FW	1/5, 1/3, 1/3, 1	FW	1/5, 1/3, 1/3, 1
	E3	E	1, 1, 1, 1	SW	1/3, 1, 1, 1	1/4	1/4, 1/4, 1/4, 1/4
	E4	FW	1/5, 1/3, 1/3, 1	SW	1/3, 1, 1, 1	1/4	1/4, 1/4, 1/4, 1/4
	Aggr.	0.340, 0.577, 0.577, 1		0.258, 0.577, 0.577, 1		0.224, 0.289, 0.289, 0.5	
	Def.V.	0.608		0.595		0.313	
Political Acceptance	E1			SW	1/3, 1, 1, 1	1/2	1/2, 1/2, 1/2, 1/2
	E2			FW	1/5, 1/3, 1/3, 1	E	1, 1, 1, 1
	E3			3	3, 3, 3, 3	1/Ab.3	1/4, 1/3, 1/3, 1/2
	E4			E	1, 1, 1, 1	SW	1/3, 1, 1, 1
	Aggr.			0.669, 1, 1, 1.316		0.452, 0.639, 0.639, 0.707	
	Def. V.			0.997		0.619	
Potential for Creation of New Jobs	E1					SW	1/3, 1, 1, 1
	E2					SW	1/3, 1, 1, 1
	E3					1/2	1/2, 1/2, 1/2, 1/2
	E4					FW	1/5, 1/3, 1/3, 1
	Aggr.					0.325, 0.639, 0.639, 0.841	
	Def.V.					0.620	

Table A.16: Pairwise comparison of Environmental Criteria with respect to Alternative 3

	Generation of Hazardous Waste			Noise Pollution		Production of Solid Waste		Waste recovery	
	Experts	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs
Air Emmission	E1	FW	1/5, 1/3, 1/3, 1	SS	1, 1, 1, 3	SS	1, 1, 1, 3	FW	1/5, 1/3, 1/3, 1
	E2	FW	1/5, 1/3, 1/3, 1	FS	1, 3, 3, 5	FW	1/5, 1/3, 1/3, 1	FW	1/5, 1/3, 1/3, 1
	E3	SW	1/3, 1, 1, 1	3	3, 3, 3, 3	1/2-3	1/3, 1/3, 1/2, 1/2	SW	1/3, 1, 1, 1
	E4	FW	1/5, 1/3, 1/3, 1	3-4	3, 3, 4, 4	1/Ab.2	1/3, 1/2, 1/2, 1	1/4-5	1/5, 1/5, 1/4 , 1/4
	Aggr	0.227, 0.439, 0.439, 1		1.732, 2.280, 2.449, 3.663		0.386, 0.485, 0.537, 1.107		0.227, 0.386, 0.408, 0.707	
	Def.V.	0.497		2.475		0.590		0.421	
Generation of Hazardous Waste	E1			FS	1, 3, 3, 5	SS	1, 1, 1, 3	SW	1/3, 1, 1, 1
	E2			4-5	4, 4, 5, 5	2	2, 2, 2, 2	SW	1/3, 1, 1, 1
	E3			VS	3, 5, 5, 7	2-3	2, 2, 3, 3	SW	1/3, 1, 1, 1
	E4			SS	1, 1, 1, 3	Ab. 3	2, 3, 3, 4	1/2	1/2, 1/2, 1/2, 1/2
	Aggr			1.861, 2.783, 2.943, 4.787		1.682, 1.861, 2.060, 2.913		0.369, 0841, 0.841, 0.841	
	Def.V.			3.017		2.073		0.762	
Noise Pollution	E1					1/3	1/3, 1/3, 1/3, 1/3	FW	1/5, 1/3, 1/3, 1
	E2					FW	1/5, 1/3, 1/3, 1	FW	1/5, 1/3, 1/3, 1
	E3					SW	1/3, 1, 1, 1	¼	1/4, 1/4, 1/4, 1/4
	E4					FW	1/5, 1/3, 1/3, 1	1/2-3	1/3, 1/3, 1/2, 1/2
	Aggr.					0.258, 0.439, 0.439, 0.760		0.240, 0.310, 0.343, 0.595	
	Def.V.					0.462		0.357	
Production of Solid Waste	E1							SW	1/3, 1, 1, 1
	E2							FW	1/5, 1/3, 1/3, 1
	E3							SW	1/3, 1, 1, 1
	E4							FW	1/5, 1/3, 1/3, 1
	Aggr.							0.258, 0.577, 0.577, 1	
	Def.V.							0.595	

Table A.17: Pairwise comparison of Alternatives with respect to Availability of Funds

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	SW	1/3, 1, 1, 1	FW	1/5, 1/3, 1/3, 1
	E2	1/2	1/2, 1/2, 1/2, 1/2	AW	1/9, 1/7, 1/7, 1/5
	E3	FW	1/5, 1/3, 1/3, 1	VW	1/7, 1/5, 1/5, 1/3
	E4	1/3	1/3, 1/3, 1/3, 1/3	FW	1/5, 1/3, 1/3, 1
	Aggregation	0.325, 0.485, 0.485, 0.639		0.159, 0.237, 0.237, 0.508	
	Defuzzyified V.	0.484		0.269	
A2	E1			FW	1/5, 1/3, 1/3, 1
	E2			FW	1/5, 1/3, 1/3, 1
	E3			FW	1/5, 1/3, 1/3, 1
	E4			SW	1/3, 1, 1, 1
	Aggregation			0.227, 0.439, 0.439, 1	
	Defuzzyified V.			0.497	

Table A.18: Pairwise comparison of Economic Criteria with respect to Availability of Funds

	Implementation Cost		
	Experts	Score	Converted STFNs
Cost of Operation and Maintenance	E1	FW	1/5, 1/3, 1/3, 1
	E2	FW	1/5, 1/3, 1/3, 1
	E3	1/5	1/5, 1/5, 1/5, 1/5
	E4	VW	1/7, 1/5, 1/5, 1/3
	Aggregation	0.184, 0.258, 0.258, 0.508	
	Defuzzyified V.	0.287	

Table A.19: Pairwise comparison of Alternatives with respect to Benefits from Recycing

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	SS	1, 1, 1, 3	FS	1, 3, 3, 5
	E2	3	3, 3, 3, 3	AS	5, 7, 7, 9
	E3	2-3	2, 2, 3, 3	5-6	5, 5, 6, 6
	E4	Ab. 3	2, 3, 3, 4	Ab. 5	4, 5, 5, 6
	Aggregation	1.861, 2.060, 2.280, 3.224		3.162, 4.787, 5.010, 6.344	
	Defuzzyified V.	2.294		4.850	
A2	E1			FS	1, 3, 3, 5
	E2			SS	1, 1, 1, 3
	E3			FS	1, 3, 3, 5
	E4			3-4	3, 3, 4, 4
	Aggregation			1.316, 2.280, 2.449, 4.162	
	Defuzzyified V.			2.489	

Table A.20: Pairwise comparison of Alternatives with respect to Cost of Operations and Maintenance

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	SS	1, 1, 1, 3	SS	1, 1, 1, 3
	E2	E	1, 1, 1, 1	FS	1, 3, 3, 5
	E3	FW	1/5, 1/3, 1/3, 1	FS	1, 3, 3, 5
	E4	2-3	2, 2, 3, 3	FS	1, 3, 3, 5
	Aggregation	0.795, 0.904, 1, 1.732		1, 2.280, 2.280, 4.401	
	Defuzzyified V.	1.056		2.420	
A2	E1			SS	1, 1, 1, 3
	E2			2	2, 2, 2, 2
	E3			Ab. 2	1, 2, 2, 3
	E4			2-3	2, 2, 3, 3
	Aggregation			1.414, 1.682, 1.861, 2.711	
	Defuzzyified V.			1.869	

Table A.21: Pairwise comparison of Alternatives with respect to İmplementation Cost

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	FW	1/5, 1/3, 1/3, 1	AW	1/9, 1/7, 1/7, 1/5
	E2	FW	1/5, 1/3, 1/3, 1	VW	1/7, 1/5, 1/5, 1/3
	E3	1/4	1/4, 1/4, 1/4, 1/4	FW	1/5, 1/3, 1/3, 1
	E4	1/Ab.4	1/5, 1/4, 1/4, 1/3	FW	1/5, 1/3, 1/3, 1
	Aggregation	0.211, 0.289, 0.289, 0.537		0.159, 0.237, 0.237, 0.508	
	Defuzzyified V.	0.317		0.269	
A2	E1			FW	1/5, 1/3, 1/3, 1
	E2			VW	1/7, 1/5, 1/5, 1/3
	E3			FW	1/5, 1/3, 1/3, 1
	E4			SW	1/3, 1, 1, 1
	Aggregation			0.209, 0.386, 0.386, 0.760	
	Defuzzyified V.			0.419	

Table A.22: Pairwise comparison of Alternatives with respect to Air Emmission

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	1/Ab. 2	1/3, 1/2, 1/2, 1	SW	1/3, 1, 1, 1
	E2	1/3	1/3, 1/3, 1/3, 1/3	1/2-3	1/3, 1/3, 1/2, 1/2
	E3	1/2	1/2, 1/2, 1/2, 1/2	1/2	1/2, 1/2, 1/2, 1/2
	E4	SW	1/3, 1, 1, 1	FW	1/5, 1/3, 1/3, 1
	Aggregation	0.369, 0.537, 0.537, 0.639		0.325, 0.485, 0.537, 0.707	
	Defuzzyified V.	0.526		0.513	
A2	E1			SW	1/3, 1, 1, 1
	E2			1/2-3	1/3, 1/3, 1/2, 1/2
	E3			1/2	1/2, 1/2, 1/2, 1/2
	E4			1/2	1/2, 1/2, 1/2, 1/2
	Aggregation			0.408, 0.537, 0.595, 0.595	
	Defuzzyified V.			0.544	

Table A.23: Pairwise comparison of Alternatives with respect to Generation of Hazardous Waste

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	SS	1, 1, 1, 3	FS	1, 3, 3, 5
	E2	FS	1, 3, 3, 5	FS	1, 3, 3, 5
	E3	2-3	2, 2, 3, 3	4-5	4, 4, 5, 5
	E4	Ab. 2	1, 2, 2, 3	Ab.4	3, 4, 4, 5
	Aggregation	1.189, 1.861, 2.060, 3.409		1.861, 3.464, 3.663, 5	
	Defuzzyified V.	2.073		3.519	
A2	E1			FS	1, 3, 3, 5
	E2			SS	1, 1, 1, 3
	E3			SS	1, 1, 1, 3
	E4			FS	1, 3, 3, 5
	Aggregation			1, 1.732, 1.732, 3.873	
	Defuzzyified V.			1.967	

Table A.24: Pairwise comparison of Alternatives with respect to Noise Pollution

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	SS	1, 1, 1, 3	FS	1, 3, 3, 5
	E2	SS	1, 1, 1, 3	3-4	3, 3, 4, 4
	E3	2	2, 2, 2, 2	Ab.3	2, 3, 3, 4
	E4	1-2	1, 1, 2, 2	FS	1, 3, 3, 5
	Aggregation	1.189, 1.189, 1.414, 2.449		1.565, 3, 3.224, 4.472	
	Defuzzyified V.	1.474		3.081	
A2	E1			FS	1, 3, 3, 5
	E2			SS	1, 1, 1, 3
	E3			FS	1, 3, 3, 5
	E4			3	3, 3, 3, 3
	Aggregation			1.316, 2.280, 2.280, 3.873	
	Defuzzyified V.			2.385	

Table A.25: Pairwise comparison of Alternatives with respect to Production of Solid Waste

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	SS	1, 1, 1, 3	FS	1, 3, 3, 5
	E2	SS	1, 1, 1, 3	VS	3, 5, 5, 7
	E3	2-3	2, 2, 3, 3	FS	1, 3, 3, 5
	E4	FS	1, 3, 3, 5	FS	1, 3, 3, 5
	Aggregation	1.189, 1.565, 1.732, 3.409		1.316, 3.409, 3.409, 5.439	
	Defuzzyified V.	1.865		3.398	
A2	E1			2-3	2, 2, 3, 3
	E2			2	2, 2, 2, 2
	E3			FS	1, 3, 3, 5
	E4			FS	1, 3, 3, 5
	Aggregation			1.414, 2.449, 2.711, 3.5	
	Defuzzyified V.			2.539	

Table A.26: Pairwise comparison of Alternatives with respect to Production of Solid Waste

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	FS	1, 3, 3, 5	FS	1, 3, 3, 5
	E2	FS	1, 3, 3, 5	3-4	3, 3, 4, 4
	E3	2-3	2, 2, 3, 3	Ab. 4	3, 4, 4, 5
	E4	Ab.3	2, 3, 3, 4	FS	1, 3, 3, 5
	Aggregation	1.414, 2.711, 3, 4.162		1.732, 3.224, 3.464, 4.729	
	Defuzzyified V.	2.833		3.306	
A2	E1			FS	1, 3, 3, 5
	E2			FS	1, 3, 3, 5
	E3			3-4	3, 3, 4, 4
	E4			3	3, 3, 3, 3
	Aggregation			1.732, 3, 3.224, 4.162	
	Defuzzyified V.			3.057	

Table A.27: Pairwise comparison of Alternatives with respect to Waste recovery

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	SS	1, 1, 1, 3	FS	1, 3, 3, 5
	E2	SS	1, 1, 1, 3	FS	1, 3, 3, 5
	E3	Ab.2	1, 2, 2, 3	Ab.4	3, 4, 4, 5
	E4	1-2	1, 1, 2, 2	3-4	3, 3, 4, 4
	Aggregation	1, 1.189, 1.414, 2.711		1.732, 3.224, 3.464, 4.729	
	Defuzzyified V.	1.486		3.306	
A2	E1			FS	1, 3, 3, 5
	E2			SS	1, 1, 1, 3
	E3			FS	1, 3, 3, 5
	E4			Ab.4	3, 4, 4, 5
	Aggregation			1.316, 2.449, 2.449, 4.401	
	Defuzzyified V.			2.586	

Table A.28: Pairwise comparison of Alternatives with respect to Compatibility with legislative and administrative situation

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	SS	1, 1, 1, 3	FS	1, 3, 3, 5
	E2	SS	1, 1, 1, 3	FS	1, 3, 3, 5
	E3	Ab.2	1, 2, 2, 3	Ab.4	3, 4, 4, 5
	E4	1-2	1, 1, 2, 2	3-4	3, 3, 4, 4
	Aggregation	1, 1.189, 1.414, 2.711		1.732, 3.224, 3.464, 4.729	
	Defuzzyified V.	1.486		3.306	
A2	E1			FS	1, 3, 3, 5
	E2			SS	1, 1, 1, 3
	E3			FS	1, 3, 3, 5
	E4			Ab.4	3, 4, 4, 5
	Aggregation			1.316, 2.449, 2.449, 4.401	
	Defuzzyified V.			2.586	

Table A.29: Pairwise comparison of Environmental Criteria with respect to Political Acceptance

	Generation of Hazardous Waste			Noise Pollution		Production of Solid Waste		Waste recovery	
	Experts	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs
Air Emmission	E1	E	1, 1, 1, 1	SS	1, 1, 1, 3	FS	1, 3, 3, 5	1/3-4	1/4, 1/4, 1/3, 1/3
	E2	SW	1/3, 1, 1, 1	FS	1, 3, 3, 5	SS	1, 1, 1, 3	FW	1/5, 1/3, 1/3, 1
	E3	SW	1/3, 1, 1, 1	2-3	2, 2, 3, 3	SS	1, 1, 1, 3	SW	1/3, 1, 1, 1
	E4	1/3	1/3, 1/3, 1/3, 1/3	Ab. 3	2, 3, 3, 4	2-3	2, 2, 3, 3	SW	1/3, 1, 1, 1
	Aggr	0.439, 0.760, 0.760, 0.760		1.414, 2.060, 2.280, 3.663		1.189, 1.565, 1.732, 3.409		0.273, 0.537, 0.577, 0.760	
	Def.V.	0.706		2.293		1.865		0.544	
Generation of Hazardous Waste	E1			FS	1, 3, 3, 5	FS	1, 3, 3, 5	SW	1/3, 1, 1, 1
	E2			FS	1, 3, 3, 5	FS	1, 3, 3, 5	E	1, 1, 1, 1
	E3			4	4, 4, 4, 4	SS	1, 1, 1, 3	SW	1/3, 1, 1, 1
	E4			VS	3, 5, 5, 7	3-4	3, 3, 4, 4	SS	1, 1, 1, 3
	Aggr			1.861, 3.663, 3.663, 5.144		1.316, 2.280, 2.449, 4.162		0.577, 1, 1, 1.316	
	Def.V.			3.609		2.489		0.982	
Noise Pollution	E1					FW	1/5, 1/3, 1/3, 1	FW	1/5, 1/3, 1/3, 1
	E2					1/4	1/4, 1/4, 1/4, 1/4	VW	1/7, 1/5, 1/5, 1/3
	E3					FW	1/5, 1/3, 1/3, 1	1/4	1/4, 1/4, 1/4, 1/4
	E4					1/Ab. 3	1/4, 1/3, 1/3, 1/2	FW	1/5, 1/3, 1/3, 1
	Aggr.					0.224, 0.310, 0.310, 0.595		0.194, 0.273, 0.273, 0.537	
	Def.V.					0.343		0.304	
Production of Solid Waste	E1							SW	1/3, 1, 1, 1
	E2							FW	1/5, 1/3, 1/3, 1
	E3							1/3	1/3, 1/3, 1/3, 1/3
	E4							1/Ab. 3	1/4, 1/3, 1/3, 1/2
	Aggr.							0.273, 0.439, 0.439, 0.639	
	Def.V.							0.444	

Table A.30: Pairwise comparison of Alternatives with respect to Political Acceptance

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	SS	1, 1, 1, 3	FS	1, 3, 3, 5
	E2	Ab.2	1, 2, 2, 3	SS	1, 1, 1, 3
	E3	2-3	2, 2, 3, 3	SS	1, 1, 1, 3
	E4	SS	1, 1, 1, 3	Ab.3	2, 3, 3, 4
	Aggregation	1.189, 1.414, 1.565, 3		1.189, 1.732, 1.732, 3.663	
	Defuzzyified V.	1.691		1.963	
A2	E1			E	1, 1, 1, 1
	E2			SS	1, 1, 1, 3
	E3			SS	1, 1, 1, 3
	E4			1-2	1, 1, 2, 2
	Aggregation			1, 1, 1.189, 2.060	
	Defuzzyified V.			1.240	

Table A.31: Pairwise comparison of Socio-Political Criteria with respect to Political Acceptance

	Social acceptance		
	Experts	Score	Converted STFNs
Compatability with legislative and administrative situation	E1	E	1, 1, 1, 1
	E2	SW	1/3, 1, 1, 1
	E3	FW	1/5, 1/3, 1/3, 1
	E4	SS	1, 1, 1, 3
	Aggregation	0.508, 0.760, 0.760, 1.316	
	Defuzzyified V.	0.811	

Table A.32: Pairwise comparison of Alternatives with respect to Potential for Creaation of New Jobs

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	FW	1/5, 1/3, 1/3, 1	VW	1/7, 1/5, 1/5, 1/3
	E2	SW	1/3, 1, 1, 1	1/5	1/5, 1/5, 1/5, 1/5
	E3	FW	1/5, 1/3, 1/3, 1	FW	1/5, 1/3, 1/3, 1
	E4	1/3	1/3, 1/3, 1/3, 1/3	VW	1/7, 1/5, 1/5, 1/3
	Aggregation	0.258, 0.439, 0.439, 0.760		0.169, 0.227, 0.227, 0.386	
	Defuzzyified V.	0.462		0.244	
A2	E1			FW	1/5, 1/3, 1/3, 1
	E2			FW	1/5, 1/3, 1/3, 1
	E3			1/3	1/3, 1/3, 1/3, 1/3
	E4			1/4	1/4, 1/4, 1/4, 1/4
	Aggregation			0.240, 0.310, 0.310, 0.537	
	Defuzzyified V.			0.336	

Table A.33: Pairwise comparison of Alternatives with respect to Social Acceptance

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	SW	1/3, 1, 1, 1	SS	1, 1, 1, 3
	E2	Ab. 2	1, 2, 2, 3	FS	1, 3, 3, 5
	E3	FW	1/5, 1/3, 1/3, 1	Ab. 2	1, 2, 2, 3
	E4	SW	1/3, 1, 1, 1	1-2	1, 1, 2, 2
	Aggregation	0.386, 0.904, 0.904, 1.316		1, 1.565, 1.861, 3.080	
	Defuzzyified V.	0.886		1.822	
A2	E1			SS	1, 1, 1, 3
	E2			2-3	2, 2, 3, 3
	E3			2	2, 2, 2, 2
	E4			E	1, 1, 1, 1
	Aggregation			1.414, 1.414, 1.565, 2.060	
	Defuzzyified V.			1.572	

Table A.34: Pairwise comparison of Environmental Criteria with respect to Social Acceptance

	Generation of Hazardous Waste			Noise Pollution	
	Experts	Score	Converted STFNs	Score	Converted STFNs
Air Emmission	E1	SW	1/3, 1, 1, 1	FS	1, 3, 3, 5
	E2	1/2	1/2, 1/2, 1/2, 1/2	SS	1, 1, 1, 3
	E3	1/Ab.3	1/4, 1/3, 1/3, 1/2	2	2, 2, 2, 2
	E4	FW	1/5, 1/3, 1/3, 1	1-2	1, 1, 2, 2
	Aggregation	0.302, 0.485, 0.485, 0.707		1.189, 1.565, 1.861, 2.783	
	Defuzzyified V.	0.492		1.804	
Generation of Hazardous Waste	E1			FS	1, 3, 3, 5
	E2			VS	3, 5, 5, 7
	E3			FS	1, 3, 3, 5
	E4			SS	1, 1, 1, 3
	Aggregation			1.316, 2.590, 2.590, 4.787	
	Defuzzyified V.			2.744	

Table A.35: Pairwise comparison of Socio-Political Criteria with respect to Social Acceptance

	Potential for Creation of New Jobs		
	Experts	Score	Converted STFNs
Political Acceptance	E1	FW	1/5, 1/3, 1/3, 1
	E2	1/Ab.5	1/6, 1/5, 1/5, 1/4
	E3	FW	1/5, 1/3, 1/3, 1
	E4	1/4	1/4, 1/4, 1/4, 1/4
	Aggregation	0.202, 0.273, 0.273, 0.5	
	Defuzzyified V.	0.299	

Table A.36: Pairwise comparison of Alternatives with respect to Continuity and Predictability

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	SS	1, 1, 1, 3	FS	1, 3, 3, 5
	E2	FS	1, 3, 3, 5	AS	5,7, 7, 9
	E3	FS	1, 3, 3, 5	VS	3, 5, 5, 7
	E4	4	4, 4, 4, 4	FS	1, 3, 3, 5
	Aggregation	1.414, 2.449, 2.449, 4.162		1.968, 4.213, 4.213, 6.3	
	Defuzzyified V.	2.562		4.187	
A2	E1			FS	1, 3, 3, 5
	E2			FS	1, 3, 3, 5
	E3			Ab.4	3, 4, 4, 5
	E4			4	4, 4, 4, 4
	Aggregation			1.861, 3.464, 3.464, 4.729	
	Defuzzyified V.			3.408	

Table A.37: Pairwise comparison of Economic Criteria with respect to Continuity and Predictability

	Benefits from Recycling			Cost of Operation and Maintenance		Implementation Cost	
	Experts	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs
Availability of Funds	E1	SW	1/3, 1, 1, 1	FW	1/5, 1/3, 1/3, 1	FS	1, 3, 3, 5
	E2	SW	1/3, 1, 1, 1	FW	1/5, 1/3, 1/3, 1	SS	1, 1, 1, 3
	E3	FW	1/5, 1/3, 1/3, 1	SW	1/3, 1, 1, 1	SS	1, 1, 1, 3
	E4	FW	1/5, 1/3, 1/3, 1	1/2	1/2, 1/2, 1/2, 1/2	FS	1, 3, 3, 5
	Aggr.	0.258, 0.577, 0.577, 1		0.286,0.485, 0.485, 0.841		1, 1.732, 1.732, 3.873	
	Def.V.	0.595		0.511		1.967	
Benefits from Recycling	E1			FS	1, 3, 3, 5	FS	1, 3, 3, 5
	E2			SS	1, 1, 1, 3	VS	3, 5, 5, 7
	E3			FS	1, 3, 3, 5	4-5	4, 4, 5, 5
	E4			SS	1, 1, 1, 3	Ab.4	3, 4, 4, 5
	Aggr.			1, 1.732, 1.732, 3.873		2.449, 3.936, 4.162, 5.439	
	Def.V.			1.967		4.014	
Cost of Operation and Maintenance	E1					FS	1, 3, 3, 5
	E2					SS	1, 1, 1, 3
	E3					FS	1, 3, 3, 5
	E4					FS	1, 3, 3, 5
	Aggr.					1, 2.280, 2.280, 4.401	
	Def.V.					2.420	

Table A.38: Pairwise comparison of Economic Criteria with respect to Continuity and Predictability

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	FS	1, 3, 3, 5	VS	3, 5, 5, 7
	E2	VS	3, 5, 5, 7	VS	3, 5, 5, 7
	E3	FS	1, 3, 3, 5	AS	5,7, 7, 9
	E4	Ab.5	4, 5, 5, 6	AS	5,7, 7, 9
	Aggregation	1.861, 3.873, 3.873, 5.692		3.873, 5.916, 5.916, 7.937	
	Defuzzyified V.	3.841		5.912	
A2	E1			VS	3, 5, 5, 7
	E2			FS	1, 3, 3, 5
	E3			FS	1, 3, 3, 5
	E4			Ab.5	4, 5, 5, 6
	Aggregation			1.861, 3.873, 3.873, 5.692	
	Defuzzyified V.			3.841	

Table A.39: Pairwise comparison of Alternatives with respect to Technical Flexibility

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	FS	1, 3, 3, 5	VS	3, 5, 5, 7
	E2	VS	3, 5, 5, 7	VS	3, 5, 5, 7
	E3	FS	1, 3, 3, 5	AS	5,7, 7, 9
	E4	Ab.5	4, 5, 5, 6	AS	5,7, 7, 9
	Aggregation	1.861, 3.873, 3.873, 5.692		3.873, 5.916, 5.916, 7.937	
	Defuzzyified V.	3.841		5.912	
A2	E1			VS	3, 5, 5, 7
	E2			FS	1, 3, 3, 5
	E3			FS	1, 3, 3, 5
	E4			Ab.5	4, 5, 5, 6
	Aggregation			1.861, 3.873, 3.873, 5.692	
	Defuzzyified V.			3.841	

Table A.40: Pairwise comparison of Economic Criteria with respect to Technical Flexibility

	Benefits from Recycling			Cost of Operation and Maintenance		Implementation Cost	
	Experts	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs
Availability of Funds	E1	FW	1/5, 1/3, 1/3, 1	FS	1, 3, 3, 5	FW	1/5, 1/3, 1/3, 1
	E2	FW	1/5, 1/3, 1/3, 1	VS	3, 5, 5, 7	SW	1/3, 1, 1, 1
	E3	SW	1/3, 1, 1, 1	FS	1, 3, 3, 5	SW	1/3, 1, 1, 1
	E4	E	1, 1, 1, 1	SS	1, 1, 1, 3	SW	1/3, 1, 1, 1
	Aggr.	0.340, 0.577, 0.577, 1		1.316, 2.590, 2.590, 4.787		0.293, 0.760, 0.760, 1	
	Def.V.	0.608		2.744		0.722	
Benefits from Recycling	E1			FS	1, 3, 3, 5	FW	1/5, 1/3, 1/3, 1
	E2			FS	1, 3, 3, 5	SW	1/3, 1, 1, 1
	E3			SS	1, 1, 1, 3	E	1, 1, 1, 1
	E4			SS	1, 1, 1, 3	SW	1/3, 1, 1, 1
	Aggr.			1, 1.732, 1.732, 3.873		0.386, 0.760, 0.760, 1	
	Def.V.			1.967		0.738	
Cost of Operation and Maintenance	E1					SW	1/3, 1, 1, 1
	E2					FW	1/5, 1/3, 1/3, 1
	E3					1/3	1/3, 1/3, 1/3, 1/3
	E4					1/4	1/4,1/4,1/4,1/4
	Aggr.					0.273, 0.408, 0.408, 0.537	
	Def.V.					0.407	

Table A.41: Pairwise comparison of Alternatives with respect to Local Technical Know How

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	FW	1/5, 1/3, 1/3, 1	AW	1/9, 1/7, 1/7, 1/5
	E2	FW	1/5, 1/3, 1/3, 1	VW	1/7, 1/5, 1/5, 1/3
	E3	SW	1/3, 1, 1, 1	VW	1/7, 1/5, 1/5, 1/3
	E4	SW	1/3, 1, 1, 1	1/6	1/6, 1/6, 1/6, 1/6
	Aggregation	0.258, 0.577, 0.577, 1		0.139, 0.176, 0.176, 0.247	
	Defuzzyified V.	0.595		0.181	
A2	E1			VW	1/7, 1/5, 1/5, 1/3
	E2			FW	1/5, 1/3, 1/3, 1
	E3			FW	1/5, 1/3, 1/3, 1
	E4			VW	1/7, 1/5, 1/5, 1/3
	Aggregation			0.169, 0.258, 0.258, 0.577	
	Defuzzyified V.			0.297	

Table A.42: Pairwise comparison of Economic Criteria with respect to Local Technical Know How

	Benefits from Recycling			Cost of Operation and Maintenance		Implementation Cost	
	Experts	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs
Availability of Funds	E1	FW	1/5, 1/3, 1/3, 1	FW	1/5, 1/3, 1/3, 1	SW	1/3, 1, 1, 1
	E2	1/3	1/3, 1/3, 1/3, 1/3	1/5	1/5, 1/5, 1/5, 1/5	1/2	1/2, 1/2, 1/2, 1/2
	E3	1/Ab.3	1/4, 1/3, 1/3, 1/2	FW	1/5, 1/3, 1/3, 1	SW	1/3, 1, 1, 1
	E4	FW	1/5, 1/3, 1/3, 1	SW	1/3, 1, 1, 1	FW	1/5, 1/3, 1/3, 1
	Aggr.	0.240, 0.333, 0.333, 0.639		0.227,0.386, 0.386, 0.669		0.325, 0.639, 0.639, 0.841	
	Def.V.	0.369		0.407		0.620	
Benefits from Recycling	E1			FS	1, 3, 3, 5	FS	1, 3, 3, 5
	E2			Ab.3	2, 3, 3, 4	SS	1, 1, 1, 3
	E3			3-4	3, 3, 4, 4	FS	1, 3, 3, 5
	E4			Ab.3	2, 3, 3, 4	FS	1, 3, 3, 5
	Aggr.			1.861, 3, 3.224, 4.229		1, 2.280, 2.280, 4.401	
	Def.V.			3.090		2.420	
Cost of Operation and Maintenance	E1					FS	1, 3, 3, 5
	E2					SS	1, 1, 1, 3
	E3					FS	1, 3, 3, 5
	E4					Ab.3	2, 3, 3, 4
	Aggr.					1.189, 2.280, 2.280, 4.162	
	Def.V.					2.412	

Table A.43: Pairwise comparison of Alternatives with respect to Technical Feasibility

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	FW	1/5, 1/3, 1/3, 1	AW	1/9, 1/7, 1/7, 1/5
	E2	SW	1/3, 1, 1, 1	VW	1/7, 1/5, 1/5, 1/3
	E3	1/3	1/3, 1/3, 1/3, 1/3	VW	1/7, 1/5, 1/5, 1/3
	E4	1/Ab.4	1/5, 1/4, 1/4, 1/3	FW	1/5, 1/3, 1/3, 1
	Aggregation	0.258, 0.408, 0.408, 0.577		0.146, 0.209, 0.209, 0.386	
	Defuzzyified V.	0.411		0.228	
A2	E1			FW	1/5, 1/3, 1/3, 1
	E2			FW	1/5, 1/3, 1/3, 1
	E3			1/5	1/5, 1/5, 1/5, 1/5
	E4			FW	1/5, 1/3, 1/3, 1
	Aggregation			0.2, 0.293, 0.293, 0.669	
	Defuzzyified V.			0.340	

Table A.44: Pairwise comparison of Economic Criteria with respect to Technical Feasibility

	Benefits from Recycling			Cost of Operation and Maintenance		Implementation Cost	
	Experts	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs
Availability of Funds	E1	FS	1, 3, 3, 5	FS	1, 3, 3, 5	FW	1/5, 1/3, 1/3, 1
	E2	SS	1, 1, 1, 3	VS	3, 5, 5, 7	SW	1/3, 1, 1, 1
	E3	SS	1, 1, 1, 3	SS	1, 1, 1, 3	FW	1/5, 1/3, 1/3, 1
	E4	Ab.2	1, 2, 2, 3	Ab.3	2, 3, 3, 4	SW	1/3, 1, 1, 1
	Aggr.	1, 1.565, 1.565, 3.409		1.565, 2.590, 2.590, 4.527		0.258, 0.577, 0.577, 1	
	Def.V.	1.778		2.742		0.595	
Benefits from Recycling	E1			FS	1, 3, 3, 5	SS	1, 1, 1, 3
	E2			SS	1, 1, 1, 3	FW	1/5, 1/3, 1/3, 1
	E3			Ab.3	2, 3, 3, 4	FW	1/5, 1/3, 1/3, 1
	E4			FS	1, 3, 3, 5	SW	1/3, 1, 1, 1
	Aggr.			1.189, 2.280, 2.280, 4.162		0.340, 0.577, 0.577, 1.316	
	Def.V.			2.412		0.661	
Cost of Operation and Maintenance	E1					FW	1/5, 1/3, 1/3, 1
	E2					VW	1/7, 1/5, 1/5,1/3
	E3					FW	1/5, 1/3, 1/3, 1
	E4					1/4	1/4, 1/4, 1/4,1/4
	Aggr.					0.194, 0.273, 0.273, 0.537	
	Def.V.					0.304	

Table A.45: Pairwise comparison of Alternatives with respect to Technical Reliability

	A2			A3	
	Experts	Score	Converted STFNs	Score	Converted STFNs
A1	E1	FS	1, 3, 3, 5	VS	3, 5, 5, 7
	E2	SS	1, 1, 1, 3	VS	3, 5, 5, 7
	E3	Ab.3	2, 3, 3, 4	FS	1, 3, 3, 5
	E4	3-4	3, 3, 4, 4	VS	3, 5, 5, 7
	Aggregation	1.565, 2.280, 2.449, 3.936		2.280, 4.401, 4.401, 6.435	
	Defuzzyified V.	2.493		4.386	
A2	E1			FS	1, 3, 3, 5
	E2			VS	3, 5, 5, 7
	E3			FS	1, 3, 3, 5
	E4			SS	1, 1, 1, 3
	Aggregation			1.316, 2.590, 2.590, 4.787	
	Defuzzyified V.			2.744	

Table A.46: Pairwise comparison of Economic Criteria with respect to Technical Reliability

	Benefits from Recycling			Cost of Operation and Maintenance		Implementation Cost	
	Experts	Score	Converted STFNs	Score	Converted STFNs	Score	Converted STFNs
Availability of Funds	E1	FS	1, 3, 3, 5	FS	1, 3, 3, 5	FW	1/5, 1/3, 1/3, 1
	E2	Ab. 2	1, 2, 2, 3	FS	1, 3, 3, 5	SW	1/3, 1, 1, 1
	E3	SS	1, 1, 1, 3	SS	1, 1, 1, 3	FW	1/5, 1/3, 1/3, 1
	E4	2	2, 2, 2, 2	Ab.3	2, 3, 3, 4	SW	1/3, 1, 1, 1
	Aggr.	1.189,1.861,1.861, 3.080		1.189, 2.280, 2.280, 4.162		0.258, 0.577, 0.577, 1	
	Def.V.	1.952		2.412		0.595	
Benefits from Recycling	E1			FS	1, 3, 3, 5	SS	1, 1, 1, 3
	E2			SS	1, 1, 1, 3	FW	1/5, 1/3, 1/3, 1
	E3			Ab.3	2, 3, 3, 4	FW	1/5, 1/3, 1/3, 1
	E4			FS	1, 3, 3, 5	SW	1/3, 1, 1, 1
	Aggr.			1.189, 2.280, 2.280, 4.162		0.340, 0.577, 0.577, 1.316	
	Def.V.			2.412		0.661	
Cost of Operation and Maintenance	E1					FW	1/5, 1/3, 1/3, 1
	E2					1/4	1/4,1/4, 1/4, 1/4
	E3					FW	1/5, 1/3, 1/3, 1
	E4					1/4	1/4,1/4, 1/4, 1/4
	Aggr.					0.224, 0.289, 0.289, 0.500	
	Def.V.					0.313	

BIOGRAPHICAL SKETCH

Can Üçüncüoğlu was born in Istanbul in 1985. He finished his high school education at Vefa Anatolian High School in 2003. He started his undergraduate studies at Industrial Engineering Department of the Istanbul Commerce University in 2004. He graduated from industrial engineering in 2008. In the same year, he started his master of science in Industrial Engineering Program of the Institute of Science and Technology of Galatasaray University.