ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

THE SELECTION OF THE BEST MANAGEMENT TECHNOLOGY TO RECYCLE PRECIOUS METALS FROM ELECTRIC AND ELECTRONIC EQUIPMENT

M.Sc. THESIS

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Department of Environmental Engineering

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

ELEKTRİK VE ELEKTRONİK EKİPMANLARDAN DEĞERLİ METALLERİN GERİ KAZANIMI İÇİN EN İYİ YÖNETİM TEKNOLOJİSİNİN SEÇİMİ

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Ezgi Tunçer, a **M.Sc.** student of ITU, **Graduate School of Science Engineering and Technology** student ID **501091742**, successfully defended the **thesis/dissertation** entitled "**The Selection Of The Best Management Technology To Recycle Precious Metals From Electric And Electronic Equipment**", which he/she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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FOREWORD

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ABBREVIATIONS

WEEE **:** Waste Electrical and Electronic Equipment
RoHS **:** Restriction of the use of certain Hazardous Substances
AHP **:** Analytic Hierarchy Process
CRT **:** Catode Ray Tube
CFC **:** Chlorofluorocarbon
E-WASTE **:** Electric and Electronic Equipment Waste
HCFC **:** Hydrochlorofluorocarbon
LCD **:** Liquid Crystal Display
PP : Polypropylene
PC : Polycarbonate
PU/ PUR : Polyurethane
ABS : Acrylonnitrile Butadiene Styrene
PS : Polystyrene
HIPS : High Impact Polystyrene
PPO : Polyphenylene Oxide Blends
PVC : Polyvinyl Chloride
PMs : Precious Metals
Au : Gold
Ag : Silver
Pd : Palladium
O&M : Operating and Maintemance

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THE SELECTION OF THE BEST MANAGEMENT TECHNOLOGY TO RECYCLE PRECIOUS METALS FROM ELECTRIC AND ELECTRONIC EQUIPMENT

SUMMARY

Today because of technological development, the production of electrical and electronic equipment are increasing and as a result of this, rapid consumption is also gaining speed. Increasing of rapid consumption causes of electric and electronic equipments which turn into waste. Industrialised countries consume significant amount of electrical and electronic equipment. Action on WEEE is an urgent needs to be managed in the world.

Fundamental problem of electronic waste mercury, lead, cadmium, such as toxic substances, besides their gold, silver, copper, palladium, such as economic value to the precious metal in the structure. Uncontrolled electronic waste are left to nature as a structure because of harmful substances in the environment and harm to human health. In addition to this, a great economic value has been included in an electronic equipment recycling system, to include loss of the precious metal.

This study investigated metallurgical processes for the recovery of precious metals from electronic waste, and recycling methods used today. In the first part of this thesis, some general information about waste electrical and electronic equipment has been given in the text. This is followed by the description of aim, scope and structure of the manual. In the second part, the definition, composition and classifications of e-wastes are described. This chapter summarizes components of WEEE and description of elements of WEEE. This includes legislative schemes in different countries and their salient features. In the thirt part, recovery of metals from e-waste implementing mechanical processing, hydrometallurgical, pyrometallurgical and biometallurgical routes are critically analyzed. In part four, describes Analitical Hierarchy Process that had been chosen. In the last part, describes a case studies on WEEE management , that on recycling of precious metals from electric and electronic equipment. At least, the results of the research are presented and discussed the following.

In this thesis, the study is realized by AHP focused on the selection of the best technology to electrical and electronic waste management. In accordance with this purpose, the environmental performance, economic benefits, technological compatibility and socio-political compatibility of different waste management options have been compared. Thus, the pairwise comparison of the post processes is comprised.

As a consequence, conceptual model is theorized the best applicable post treatment alternatives to recovery precious metals for decision makers. It is observed the biosorbtions process that is one of biometallurgical technologies are preferable and effective than traditional methods.

ELEKTRİK VE ELEKTRONİK EKİPMANLARDAN DEĞERLİ METAL GERİ KAZANIMI İÇİN EN İYİ TEKNOLOJİ SEÇİMİ

ÖZET

Günümüzde teknolojik gelişmeler nedeni ile elektrikli ve elektronik ekipman (EEE) çeşitliliği ve üretimi hızla artmaktadır. Bu artışa bağlı olarak toplumda tüketim hızı da giderek hızlanmaktadır. Tüketim hızının artması, atık haline gelen elektrikli ve elektronik ekipman (EEE) miktarının yükselmesine neden olmaktadır. Bu yükselme oranları incelendiğinde endüstriyel olarak gelişmiş ülkeler önemli miktarda elektrik ve elektronik ekipman tüketiği belirlenmiştir. Elektronik atık yönetimi konusunda acilen aksiyon alınmalıdır.

Elektronik atıkların temel problemi barındırdıkları bileşenler arasında civa, kurşun, kadminyum gibi toksik maddeleri içermeleridir. Bunun yanı sıra, yapılarındaki altın, gümüş, bakır ve paladyum gibi değerli metaller geri dönüşüm ile ekonomik avantaj sunar.

Kontrolsüz bir biçimde doğaya terkedilen elektronik atıklar, yapısındaki tehlikeli maddelerden dolayı çevre ve insan sağlığı için tehlike oluştururlar. Elektronik atık yönetimi içerdiği yüksek konsantrasyonlu toksik bileşikleri içerdiğinden ayrı bir uzmanlık gerektirmektedir. Buna ilaveten, elektronik ekipmanların geri kazanım yönteminde değerli metallerin geri dönüşümü yapılamaması durumunda ekonomik kayıplar söz konusudur.

Bu çalışmada, günümüzde değerli metallerin geri kazanımda kullanılan metalurji prosesleri araştırılmıştır. Bu tezin ilk bölümünde, elektrik ve elektronik ekipman hakkında bazı genel bilgiler metinde verilmiştir. Bunu amaç, kapsam ve dökümanın yapısının açıklanması takip eder.

İkinci bölümde, elektronik atıkların tanımı, içerdiği bileşenler ve sınıflandırması yapılmıştır. Bu bölüm elektronik atıkların bileşenlerini ve elektrik ve elektronik ekipman atıklarınının içeriklerini tanımlamaları özetler. Ayrıca bu bölüm, farklı ülkelerdeki yasal düzenlemeleri ve onların göze çarpan özelliklerini içerir.

Üçüncü bölümde, mekanik, hidrometalurji, pirometalurji ve biometalurji yöntemleri kullanılarak elektronik atıklardan metallerin geri kazanımı analiz edilmiştir. Mekanik yöntem genellikle esas islem öncesi ön işlem olarak kullanılmaktadır. Mekanik /Fiziksel yöntemler kimyasal katkı maddeleri gerekmeksizin değerli metallerin geri kazanımı için alternatif sağlamaktadır. Parçalara ayırma, kırma, yoğunluğa göre ayırma, magnetik ayırma ve elektrostatik ayırma geri dönüşüm endüstürülerinde kullanılmaktadır. Hidrometalurji elektronik atıkların geri kazanımı esnasında sıksık kimyasal arıtım gerektirmektedir.

Elektronik atıklardan değerli metallerin geri kazanımı iyon değişimi, solvent extraksiyonu, elektrokimyasal, liç yöntemleri ile gerçekleşmektedir. Pirometalurji kimyasal katkı maddesi kullanımı gerektirmeyen termal yöntemdir. Biyometalurji yöntemleri olan biyosorbsiyon ve bioliç hala gelişmekte olan bir teknolojilerdir.

Bölüm dörtte, seçilen Analitik Hierarşi Prosesi tanımlandı. Son bölümde, elektrikli ve elektronik ekipmanlardan değerli metallerin geri kazanımı konusunda bir örnek çalışma tanımlanmıştır. Sonunda, araştırmanın sonuçları sunuldu ve tartışıldı.

Bu çalışmada, elektrik ve elektronik atık yönetimi için en iyi teknoloji seçimi amacıyla Analitik Hierarşi Prosesi uygulanarak gerçekleştirilmiştir. Bu amaç doğrultusunda, farklı atık yönetim seçeneklerinin çevresel performans, ekonomik faydalar, teknolojik uygunluk ve sosyo-politik uygunlukları karşılaştırılmıştır. Dört ana kriter ve ondört alt kriterker problemin tanımına göre belirlenerek, son işlemlerin ikili karşılaştırmaları oluşturulmuştur.

Sonuç olarak, kavramsal modelde değerli metal geri kazanımı için en uygun uygulanabilir son arıtım alternatifleri karar vericilere karar vermelerinde yardımcı olması için kuramlaştırılmıştır. Biyometalurji teknolojilerden biri olan biyosorbsiyon prosesi'nin geleneksel metodlara göre daha tercih edilebilir ve etkili olduğu gözlenmiştir. Biyometallurji tüketimi, kimyasal gereksinimi,ilk yatırım ve işletim maliyeti açısından pirometallurji ve hidrometallurji yöntemlerinden daha avantajlıdır. Ana kriterlere göre alternatifler karşılaştırıldığında biyosorbsiyon yöntemi yeni, temiz ve çevredostu teknoloji oldudundan dolayı diğer alternatiflere göre daha avantajlıdır. Bunun yanı sıra, düşük yatırım ve operasyon maliyeti gerektirdiğinden dolayı verimlidir.

Sosyol ve politik kabul edilebilirlik açıdan az atık oluşumu gerçekleşen düşük yatırım maliyeyine sahip biyosorbsiyon prosesinin daha tercih edilebilir olduğu görülmektedir.

Ekonomik açıdan, biyosorbsiyon yöntemin biyoliç yöntemine göre çok az daha tercih edilebilir olduğu görülmektedir. Eritme yöntemi yüksek ilk yatırım maliyeti gerektirir. Enerji tüketimi ve kirlilik kontrol ekipmanları direk işletim maliyetine katkıda bulunmaktadır. Piroliz oldukça yüksek yatırım maliyeti gerektirir. Bunun yanı sıra, piroliz yöntemi operasyon esnasında enerji üretir. Böylece, operasyon ve bakım maliyetleri azalır.

Çevresel kriterler hava kirliliği, atık su oluşumu, katı atık oluşumu, tehlikeli atık oluşumu, gürültü kirliliği, enerji/ hammadde kullanımıdır. Biyosorbsiyon yönteminin düşük çevresel etkilere sahip olduğu için daha kabul edilebilir olduğu görülmektedir. Biyoliç yönteminin çevresel açıdan diğer pirometallurji ve hidrometallurji yöntemlerine göre daha hassas olduğu görülmektedir. Çünkü kimyasalların kullanımı, enerji kullanımı ve agresif koşullar azaltılmıştır. Sonuç olarak, teknik açıdan güvenilirlik önemli bir kriterdir. Elektrokimyasal yöntem temiz, güvenilir ve kapalı bir yöntemdir.

Gelişmiş ülkelerde elektronik atık yönetimi konusunda önemli adımlar atılmıştır ve üçüncü bölümde ilgili detaylar verilmiştir. Türkiye'de atık sorunu ve buna getirilen çözümler üzerine tartışmalar Türkiye'nin AB üyelik sürecine girmesiyle başlayan dönemle birlikte, son yıllarda, hızla değişen yönetmeliklerle, konunun tüm paydaşlarınca tartışılmaya devam ediliyor.

Türkiye Cumhuriyeti Çevre ve Şehircilik Bakanlığı aracılığıyla çevre mevzuatını Avrupa Birliği direktiflerine uygun olarak ülkemiz gerçeklerine göre uyumlaştırma çerçevesinde Elektrik ve Elektronik Ekipmanların yönetimi konusunda önemli adımlar atılmıştır. Temel sıkıntı olan atık yönetimi sorununda kamu kurum ve kuruluşları, üreticiler ve nihai kullanıcılar arasındaki sorumlulukların birleştirildiği ortak bir mekanizmayla düzenlenme çalışılmalarına devam edilmektedir.

1. INTRODUCTION

The production of electrical and electronic equipment (EEE) is one of the fastest growing markets in the world. At the same time this also means that the amount of waste electrical and electronic equipment (WEEE) will continue to increase in the coming decades (Hischier et al., 2005).

Currently, 40 million tons per year of e-waste are being generated globally with major share of Europe, USA and Australasia. However, China, Eastern Europe and Latin America are expected to become significant e-waste producers in the next decade In Europe, it is expected that the production of e-waste will increase by 45% between 1995 and 2020 (UNEP, 2009).

E-waste is classified as hazardous waste due to its toxic ingredients, including heavy metals and harmful chemicals such as lead, cadmium, mercury, arsenic etc., with the potential to pollute the environment and damage human health when it is processed, recycled or disposed of. Therefore, should be managed properly. (Sawhney P. et all., 2008). However, the presence of precious metals (PMs) in e-waste such as gold (Au), silver (Ag), platinum (Pt), Gallium (Ga), palladium (Pd), tantalum (Ta), tellurium (Te), germanium (Ge) and selenium (Se) makes it attractive for recycling. Avoiding pollution and saving the valuable resources requires specific treatment of the e-waste. (Deupzer O., 2011).

Therefore, a three pillars strategy of waste prevention, recycling and reuse has been suggested to minimize the environmental impact and promote the efficient utilization of wasted resources (Khaliq A. et all, 2014).

In this thesis, metal extraction processes from e-waste, particularly the existing industrial practices and routes, will be reviewed. Industrially, different metallurgical routes are used to extract valuable metals from e-waste. Both pyrometallurgical and hydrometallurgical processes are commonly employed to recover PMs. These routes will be described and their advantages and disadvantages will be outlined.

In the final part of this thesis, AHP was performed to select of the best technology to electrical and electronic waste management.

1.1 Purpose of Thesis

The main purpose of this research is to selection of the best management technology to recycle precious metals from electric and electronic wastes. An Analitical Hierarchy Process (AHP) on electrical and electronic equipment (EEE) was performed based on a scenario including eight different post treatment alternatives.

1.2 Scope of Thesis

The manual has six chapters. Chapter 1 describes rationale for developing this manual. This is followed by the description of aim, scope and structure of the manual. Chapter 2 describes Electrical and Electronic Equipment. This chapter summarizes components of WEEE and description of elements of WEEE. This includes legislative schemes in different countries and their salient features. Chapter 3 describes management technology of Electrical and Electronic Equipment. Chapter 4 describes Analitical Hierarchy Prores that had been chosen. Chapter 5 describes a case studies on WEEE management , that on recycling of precious metals from electric and electronic equipment. The results of the research are presented and discussed the following Sections 6.

2. ELECTRIC AND ELECTRONIC EQUIPMENT

2.1 Definition of E-waste

The definition of electric and electronic waste (WEEE) has yet to be standardized. A number of countries have come outwith their own definitions, interpretation and usage of the term WEEE. The most widely accepted definitions of WEEE has been described by European Union, Canada, Japan, USA, Basel Convention and OECD. (Mayers K., 2001).

Selected definitions of WEEE are given below:

According to EU WEEE Directive (EU 2002a) , Electrical or electronic equipment which is waste including all components, subassemblies and consumables, which are part of the product at the time of discarding.' Directive 75/442/EEC, Article defines 'waste' as 'any substance or object which the holder disposes of or is required to dispose of pursuant to the provisions of nationallaw in force.'

Basel Action Network, E-waste encompasses a broad and growing range of electronic devices ranging from large household devices such as refrigerators, air conditioners, cell phones, personal stereos, and consumer electronics to computers which have been discarded by their users.

Organisation for Economic Co-operation and development (OECD 2001) , 'Any appliance using an electric power supply that has reached its end of life.'

According to definition of the UNEP, WEEE is a highly complex product which requires special treatment options such as segregation, collection, transportation, treatment and disposal. It can be contain hazardous and non- hazardous waste. (UNEP, 2011).

2.2 Characterization of E-waste

There are many different models of each type of electrical and electronic equipment (EEE) and each model may have different composition of e-waste that is require different dismantlement and recycling methods. (Osibanjo O. And Nnorom I.C., 2007).

WEEE consist of more than 1000 different substances, which is in a scope of "hazardous" and "non-hazardous" categories. Inclusively, electrical and electronic equipments especially comprise of ferrous and non-ferrous metals, plastics, glass, wood & plywood and other items as you can see Figure 2.1 (Khaliq A. et all, 2014).

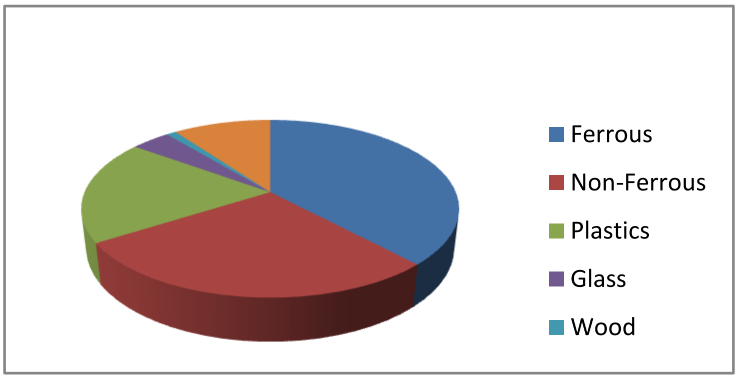

Figure 2.1 : Components in WEEE

As can be seen from Table 2.1 (Çığgın C. T., 2006), ferrous metals account for the largest portion of materials in WEEE, with plastics also making a large contribution.

Table 2.1 : Composition of various EEE

Equipman Categories	Iron	Non-ferrous metal	Glass	Plastic	Other
Big house appliances	61%	7%	3%	9%	21%
Small house appliances	19%	1%	0%	48%	32%
IT equipmant	43%	0%	4%	30%	20%
Telecommunication	13%	7%	0%	74%	6%
TV, radio etc.	11%	2%	35%	31%	22%
Charged and gaseous lamp	2%	2%	89%	3%	3%

2.2.1 Metal

Electrical and electronic equipment contains many substances, many of which are metals. Metals also constitute the largest weight of materials in WEEE, approximately 70% overall of electrical and electronic equipment. Generally, metals in e-waste can be grouped into ferrous and non-ferrous metals, such as the following. Ferrous metals consist of metals like copper, aluminium, iron and non-ferrous metals like precious metals such as silver, gold, platinum, palladium etc. (ITU, 2012).

While some of these metals are used in WEEE in relatively large amounts, some metals are used in very small amounts. Recovery of all metals from complex substances is simply not possible. It is possible to recover every type of metal contained in EEE in laboratory scale. In the recovery process, there might be evitable metal losses (ITU, 2012)

Rare earths play a key role in EEE. Similarly, electrical and electronic equipment especially cell phones contain precious metals such as gold (Au), silver (Ag), and palladium (Pd). It has been economic return from recycling despite the small mass contained per equipment (Neira J. et all., 2006). In Table 2.2 main precious metal types are summarized.

Table 2.2 : Precious metal used in WEEE

Precious Metal	Uses
Gold	Electronics: Computers (PCBs) - Mobile phones
Silver	Electronics: Computers (PCBs) - Mobile phones, Photovoltaics and catalysts
Platinum	Automative catalysy
Palladium	Automative catalysy
Rhodium	Flat panels, Electric sector
Ruthenium	Electronics: Computers: Hard disk
Copper	Electrical and electronics devices: Computers (PCBs) - Mobile phones
Cobalt	Catalysts, Batteries

2.2.2 Plastic

The electrical and electronic equipments contain various kinds of plastics. Plastics approximately consist of one thirt of the material recovered by weight from WEEE categories such as IT&T equipment, large household appliances and consumer electronics The most prevelent polymers are PS, HIPS, ABS, PP, PC and PU, they are used in EEE (VERC, 2006).

Pre-shredding and post-shredding routes are used as treatment alternative for plastic from WEEE. Pre-shredding mechanical recycling treatments (based on hand/automated sorting & disassembly of large plastic parts), and Post-shredding technologies, either aimed at mechanical recycling of sorted polymers fractions or at recovery of mixed plastics or unsorted shredder residue (Yeşilyurt Z. et all, 2007). Polimers used in WEEE as can be seen from Table 2.3 (VERC, 2006).

Table 2.3 : Polimers used in WEEE

Categories	Polymers
Large household appliances	Polypropylene (PP), followed by Polyurethane (PUR), Acrylonnitrile Butadiene Styrene (ABS), Polystyrene (PS) and High Impact Polystyrene (HIPS).
Cooling and freezing appliances	ABS, HIPS and PUR with PP and PVC
Small electronic appliances	PP and HIPS, with ABS
IT&T equipment	AB , followed by ABS/PC and HIPS.

Plastic recycling requires different technology/facility than metal recycling. Ttherefore, plastic parts must be separated in the pre-treatment phase so they can be sent to various plastic recyclers. Different models use different plastics with various quality, color, coating and/or adhesives (Neira J. et all., 2006).

The composition of plastics from mixed WEEE processing is complex, containing at least five different polymers in large amounts and many more used in smaller quantities for specific applications. The major components are; Acrylonitrile Butadiene Styrene (ABS) Polycarbonate (PC) PC/ABS blends High-Impact Polystyrene (HIPS) Polyphenylene Oxide blends (PPO).

In this context, there is a need for conceptual understanding of WEEE options to maximize resale value, plastics must then be sorted by polymer type (e.g. HIP, ABS thermoplastic), and by colour (e.g. white, black). Identification of polymer type can be difficult, especially for older computing equipment (ITU, 2012).

If plastic types cannot be separated by type, a mix of different types of plastics may have little if any economic value, although some mixed plastics may be used for materials such as lumber or pallets. If no use or market can be found, smelters with appropriate emission control systems may use a limited volume of plastics in the metal recovery process, where they serve as a source of heat and substitute for other hydrocarbon fuels and as a reducing agent. Alternatively, incinerators with energy recovery systems, as well as appropriate emission control systems, may recover energy content from plastics (ITU, 2012).

2.2.3 Glass

The current situation regarding display or glass recycling from cell phones is almost the same as plastic. Expected profit from glass recycling is too small relative to the labor costs associated with separation of the material for recycling. Also, the material could be heterogeneous and contaminated which results in lower grade secondary material with lower value. Therefore, it is most likely that the glass is incinerated and used as flux during copper smelting.

The overall recycling performance, or decision regarding whether recovery should be implemented for a given material, is driven by a combination of different factors. Whereas plastic and glass have almost no factors that lead to high recycling performances, metals (copper and precious metals) have some. Therefore, copper and precious metals are recovered as a priority (Neira J. et all., 2006).

The major source of glass in waste electronics is from CRTs, although this is likely to shift towards glass from flat-panel displays as the number of CRTs declines. CRTs are composed of two main glass types: funnel glass (the back of the tube), which contains high levels of lead oxide, and panel glass (the screen), which contains barium and strontium oxides. The preferred route for recycling is a closed-loop system. Using the glass in the manufacture of new CRTs, is difficult for a number of reasons; (i) low levels of contamination are required for the production of new tubes that are difficult to reach with post-consumer recycled product; (ii) there is a declining market for CRTs as they are replaced by flat panel displays; (iii) manufacture of CRTs is now mainly carried out in non-OECD countries, making the transport of ‘waste’ glass difficult because of the transfrontier shipment of waste regulations. A number of other outlets for recycled glass have been identified, including use in bricks and other building products, as aggregate and as a flux in smelting operations. These have so far not achieved widespread commercial use.

2.3 Components of Electric and Electronic Wastes

E-waste comprises of wastes generated from used electronic devices and house hold appliances which are not fit for their original intended use and are destined for recovery, recycling or disposal. Such wastes encompasses wide range of electrical and electronic devises such as computers, hand held cellular phones, personal stereos, including large household appliances such as refrigerators, air conditioners etc. E-wastes contain over 1000 different substances many of which are toxic and potentially hazardous to environment and human health, if these are not handled in an environmentally sound manner.

	Metal	Motor \ Compressor	Cooling	Plastic	Insulation	Glass	CRT	LCD	Rubber	Wiring / Electrical	Concrete	Transformer	Magnetron	Textile	Circuit Board	Fluorescent lamp (ineballast)	Incandescent lamp	Heating element	Thermostat	BFR – containing plastic	Batteries	CFC, HCFC, HFC, HC	External electric cables	Refractory ceramic fibers	Radioactive substances	Electrolyte Capacitors (over L/D 25mm)
Large Household Appliances																										
Refrigerator	■	■	■	■	■	■	-	-	■	■	-	-	-	-	-	-	■	-	■	■	-	■	■	-	-	-
Washing Machine	■	■	-	■	-	■	-	-	■	■	■	-	-	-	■	-	-	■	■	-	-	-	■	-	-	o
IT & Telecom																										
Personal Computer (Base & Keyboard)	■	■	-	■	-	-	-	-	-	■	-	■	-	-	■	-	-	-	-	-	■	-	■	-	-	-
Personal Computer (Monitor)	-	-	-	■	-	-	■	■	-	-	-	-	-	-	■	-	-	-	-	-	-	-	■	-	-	-
Laptop	-	■	-	■	-	-	-	■		■	-	■	-	-	■	■	-	-	-	■	■	-	■	-	-	-
Consumer Equipment																										
Television	■	-	-	■	-	-	■	-	-	■	-	■	-	-	■	-	-	-	-	■	-	-	■	-	-	-

Figure 2.2 : Components in WEEE

Waste Electrical and Electronic Equipment (WEEE) is both valuable and harmful. Before exploring methods for waste processing and resource recovery, it is necessary to characterize the waste, both in terms of chemical and mineralogical composition. Valuable materials in WEEE, which typically provide the incentive for recycling, include base metals such as copper and precious metals such as gold (Au), silver (Ag), platinum (Pt), Gallium (Ga), palladium (Pd), tantalum (Ta), tellurium (Te), germanium (Ge) and selenium (Se). (Deupzer O., 2011). Harmfull materials such as printed circuit boards, flame retarded plastics, cathode ray tubes, liquid crystal displays, batteries, mercury switches, capacitors and resistors in WEEE can be cause an important source of probable environmental contaminants.

These components contain a wide range of materials including including heavy metals and harmful chemicals such as mercury (applied in fluorescent lamps,batteries or switches), lead (applied in solder), cadmium, chromium, CFC's (chloro-fluorocarbons), PCB's (polychlorinated biphenyls), PCN's (polychlorinated napthalenes) and brominated flame retardants with the potential to pollute the environment and damage human health when it is processed, recycled or disposed of. Therefore, should be managed properly (Wager et al., 2011).

Several materials that can cause environmental problems even if its small quantities, found in items of WEEE. The following substances are targeted by the EU draft directive on WEEE:

Mercury (Hg): A large use of mercury is for fluorescent tubes, where it transforms the UV-light created in the gas discharge to visible light. Mercury is also used in relays, tilt switches, and in medical equipment. Many older appliances contain mercury-bearing components.

Cadmium (Cd): Cadmium is used in batteries, as a pigment and stabiliser in plastics, in specialist treatment of mechanical surfaces and in speciality solders. It is also used as a fluorescent material in screens and was used in old cathode ray tubes (CRT's).

Lead (Pb): Lead is used in batteries. lead from electrical and electronic equipment increase efficiency during the recycling of batteries. By far, the largest source of the lead in consumer electronics has been found to be contained in CRT's. CRT's are found primarily in television sets and computer monitors and can vary considerably in their composition but all contain substantial proportions of lead. Other important sources include soldering on printed circuit boards, pigments and stabilisers in plastics, and leaded glass.

Hexavalent Chromium (Cr): Hexavalent Chromium is used as a corrosion protector for steel plates and in printed circuit boards and plastic covers. Electrical and electronic equipment does not account for a significant share of chromium use and most producers no longer use it at all.

Brominated Flame Retardants (BFR's): BFR's are designed into electronic products as a means of ensuring flammability protection. Plastics with brominated flame retardants is used in EEE. They are mainly used in printed circuit boards, components (such as connectors), plastic covers and cables.

The above mentioned reasons, as well as international society, some international society, some national governments to say that various efforts in the management of electronic waste. Both international and national level to manage e-waste is underway.

2.4 Legislative Aspect of WEEE Management

Legislations, directives, common contracts and civil organization were established globally. Legal and legislative arrangement, to implement and enforce throughout lifecycle stages, particularly pre and post management stage, by encouraging eco-design and extended producer responsibility to reduce the environmental impacts of WEEE (Özgün Ç, 2008).

The first applications were enounced in Europe.Waste Electrical and Electronic Equipment (WEEE) (Directive 2002/96/EC) along with the complementary Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS) are two main legislations in Europe (Sawhney P. et all., 2008).

Developed countries such as Belgium, Denmark, Italy, Netherlands, Sweden, Switzerland, Portugal, Japan, China, Taiwan and Korea, have been established policies/ laws/ regulations related to WEEE/E-waste management followed by their institutionalization and enforcement. However, developing countries such as China, Taiwan, Asian and African are carrying the similar troubles (UNEP, 2011) (Widmer R., 2004).

In this chapter, we present the situation of the world and comparatively Turkey.

2.4.1 International legal framework

Generation of electrical and electronic wastes is the significant problem in developed countries such as U.S., EU and Japan. Several million tonnes of WEEE are being generated in developed countries.

2.4.1.1 EU directives

The European Union (EU) enacted two directives in 2003. The first is The Directive on Waste Electrical and Electronic Equipment (WEEE) that requires to reduce the generation of and encourage the reuse and recycling of electronic waste. The second is The Directive on the Restriction of the Use of Certain Hazardous Substances (RoHS) in Electrical and Electronic Equipment aims to phases out using hazardous substances such as lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBBs) and poly brominated diphenyl ethers (PBDEs) in all electronic equipment to minimize the risks and environmental impact of the treatment and disposal of electronic waste (Macauley M. et al., 2002) (ERICSSON, 1999).

2.4.1.2 WEEE directives

The Directive on Waste Electrical and Electronic Equipment aims at preventing WEEE. Several management methods such as reusing, recycling and recovering so as to reduce its disposal (St. Gallen, 2010). The directive imposes the responsibility for the disposal of waste electrical and electronic equipment (WEEE) on the manufacturers of such equipment.(Çağrı Ö., 2008).

The WEEE Directive's scope covers 10 categories of electrical and electronic equipment (EEE) as defined in Annex IA that can be seen from Table 2.4 (WEEE Directive 2003).

Table 2.4 : WEEE categories

Large household appliances	Electrical and electronic tools
Small household appliances	Toys, leisure and sports equipment
IT and Telco. equipment	Medical devices
Consumer equipment	Monitoring and control instruments
Lighting equipment	Automatic dispensers

2.4.1.3 Restriction of hazardous substance directive

The Directive on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment was adopted to phases out hazardous substances in all electronic in February 2003.

Restriction of Hazardous Substances Directive (RoHS) restricts the use of six hazardous Materials such as lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBBs) and poly brominated diphenyl ethers (PBDEs) in EEE. PBB and PBDE are flame retardants used in several plastics.

2.4.1.4 Japan directives

The Japanese parliament has enacted a ”Law for recycling of specific kind of consumer electric goods” that will come into force in April 2001. The legislation will at first include only four appliances. These are washing machines, freezers and refrigerators, air conditioners and television sets. Regulation about WEEE will be different in Japan than in the EU. For example, the last user of the product will pay for take-back and EoL treatment in Japan, but in the EU the producers and importers will carry the costs. Another difference is that energy recovery will be considered as recycling according to the Japanese law

Japan does not have any direct legislation dealing with the RoHS substances, but its recycling laws have spurred Japanese manufacturers to move to a lead-free process in accordance with RoHS guidelines. A ministerial ordinance Japanese industrial standard for Marking Of Specific Chemical Substances (J-MOSS), effective from July 1, 2006, directs that some electronic products exceeding a specified amount of the nominated toxic substances must carry a warning label.

2.4.1.5 USA directives

In the USA there is at the time being no proposal for producer responsibility regarding WEEE on a national level. On a state level though, some states have proposed legislation similar to the coming directive in Europe.

California passed the Electronic Waste Recycling Act of 2003. This law holds manufactures to the same standards as the RoHS. These are just two examples of legislation being written to limit the levels of toxins present in consumer goods and establish mandated limits on pollution of different kinds. Managing waste, especially electronic waste, is a global issue that is gaining the attention of governments and legislation.

2.4.2 National framework

Turkey's Specified Home Appliances Recycling Law which was enacted in 1998 and came into force in April 2001, Turkish electronics industry experienced a good growth performance in last few years. Therefore the need of the projects for recycling are becoming crucial.

Turkey, as one of the biggest steel scrap importers of the world, recycles more than 2 million tons of steel scrap annually. Recycling of nonferrous metals is also widespread and conducted at industrial scale, including aluminum, copper, lead and silver. The scrap metal recycling industry essentially is built on small and medium scale scrap dealers spread around the country. This type of operation is also valid for most of collection and recovery of recyclable MSW (Electronica.ca, 2005).

There are some recycling companies acting in Turkey, but they are more focused on waste generated by the electronic manufacturing sector (obsolescent items, production line rejects). Usually, the devices are dismantled, separated according to materials and the material fractions are then shredded. The final material is sent to industries for reuse as raw material or is disposed off at industrial landfills. One prominent exception is circuit boards, which are sent to Europe for precious metals recovery.

3. ELECTRIC AND ELECTRONIC WASTE MANAGEMENT TECHNOLOGIES

Electronic waste is now the fastest growing waste stream in the industrialized world. Electrical and electronic wastes consist of hazardous and non-hazardous waste, that requires special management options such as segregation, collection, transportation, treatment and disposal (UNEP, 2011). Figure 3.1 shows electrical and electronical waste management stage (BİPRO, 2012).

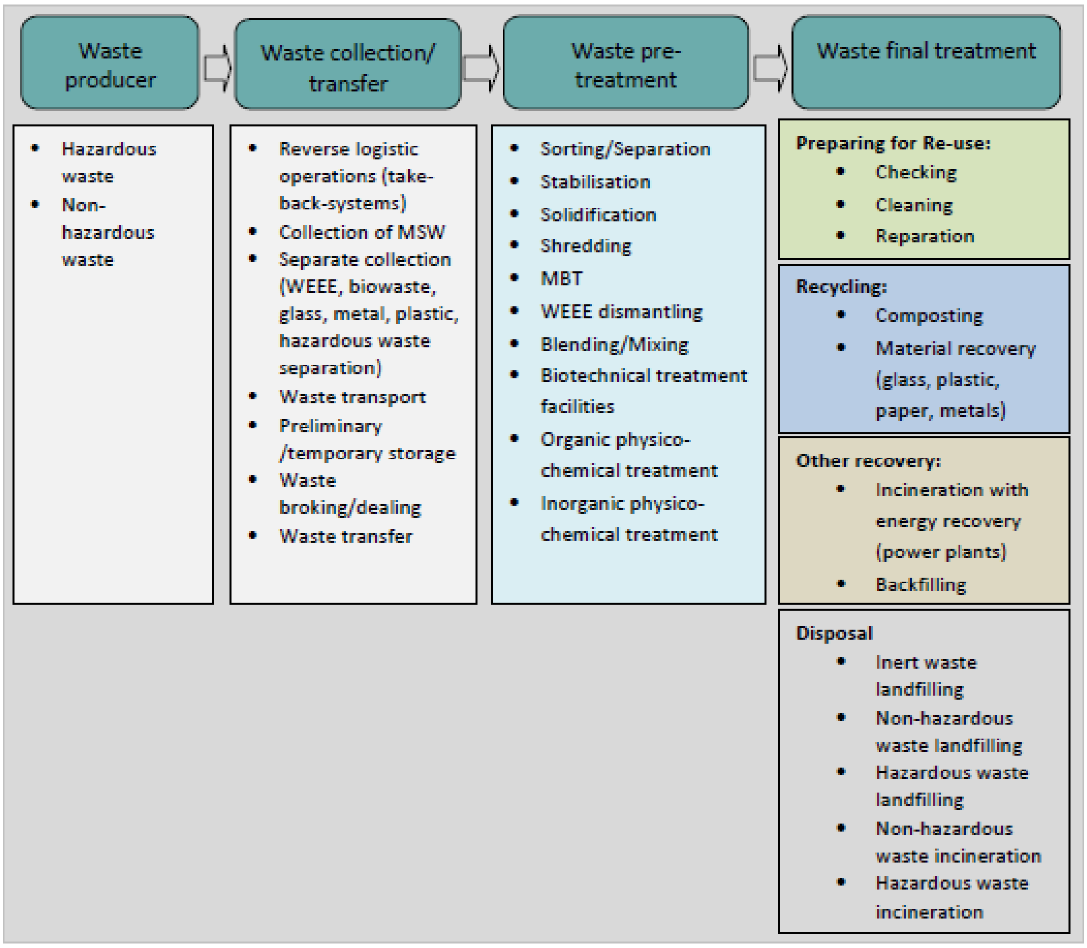

Figure 3.1 : Flowchart of the electrical and electronic waste management stage

In this context, there is a need for conceptual understanding of WEEE options. Therefore, the major objective of this chapter is to describe the pre and post treament options. (UNEP, 2011)
The E-Waste management options consist of two main subsequent steps: First one, is pre treatment options that include mechanical/physical recycling and secound one is post treatment options consisting of hydrometallurgical, pyrometallurgical and biometallurgical process (Özgün Ç., 2008). Each step is crucial for the recovery of metals and recycling economy. Figure 3.2 shows overview of waste management operations (BİPRO, 2012).

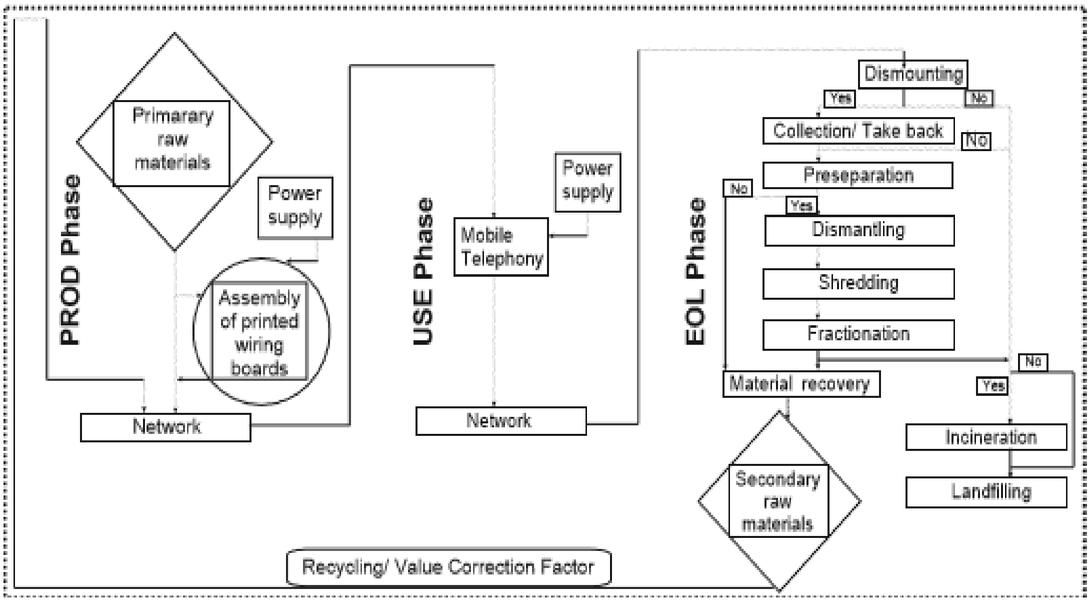

Figure 3.2 : Overview of waste management operations

3.1 Pre-Threatment Processes

Pre-processing technology, using mainly physical separation for preparing suitable fractions for further processing, influences the quality and quantity of the input streams. However, several socio political, technical, economic and environmental issues must be considered as well.

The aim of dismantling and pre-processing is to liberate the materials and direct them to adequate subsequent final treatment processes. It has to be noted that pre-processing of e-waste is not always necessary. Small, highly complex electronic devices such as mobile phones, MP3 players etc. can (after removal of the battery) also be treated directly by an end-processes to recover the metals (Kang H.Y. and Schoenung J.M., 2005).

3.1.1 Mechanical / physical processes

Mechanical/physical processes which provide an alternative means of recovering valuable materials usually do not require chemical agents.

Preprocessing of e-waste is one of the most important steps in the recycling chain. A basic flow sheet diagram of preprocessing is shown in Figure 1. (E Waste Management online book). Mechanical/physical processes such as dissassembly, shredding, gravity seperation, magnetic seperation and electrostatic seperation that is based on the differences in specific physical properties like specific gravity, magnetic properties, and electrical conductivity have been utilized in recycling industry. (Cui and Forssberg, 2003). Table 3.3 illustrates the pre-processing of e-waste to separate metal and non-metal fractions (Aydın B., 2011).

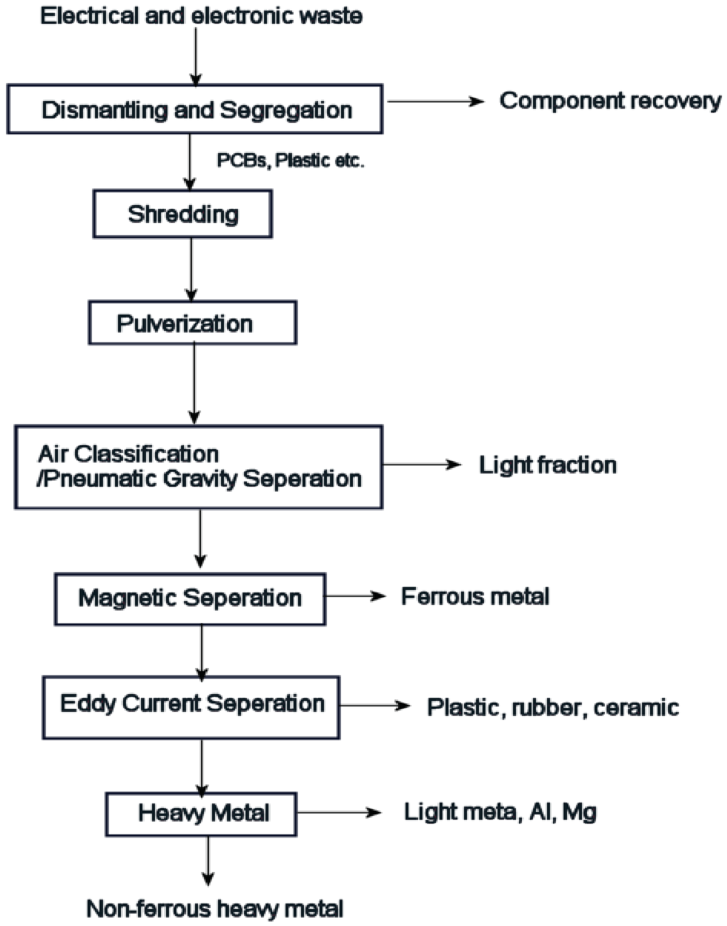

Figure 3.3 : Simplified schema of material recovery process

There are three main aim of sorting, shredding and dismantling processes that is used during pre processing. First one, small grain size material could be recover easily regard to bigger one. Second one, material owning same grain size and same schame is decomposable more effective than other during the electrostatic seperation. Last objective is disconnecting of different materials from each other.

3.1.1.1 Crushing and shredding

Mechanical pre-processing where electronic scrap is shredded into pieces leads to major losses of, especially, precious metals in dust and ferrous fractions. Hammer mill that accomplisg size reduction is one of the most common equipment for crushing and shredding.

Shredding is a process in which products are fed into a shredder which fragments, grinds, rips or tears the product into pieces, which are then sorted into different materials streams and recyclable or valuable materials extracted. Figure 3.4 illustrates a typical recycling process of waste electrical and electronic equipment (Gramatyaka P. et all, 2007).

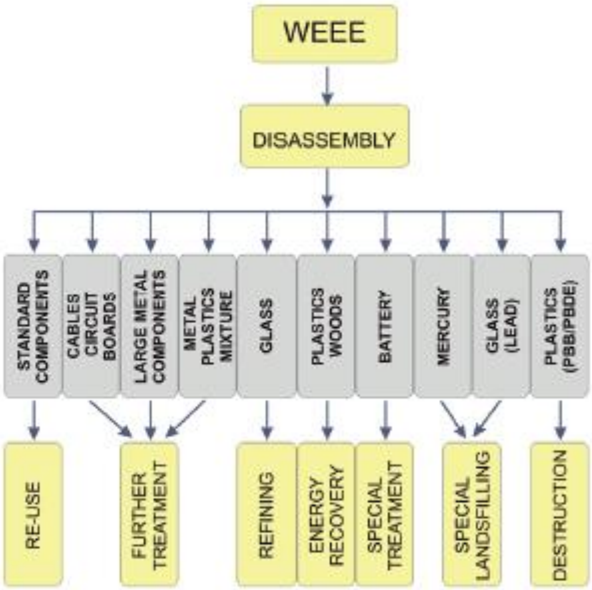

Figure 3.4 : Typical recycling process of WEEE

Sizing is a function of hammer speed, hammer design and placement, screen design and hole size and air assist. Because impact is the primary force used in a hammer mill to generate particulate reduction from bulk, anything that increases the chance of a collision, increases the magnitude of the collision or enhances material take-off is advantageous to particle size reduction. The magnitude of the collisions is increased by hammer speed; this produces particles of smaller mean geometric size. Material disintegration may also be effected by the use of metal crushers which have low specific energy consumption and offer high operational immunity to the presence of solid pieces and may be also used as a pre-stage prior to shredding (E Waste Management online book).

3.1.1.2 Magnetic separation

Separation of magnetic substances, in particular, iron, has been used for over 200 years in the concentration of iron ores. In the last 100 years, the technique has been applied for a wide range of ores and mineral wastes using a wide variety of devices. The removal of small quantifies of iron and iron-beating components and the separation of ferrous and nonferrous components are important applications. The property of a material, which determines its response to a magnetic field is the magnetic susceptibility. Materials are classified in two groups based on magnetic susceptibility. Paramagnetic materials are those attracted by a magnetic field, and diamagnetic materials, which are repelled by a magnetic field. The materials which are very strongly paramagnetic e.g., iron and magnetite, Fe304) are placed in a separate group called ferromagnetic. Examples of paramagnetic materials are hematite, ilmenite and pyrrhotite. Non-metallic compounds like silica, silicates and aluminosilicates are diamagnetic (EWM Book, 2012).

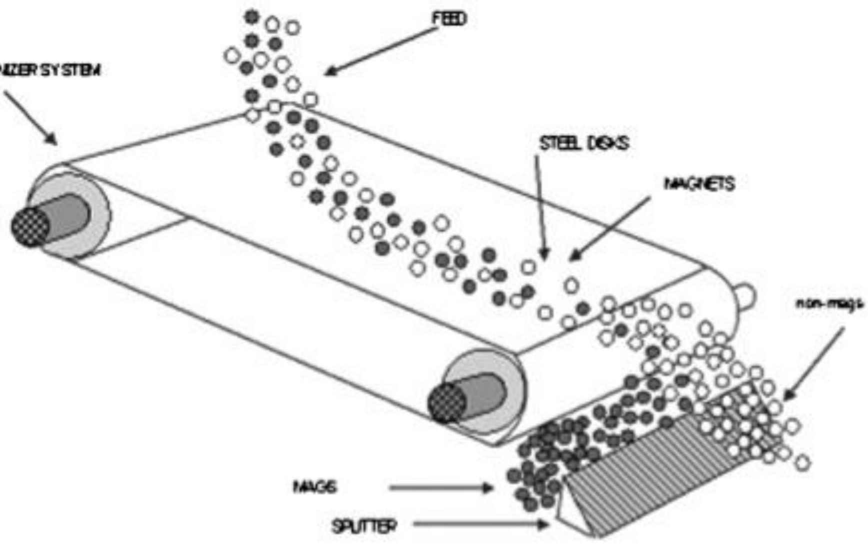

Figure 3.5 : Principle of a magnetic seperator

Magnetic separators such as low-intensity drum types are widely used for the recovery of ferromagnetic materials from non-ferrous metals and other non-magnetic materials. There have been many advances in the design and opera- tion of high-intensity magnetic separators due mainly to the introduction of rare-earth alloy permanent magnets with the capability of providing high field strengths and gradients (EWM online book, 2013).

3.1.1.3 Gravity separation

Several different methods may deploy to separate heavier fractions from lighter ones, the basis being the difference in density to enable such. Gravity concentration separates materials of different specific gravity by their relative movement in response to the action of gravity and one or more other forces, such as the resistance to motion offered by water or air. The motion of a particle in a fluid is dependent not only upon the particle's density, but also on its size and shape; large particles are affected more than smaller ones. In practice, close size control of feeds to gravity separation equipment is required in order to minimise size effects and render the relative motion of the particle gravity dependent. The use of air to separate materials of different density has been established and air tables are used extensively within the food industry for grain separation and within the metals industry for applications such as refining of crushed slag in foundry output. In recent years both air and water-based gravity tables have been adapted for the sorting of electronic scrap and form an integral part of a number of electronic recycling plant operations. Essentially, an air gravity table is similar to a mechanised gold pan that operates continuously and with a high degree of efficiency. The table is com- prised of a deck, in somewhat of a rectangular shape, covered with riffles (raised bars running perpendicular to the feed side of the table), mounted in a near flat position, on a supporting frame that allows the table to slide along the long axis of the table. Instead of water as the medium, air is used and is continuously injected through the porous bed of the table.

3.1.1.4 Electrostatic separation

This technique is based on differences in electrical conductivities of the materials. The separators are commonly called high tension separators. A grounded rotor into the field of a charged ionizing electrode carries the feed. A charge is imparted to the feed particles by ion bombardment. The conductor particles lose their charge to the ground rotor and are thrown from the rotor surface by centrifugal force. They then pass along a nonionizing electrode and are further repelled from the rotor. The nonconducting particles are held to the rotor surface as they do not dissipate their charge rapidly. Their charge is slowly lost and eventually they drop from the rotor. The middling particles (those with conductivity in between those of conducting and nonconducting components) lose their charge faster and drop first. The residual nonconducting particles are removed from the rotor by a brush. Since the charge on the surface of a coarse particle is lower in relation to its mass than that on a fine particle, the separation is also influenced by the particle size. Thus a coarse particle is more readily thrown from the rotor surface and the fine particles tend to be trapped by nonconducting particles and report preferentially with the nonconductor fraction. In practice, therefore, it is often necessary to use multiple stages of cleaning. Electrostatic separation is frequently applied as a step in metal recycling operations, for metal recovery from electronic scrap and in the recovery of precious metals from used catalysts (EWM Book, 2012).

The rotor type electrostatic separator, using corona charging, may be utilised to separate raw materials into conductive and non-conductive fractions. The extreme difference in the electrical conductivity or specific electrical resistance between metals and non-metals affords an excellent pre-condition for the successful implementation of a corona electrostatic separation in recycling of waste. Electrostatic separation has been mainly used for the recovery of copper or aluminium from chopped electric wires and cables and, more specifically, for the recovery of copper and precious metals from printed circuit board scrap; see Figure. (EWM online book, 2013).

3.2 Post-Treatment Processes

The hydrometallurgical and pyrometallurgical processes are the major routes for processing of e-waste.

3.2.1 Hydrometallurgical processes

Recovery of metals and useful products from electrical and electronic equipment often requires chemical treatment. The recovery of PMs from the leached solution is carried out by ion exchange, solvent extraction, electrochemical, and leaching methods.

Acid or caustic leaching are employed for selective dissolution of PMs from e-waste by hydrometallurgy process. This process normally requires a small grain size to increase the metal yield. (P. Gramatyaka et all., 2006). In the process, some reagent material that can be cause pH change need to be added. Also, metals are recovered from solutions by solvent extraction method that use of organic diluents (Özduğan E., 2010). Table 3.1 illustrates the options for precious metals separation (Khaliq A. et all., 2014).

Table 3.1 : Options for precious metals separation

	Au	**Ag**	**Cu**
Computers PCBs Mobile phones	Ion exchange resins Adsorbtion on carbon Solvent extraction Electrolytic deposition Precipitation Cementation	Ion exchange resins Solvent extraction Electrolytic deposition	Cyrstalization Solvent extraction Electrolytic deposition Precipitation Cementation Biosorption

3.2.1.1 Ion exchange

Ion exchange is the process through which ions in solution are transferred to the internal surface of a solid which, in turn releases ions of a different type but of the same polarity. It occurs as a special type of sorption process. Ion exchange is based upon replacement of ions in solutions with different ions which are originally present in the solid. There are many similarities between adsorption and ion exchange.

Since ion exchange occurs between a solution and the internal surface of a solid it can be viewed as a special type of sorption process. There are many similarities between adsorption and ion exchange. The two processes are often analyzed using similar models. Unlike adsorption ion exchange requires an interchange of materials, i.e., the ions (as opposed to a unidirectional transfer) since the electroneutrality of the solution must be maintained (George C Cushnie Jr., 1994).

During ion exchange the ions being exchanged are reversibly removed from the wastewater and transferred to the ion exchanger. This means that ion exchange is a physical separation process in which the ions exchanged are not chemically altered. Since the chemical characteristics of the ions exchanged are not modified the use of ion exchange in wastewater treatment is associated with the removal of hazardous ionic material(s) from the wastewater and its transfer to the ion exchanger

Ion exchange materials are made of organic or inorganic matrices that is containing ionic functional groups. Both natural ion exchange materials (zeolites), resign and synthetic ion exchange materials exist. The vast majority of the ion exchangers used in industrial wastewater treatment is of synthetic origin. The most common type of synthetic ion exchange materials are organic resins.

3.2.1.2 Solvent extraction

In the separation technique of solvent extraction a solute is transferred from one liquid phase to another immiscible or partially miscible liquid, which is in contact with the first phase. The aqueous phase contains the metal which is to be concentrated into the organic phase. The principle was originally applied in analytical chemistry where dilute aqueous solutions were concentrated using an extractant in the organic phase. A well known example (in chemical analysis) is that of extracting copper in low concentration using 8-hydroxy quinoline, represented by (EWM Book, 2012).

3.2.1.3 Electrochemical

Electrochemical process is used as the refining steps to recover pure metal at the end. Electrochemical processes (for example electrorefining or electrowinning) has been used to seperate and recovery metals in effluents. Electrochemical processing is used both in the primary extraction of metals from their ores (electrowinning) and in the subsequent refinin of metals to high purity (electrorefining). Many metals are recovered from effluents by electrochemical process, based on based on the fundamental laws of chemistry and electrochemistry like the principle of cathodic reduction of metal ions at the cathode of an electrolytic cell. The process can produce a coherent solid or be obtained in the form of a powder using high current density. Electrorefining processes are usually carried out in aqueous electrolytes or molten salts. If the metals have been concentrated hydrometallurgically (e.g., selective dissolution, ion-exchange or solvent extraction), they can be electrodeposited directly from aqueous solution onto an inert cathode. The precious metals are concentrated in the anode slimes which a re then treated hydrometallurgically or electrolytically to recover gold, silver, palladium or platinum. Both operations are accomplished in an electrolytic cell, a device that permits electrical energy to perform chemical work (Bard A.J. and Stratmann M., 2007).

3.2.1.4 Leaching

Leaching solvents are mainly includes folloings; H2SO4 and H2O2, HNO3, NaOH, HCl etc. (P. Gramatyaka et all., 2006).

By leaching a soluble component from a solid is extracted using a solvent, called leachant. The material to be leached should be finely ground in order to liberate the component to be leached. In addition, fine particle size enhances the rate of leaching reaction. Some of the principal factors to be considered in leaching operation are the following:

1. Chemical and physical character of the material to be leached. 2. Corroding action of the reagent on the materials of construction of leach vessels. 3. Selectivity for the desired constituent to be leached. 4. Feasibility of regenerating the leaching agent. This is very important both from economic as well as environmental points of view (Zhang Y., 2011).

Selectivity of a leaching agent toward a specific component in a waste material depends upon several factors including concentration of the leaching agent, temperature and contact time. The importance of each will be considered. Concentration of the leaching agent: In some cases a certain minimum concentration of the leaching agent is adequate and no benefit is derived by increasing the concentration. For example, most carbonates can be dissolved by acid at moderate concentration. However, in many other cases the dissolution rate can be enhanced by increasing the concentration of the leaching agent; for example, most of the heavy metal oxides and hydroxides require higher concentration of acids (Neira J., 2006).

3.2.2 Pyrometallurgical processes

Thermal treatment route is called pyrometallurgical processing. Pyrometallurgical processing involves high temperature reactions, roasting, smelting and converting (for example, metal oxide to metal) (P. Gramatyaka et all., 2006).

Many metallurgical residues containing valuable metals occur as oxides. The recovery of metals from them is usually done by direct reduction of the oxides at temperatures above 1500°C. This is done using carbon (or any carbonaceous material like coal, coke, etc.) as reducing agent. In addition, metallurgical residues of pyrometallurgical operations, include large quantities of metallurgical dust, which is also becoming a secondary source of metals.

The oxide waste is heated with a reducing agent, such as carbon in the form of coke or coal; the oxygen of the metal combines with the carbon and is removed in carbon dioxide gas. The waste material in e- waste (non-metallic parts) is called gangue; it is removed by means of a substance called a flux which, when heated, combines with it to form a molten mass called slag (Hoffman, 1992).

3.2.2.1 Pyrolysis

Pyrolysis are thermochemical processes whereby carbonaceous feedstocks are transformed at moderate temperatures. Pyrolysis is thermal degradation or volatilization of the tires in total absence or small amount of oxygen in which the structures of polymers break down into smaller intermediate products. The decomposition temperature of a substance is the temperature at which the substance breaks up into smaller substances or into its constituent atoms. The pyrolysis takes place under reduced atmospheric pressure and under further addition of heat (Zuo X., 2011).

Pyrolysis is one of the best methods for treating complex mixtures of waste polymers and to recover the material and energy content. Pyrolysis is a process where the material is heated up in an inert gas atmosphere. At certain temperatures the organic fractions (plastic, rubber, paper, wood etc.) decompose and form volatile substances which can be used in the chemical industry or for the generation of energy by combustion of the gases or oils. At the present there exists no process which uses this method in industrial scale (P. Gramatyaka et all., 2006).

Dehalogenation of the pyrolysis product of electronic scraps is essential to make it commercially acceptable. It would be obviously the most advantageous solution as pyrolysis and dehalogenation are carried out simultaneously. The pyrolysis process has several advantages. There are converting the organic solid substance into fuel gas, fuel oil and carbon-black as storage energy, emitting toxic substances such as sulfur, bromine and heavy metals in wastes and keeping metals from being oxidized (Zhang Lifeng and Krumdick G.K., 2011).

3.2.2.2 Smelters

Smelting is the most common process used for metal recovery from WEEE. This process is used to recover the copper content of electronic scrap plus any other "noble" metals that on melting dissolve in copper, such as silver, gold, platinum, and palladium. Iron and aluminum are not recovered in the copper smelting process, and instead are oxidized to slag. Several processes require melting of the feed material. This is done in smelting furnaces.

Smelting processes were developed initially for fusing high grade lump ore either as produced by the mine or obtained by hand, or in the case of nickel pyrrohtite ores by magnetic cobbing. Such lump ores were suited to smelting in a low shaft blast furnace with coke. The shaft furnace was simple and low cost to construct and could be readily expanded to accommodate higher tonnages. It comprised a hearth, water-cooled boiler plate jackets with entry ports for low-pressure air injection and a spout for discharge of combined matte and slag to a settle chamber. Off gas was released through to permit settling of coarse dust before exhausting to atmosphere through a brick lined stack that provided the draft to pull the furnace exhaust gas through the flow system.

3.2.3 Biometallurgical processes

Certain natural materials of biological origin can retain large quantities of metal ions by one of the different possible mechanisms including sorption and complexation. The biological material of such properties is called biomass and the phenomenon is called biosorption. It has been exploited for the separation and recovery of metals from effluents as well as for toxicity removal. This chapter will describe the sources of biomass, possible mechanisms of metal uptake and their potential in metal recovery from metallurgical effluents.

There are only limited laboratory studies for e-waste processing through biometallurgical routes, e.g., bioleaching of metals from e-waste. Nevertheless, this route has a potential for further development (Khaliq A. et all., 2014).

3.2.3.1 Bioleaching

Bioleaching is the extraction of metals from ores using the principal components of water, air and microorganisms, all of which are found readily within the environment. In the case of ores containing iron and sulphur e.g. pyrite and chalcopyrite, bioleaching is brought about by bacteria such as Thiobacillus ferrooxidans, Leptospirillum ferrooxidans, Thiobacillus thiooxidans, Sulfolobus species and others. These microorganisms derive energy from the oxidation of ferrous ions, the oxidation of sulphur and the fixation of carbon dioxide.

There are two dominant mechanisms, which are considered to be involved in bioleaching. In the first mechanism, the catalytic action of the microorganisms is responsible for the dissolution of the mineral. Most researchers have proposed that the microorganisms interact with the mineral surface directly, enhancing the rate of dissolution. Through a bacterial oxidation, the bacteria then change the metal sulphide particles into soluble sulphates therefore dissolving the metals. The first mechanism is referred to as the direct mechanism. In the second mechanism, the microbial action results in the oxidation of ferrous ions to ferric ions, and the ferric ions then chemically oxidise the sulphide minerals. This is referred to as the indirect mechanism (Willner J. and Fornalczyk A., 2013).

Mining companies may be able to use bioleaching as a way to exploit low-grade ores and mineral resources located in areas that would otherwise be too expensive to mine.

Additionally, there are several perceived advantages to using bioleaching such as the use of naturally occurring key components (microorganisms, water and air), the use of atmospheric pressure and ambient temperature conditions and the avoidance of generation of dust and SO2.Bioleaching technologies can deliver significant environmental benefits when compared to traditional smelting and other treatment methods and also capital and operating cost advantages over smelting. Biotechnology also support the assertion that bioleaching has a less harmful impact on the environment than conventional extraction methods, because it uses less energy and does not produce SO2 emissions (Jonglertjunya W., 2003).

3.2.3.2 Biosorbtion

Biosorption process is a passive physico-chemical interaction between the charged surface groups of microorganisms and ions in solution. Biosorbents are prepared from the naturally abundant and/or waste biomass of algae, fungi or bacteria. Physico-chemical mechanisms such as ion-exchange, complexation, coordination and chelation between metal ions and ligands, depend on the specific properties of the biomass (alive, or dead, or as a derived product) (Macek T. and Mackova M., 2011).

Compared with the conventional methods, biosorption based process offers a number of advantages including low operating costs, minimization of the volume of chemical/biological sludges to be handled and high efficiency in detoxifying (Sohaili J. et all., 2012).

3.3 Disposal

The dramatic increase in waste for disposal led to the creation of the first incineration plants. Municipal systems of waste disposal sprung up at the turn of the 20th century in other large cities of Europe and North America. Landfilling and incineration are the predominant practices in waste management with major differences between countries (EPA, 2003).

3.3.1 Landfill

Disposing of waste in a landfill involves burying waste to dispose of it, and this remains a common practice in most countries. Historically, landfills were often established in disused quarries, mining voids or borrow pits. A properly-designed and well-managed landfill can be a hygienic and relatively inexpensive method of disposing of waste materials. Older, poorly designed or poorly managed landfills can create a number of adverse environmental impacts such as wind blown litter, attraction of vermin, and generation of liquid leachate (Holmes I., 2012).

Another common byproduct of landfills is gas (mostly composed of methane and carbon dioxide), which is produced as organic waste breaks down anaerobically. This gas can create odor problems, kill surface vegetation, and is a greenhouse gas. Design characteristics of a modern landfill include methods to contain leachate such as clay or plastic lining material. Deposited waste is normally compacted to increase its density and stability, and covered to prevent attracting vermin (such as mice or rats). Many landfills also have landfill gas extraction systems installed to extract the landfill gas. Gas is pumped out of the landfill using perforated pipes and flared off or burnt in a gas engine to generate electricity (Özgün Ç., 2008).

3.3.2 Incineration

Incineration is a disposal method that involves combustion of waste material. Incineration and other high temperature waste treatment systems are sometimes described as "thermal treatment". Incinerators convert waste materials into heat, gas, steam, and ash.

Incineration is carried out both on a small scale by individuals and on a large scale by industry. It is used to dispose of solid, liquid and gaseous waste. It is recognized as a practical method of disposing of certain hazardous waste materials (such as biological medical waste). Incineration is a controversial method of waste disposal due to issues such 30 as emission of gaseous pollutants. Incineration is common in countries such as Japan where land is scarcer, as these facilities generally do not require as much area as landfills.

Facilities generate heat, steam and/or electricity. Modern combustion technologies maintain the advantages of incineration without its numerous disadvantages, while providing a clean energy source. Municipal solid waste, sewage, sludge, "dirty coals", and coal byproducts, are cleanly and efficiently consumed for energy production with emissions well within strict regulatory standards. The fly ash byproduct is inert, and can be mixed with compost.

Each route has advantages and disadvantages that should be considered for the selection of an appropriate recycling process (Rabl A. et all., 2008).

4. ANALITICAL HIERARCHY PROCESS

Analitical Hierarchy Process (AHP) bring up firstly by Myers ve Alpert in 1968. AHP is presented by By Tomas L. Saaty in 1980 probably the best known and most efficient decision making and weighting methods that is used. Several papers have compiled the AHP success stories in very different fields (Nabavi V., 2012).

The AHP approach is a systematic analysis technique for MCDM and it facilitates a rigorous definition of priorities and preferences of the decision makers (Karimi A. R. et all., 2011). The most important feature of AHP can be involved objective and subjective idea of decision makers in decision making process (Demirtaş Ö., 2009).

4.1 Decision Making Process by AHP

AHP is a powerful and decision making methodology in order to determine the priorities among different criteria. The AHP encompasses six basic steps as summarized as below:

- ✓ Definition of the problem and the purpose
- ✓ Determine criteria and sub criteria
- ✓ Determine the alternatives
- ✓ Comparise of the hierachical structure
- ✓ Pairwise comparison of alternatives to form a matrix for each criteria and normalise each matrix
- ✓ Pairwise comparison of criteria to form a matrix and normalise the matrix

Final score for each alternative with respect to consistency analysis (Akay Ö., 2011).

4.1.1 Hierarchical structure

Analitical Hierarchy concsist of criteria, subctriteria and alternatives and each of these steps set a framework of problem. First of all, goal is determined to realize the current situation. In line with this purpose, potential alternatives is determine by considering criteria that is affecting selection. In this way, the hierarchical structure of AHP sets as shown in Figure 4.1 (Işıklar G. and Büyüközkan G., 2006).

The crucial point is to determine levels of criteria and sub criteria when hierarchy is creating. While the top level shows objective, the low levels alternatives. Criteria and subcriteria is one of the these (Nabavi V., 2012).

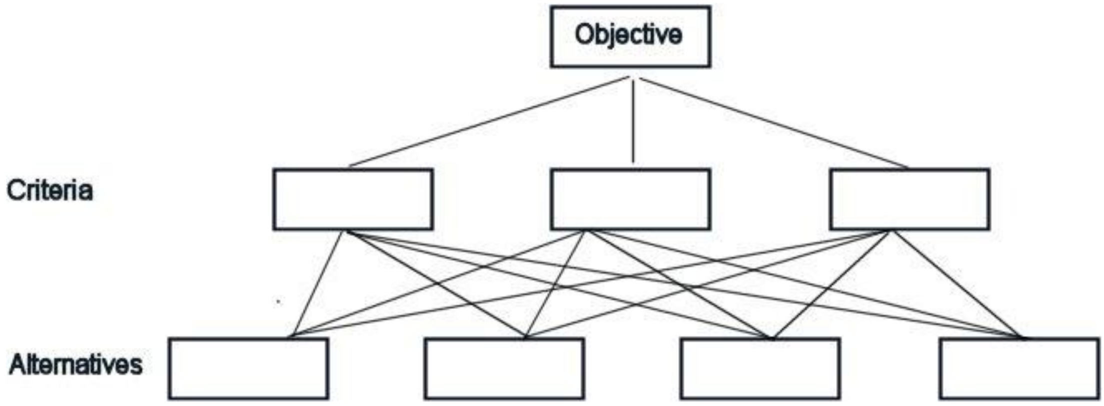

Figure 4.1 : The hierarchical structure of AHP

4.1.2 Pairwise comparision

First step, definition of the attitutes with regard to aim of the project. Proposal priority is determined and criteria and subcriteria that is effect to aim is determined. After this stage, pairwise comparision matrises are constitute to definition importance of between criteria and subcriteria.

Table 4.1 : Pairwise comparision matrix

	K_1	K_2	K_3	....	K_m
K_1	a_{11}	a_{12}	a_{13}	....	a_{2m}
K_2	a_{21}	a_{22}	a_{23}	....	a_{2m}
:	:	:	:	....	:
K_m	a_{m1}	a_{m2}	a_{m3}	....	a_{mm}

Pairwise comparision of criteria is perform with regard to order to importance ın Table 4-2. Numerical assesment scale is used at pairwise comparision of the criteria.

Significancy scale which is suggest by Saaty (scale ranging from 1 to 9) is use to comprise this matrix. This scale that is suggest by Saaty has provide the best result. Other scale such as 1-5, 1-7, 1-15 and 1-20 is insufficient to get the favorable solution (Akay Ö., 2011). Figure 4.2 illustrates the numerical assesment, scale and linguistic meanings (Ciocoiu C. N., 2012).

Table 4.2 : The numerical assesment, scale and linguistic meanings

Intensity	Evaluation	Explication
1	Equal importance	The spedified criteria contribute equally to objective
3	Weakly importance	Acriterion is slightly favored compared with other
5	Essentially importance	A criterion is clearly dominates the other in importance
7	Very Strongly importance	A criterion is strongly favored compared with other
9	Absolutely importance	A criterion is unquestionably more important than other
2,4,6,8	Intermediate values	When compromise is giving between to adjacent judgments

Pairwise comparison of alternatives for each criteria is calculating to form a matrix. All results will be normalized and criteria and sub-criteria is weighted. After calculating the all paired comparison matrix cells, an significant point about the paired comparison matrix is their inconsistency rate, which should be ≤0/1 in order for the judgments to be stable. Therefore, if this rate is greater than 0/1 in some paired comparison matrices, the relevant expert needs repeat his judgment and then calceulate the geometric mean of paired comparison matrix cells (Yüksel H., 2009).

4.2 AHP Calculation Software - Expert Choice

The Analytic Hierarchy Process (AHP) as described in this first publication and are unaware of successive developments. This fact is probably due to the leading software supporting AHP, namely, Expert Choice, which still incorporates AHP as it was described in its first publication.

Software supporting programme that is namely Expert Choice (EC) is developed by Prof. Dr. Ernest Forman at University of George Washington (Aydın, 2008).

5. THE SELECTION OF BEST ALTERNATIVE FOR WEEE

In this thesis, eight post treatment technology was defined to recover precious metals from WEEE. The weight of each criteria was calculated using AHP method.

Table 5.1 : Criteria and sub-criteria summary

Attributes	Indicators Involved
Socio Political Criteria	
Political and legislative	Compliance & harmonisation with national and international legislation. A low waste technology always be preferred.
Social Acceptance	The degree of social accceptance depends on many factors; env. sensitive technology, impacts on human health.
Economic Criteria	
Benefits From Recycling	Production of marketable secondary raw material and products (electricity), product quality, land requirement
Operation and maintenance Cost	Processing, labour etc. Revenues and additional industries and services involved
Investment Cost	Investment costs for additional plants and technologies used in a scenario, land demand.
Environmental Criteria	
Air Emissions	Emissions of toxic substances contribute to climate related impacts and causes adverse consequenses to public health and environment.
Production of w.w.	Freshwater consumption of a recycling scenario.
Production of s.w.	The amount of sludge production of each activity is examined. Treatment requirements.
Generation of h.w.	Special attention must be paid to the harmfull consequences to the human health and environment
Noise Pollution	Production of noise on the surrounding area.
Resource usage/Energy Consumption	Consumption of natural resources (principally raw material and energy).
Technological Criteria	
Operability	Flexibility, requirement of personal stuff, accountability
Reliability	Tecnology security
Functionality	Recovery percentage

Implementing an Analitical Hierarchy Process and comparization of socio-political, economical, environmental and technological criteria was evaluated by using Expert Choise programme.

5.1 Determination of the Criteria

In the first stage of research, the relevant criteria, sub-criteria and alternatives are chosen on the basis of the review of literature and discussions with academia (with regard to aim of the research) as you can see in the Table 5.1 (Rousis K et all., 2008).

5.2 Description of the Criteria

Fourteen individual criteria were selected in total, categorized in 4 groups, as described below. The proposed model is based on the analysis of environmental, economical, socio-political and technical attributes that may affect an implementation of WEEE management systems.

And the relevant criteria, sub-criteria and alternatives are structured in the form of a network is presented in Figure 5.1.

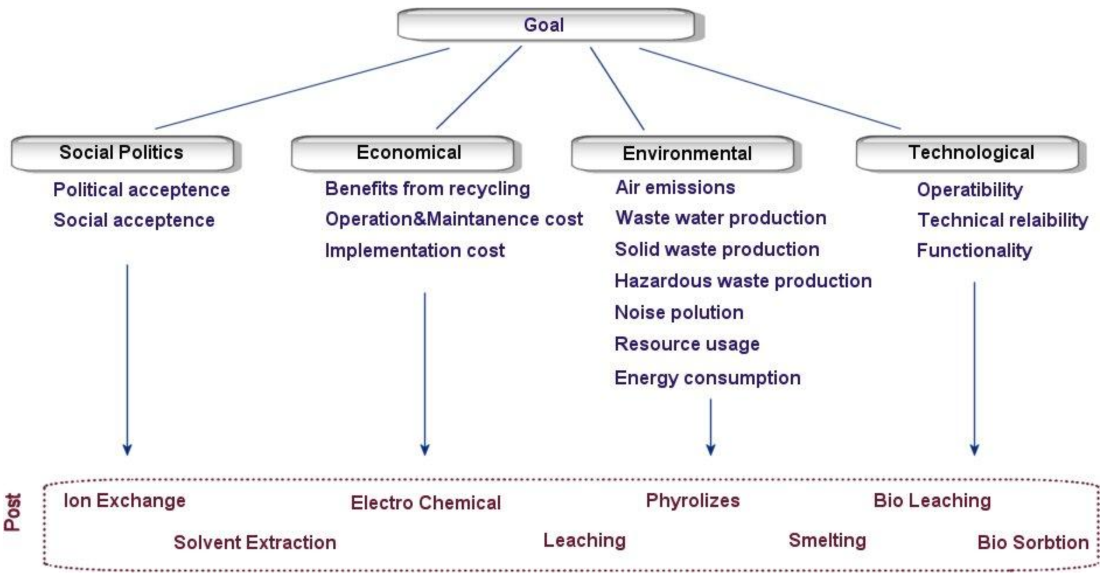

Figure 5.1 : Structure of the WEEE management process

5.2.1 Socio-political criteria

Political acceptance and legislative aspects : Compliance with national and international legislation is an important aspect of WEEE recycling. The WEEE legislation is very complex and includes regulations regarding WEEE collection, producer responsibility, collective systems, export/import rules, dangerous substances and treatment methods, etc. Harmonisation of all regulations regarding WEEE management contributes to increasing its efficiency by eliminating the possibilities of breaking the law (Ciocoiu. C.N., 2012).

Social acceptance : The degree of social acceptance of the proposed solution for WEEE management is dependent on many factors, such as the prevention/reduction of environmental repercussions that are caused by the existing management practices ad healty and safety issues

5.2.2 Economic criteria

Benefits from Recycling : Product quality is one of the benefit from recycling criteria with positive economic revenue. In addition to this, production of marketable secondary raw material and products (electricity), and land requirement are others.

Operation and maintenance costs : Processing such as treatment plant, labour etc. Revenues and additional industries and services involved by implementing a scenario. The lowest cost solution may compromise the desired environmental outcome. There a many false economy traps to fall into and it is important that there are acceptable and realistic ambitions for volumes, costs and standards. Smaller distances dramatically reduce transport and logistics costs. But, it is not taken into consideration.

Investment Cost : This criteria include two parameters. The first of this is the monetary expenses for the construction of the plant. The second is concerned with land demand.

5.2.3 Environmental criteria

Electrical and electronic products can affect the environment throughout their life cycle from when raw materials are extracted from the earth to when materials from the products are reused, recycled, recovered or discarded. As the materials contained in different WEEE are substantially different, the environmental impact of WEEE depends on both the type of WEEE and the way it is treated.

5.2.3.1 Air emissions

Emissions of toxic substances proceed from inefficient use of materials and energy. Air Emissions comprise a basis for (contribute to) global problems (ex. climate related impacts) and local impacts (ex. eco-toxic emissions, damage to human health).

5.2.3.2 Waste water production

Freshwater consumption and consequently water pollution of a recycling scenario.

5.2.3.3 Solid waste production

The amount of sludge production of each activity is examined. Treatment requirements.

5.2.3.4 Hasardous waste generation

Many products are disposed of as they still possess their full functionality simply because expanding performance and functionality is presented to the customer in the shape of new products. The effect of this rapid innovation is an extremely high turnover of hardware and software which result in an increased amount of electronic waste.

5.2.3.5 Noise production

Production of noise on the surrounding area. The noise pollution thay originates from the management plants is an important factor that should be taken into consideration during the planning application of the management systems.

5.2.3.6 Resource use and energy consumption

Consumption of natural resources (principally raw material and energy). Resources use was highlighted as an important environmental criterion. Electronics contain substantial quantities of precious metals such as gold, silver and platinum. The concentration of gold in a circuit board may be 40 to 800 times greater than that found in natural gold ore.Therefore, mining e-waste for such metals can be more efficient than mining the earth. However, despite the potential for inherent environmental benefit in mining e-waste, historically, the high costs of separating the aggregated materials in e-waste have limited the growth of e-waste recycling markets. As a result of WEEE recycling, greater levels of limited physical resources will be available for use because they will not be disposed of in landfill, and there will be less need to mine or produce virgin materials.

Energy consumption with the goal to solve the negative aspects induced by WEEE, in August 2007 entered into force in EuP Directive 2005/32/EC. The directive aims to reduce the energy use and other negative environmental impacts throughout the life cycle of products powered by electricity, fossil or renewable fuels. Technology is the most important source of energy saving. Less energy is needed to produce the same amount of product, using the same amount of equipment. So, the technological progress has led to an improvement of energy efficiency. On the same time a bigger pool of electronic products appeared due to lower prices on electronic products, which has the consequence of increase of energy consumption. Stimulating different energy saving measures will have to be complemented with recycling actions to tackle this rebound effect.

5.2.4 Technologic criteria

Technologies are vital in the e-waste management chain to maximize the material recovery and minimize the risks.

5.2.4.1 Operability

The parameters examined as far as operability of the proposed management systems is concerned are the following; the simplicity of operation and the requirement skilled personnel.

5.2.4.2 Reliability

The existing experience from the application of similar technologies and management systems plays an essesntial role in the evaluation of the proposed administrative plans or systems. More specifically, if there is a need for the introduction of new technologies, the evaluation of the existing experience is very important for the potential adoption of these technologies.

5.2.4.3 Functionality

The parameters examined as far as the functionalism of the proposed management systems is concerned with recovery rate (%) (Rousis K. et all., 2008).

5.3 Pairwise Comparision of the Criteria

First of all, each main criteria were compared according to propose. After that, each sub- criteria that was determined for each main criteria were compared and alternatives were compared between each other according to each of sub-criteria At this comparison, scale that are given in Table 5.2 were used (Rousis K. et all., 2008). Finally, the weight of each criteria was calculated using AHP method. Thus, the best alternative was chosen by using Analitical Hierarchy Process (AHP).

Table 5.2 : Weight coefficients for each criterion of each group of criteria

Evaluation of the WEEE management system	Weight Coefficient (%)
Socio-Political	
Political Acceptance (Legislative)	50
Social Acceptance	50
Total	100
Economic	
Benefits from Recycling	20
Cost of operation and maintenance	40
Cost of Investment (Implementation Cost)	40
Total	100
Environmental	
Air emissions	20
Production of w.w.	20
Production of s.w. Residues	20
Generation of h.w.	25
Noise Pollution	5
Resource Usage/Energy Consumption	10
Total	100
Technological	
Operability (Flexibility)	30
Technical Reliability (Existing Experience)	40
Functionality	30
Total	100

Table 5.3 : Pairwise comparision of main criteria respect to the propose

	Socio- Political	Economical	Environmental	Technical
Socio- Political		7,0	7,0	5,0
Economical			1,0	3,0
Environmental				3,0
Technical	Incon: 0,03			

In Table 5.3 AHP comparison matrise that is given pairwise comparision of main criteria is expensed.

According the results, Economical and environmental criteris have similar priorities in selection of the best management technology. Technologic and socio political criterias have lesser priorities than others. By using Expert Choise programme, Weightness vektor of socio-political, economical, environmental and technological criteria was evaluated. Weightness vektor for economic and environmental criterias is 0,395, inconsistence rate is 0,03.

Table 5.4 : Abbreviations of the alternatives

Abbreviations	Alternatives
IE	Ion Exchange
SX	Solvent Extraction
EW	Electrochemical
L	Leaching
P	Pyrolysis
S	Smelting
BL	Bioleaching
BS	Biosorbtion

Pairwise comparison matrix for the subcriteria with respect to socio-political criteria illustrates in Table 5.5 and table 5.6.

Table 5.5 : Comparision respect to political criteria

	IE	SX	EW	L	P	S	BL	BS
IE		2,0	3,0	3,0	4,0	5,0	3,0	4,0
SX			2,0	4,0	5,0	6,0	2,0	3,0
EW				5,0	6,0	7,0	2,0	3,0
L					2,0	3,0	6,0	7,0
P						2,0	7,0	8,0
S							8,0	9,0
BL								2,0
BS	Incon: 0,03							

Table 5.6 : Comparision respect to social criteria

	IE	SX	EW	L	P	S	BL	BS
IE		2,0	3,0	3,0	4,0	5,0	4,0	5,0
SX			2,0	4,0	5,0	6,0	3,0	4,0
EW				5,0	6,0	7,0	2,0	3,0
L					2,0	3,0	6,0	7,0
P						2,0	7,0	8,0
S							8,0	9,0
BL								2,0
BS	Incon: 0,04							

Pairwise comparision matrix for the subcriteria with respect to economic criteria illustrates in Table 5.7, table 5.8 and table 5.9.

Table 5.7 : Comparision respect to benefits from recycling criteria

	IE	SX	EW	L	P	S	BL	BS
IE		3,0	2,0	1,0	3,0	2,0	4,0	4,0
SX			2,0	3,0	5,0	4,0	2,0	2,0
EW				2,0	4,0	3,0	3,0	3,0
L					3,0	2,0	4,0	4,0
P						2,0	6,0	6,0
S							5,0	5,0
BL								1,0
BS	Incon: 0,05							

Table 5.7 illustrates pairwise comparision of the alternatives with respect to benefits from recycling criteria.

Table 5.8 : Comparision respect to operation and maintenance cost criteria

	IE	SX	EW	L	P	S	BL	BS
IE		2,0	2,0	3,0	3,0	4,0	5,0	6,0
SX			3,0	4,0	2,0	3,0	6,0	7,0
EW				2,0	4,0	5,0	4,0	5,0
L					5,0	6,0	3,0	4,0
P						2,0	7,0	8,0
S							8,0	9,0
BL								1,0
BS	Incon: 0,06							

Table 5.8 illustrates pairwise comparision of the alternatives with respect to operation and maintenance cost criteria.

Table 5.9 : Comparision respect to investment cost criteria

	IE	SX	EW	L	P	S	BL	BS
IE		5,0	3,0	4,0	3,0	2,0	6,0	7,0
SX			3,0	2,0	7,0	6,0	2,0	3,0
EW				2,0	5,0	4,0	4,0	5,0
L					6,0	5,0	3,0	4,0
P						2,0	8,0	9,0
S							7,0	8,0
BL								1,0
BS	Incon: 0,03							

Table 5.9 illustrates pairwise comparision of the alternatives with respect to investment cost criteria.

Pairwise comparision matrix for the subcriteria with respect to environmental criteria illustrates from Table 5.10 to table 5.15.

Table 5.10 : Comparision respect to air emission criteria

	IE	SX	EW	L	P	S	BL	BS
IE		1,0	3,0	4,0	6,0	7,0	3,0	2,0
SX			3,0	4,0	6,0	7,0	3,0	2,0
EW				3,0	4,0	5,0	5,0	4,0
L					3,0	4,0	6,0	5,0
P						2,0	8,0	7,0
S							9,0	8,0
BL								2,0
BS	Incon: 0,04							

Table 5.10 illustrates pairwise comparision of the alternatives with respect to air emission criteria.

Table 5.11 : Comparision respect to production of waste water criteria

	IE	SX	EW	L	P	S	BL	BS
IE		2,0	3,0	1,0	8,0	7,0	5,0	4,0
SX			2,0	2,0	7,0	6,0	4,0	3,0
EW				3,0	6,0	5,0	3,0	2,0
L					8,0	7,0	5,0	4,0
P						2,0	4,0	5,0
S							3,0	4,0
BL								2,0
BS	Incon: 0,03							

Table 5.11 illustrates pairwise comparision of the alternatives with respect to production of waste water criteria.

Table 5.12 : Comparision respect to production of solid waste criteria

	IE	SX	EW	L	P	S	BL	BS
IE		3,0	4,0	1,0	6,0	5,0	4,0	4,0
SX			6,0	3,0	8,0	7,0	6,0	6,0
EW				4,0	3,0	2,0	1,0	1,0
L					6,0	5,0	4,0	4,0
P						2,0	3,0	3,0
S							2,0	2,0
BL								1,0
BS	Incon: 0,02							

Table 5.12 illustrates pairwise comparision of the alternatives with respect to production of solid waste criteria

Table 5.13 : Comparision respect to generation of hazardous waste criteria

	IE	SX	EW	L	P	S	BL	BS
IE		3,0	4,0	1,0	6,0	5,0	4,0	4,0
SX			6,0	3,0	8,0	7,0	6,0	6,0
EW				4,0	3,0	2,0	1,0	1,0
L					6,0	5,0	4,0	4,0
P						2,0	3,0	3,0
S							2,0	2,0
BL								1,0
BS	Incon: 0,02							

Table 5.13 illustrates pairwise comparision of the alternatives with respect to hazardous waste criteria.

Table 5.14 : Comparision respect to noise pollution criteria

	IE	SX	EW	L	P	S	BL	BS
IE		1,0	3,0	1,0	3,0	4,0	4,0	3,0
SX			3,0	1,0	3,0	4,0	4,0	3,0
EW				3,0	5,0	6,0	2,0	1,0
L					3,0	4,0	4,0	3,0
P						2,0	6,0	5,0
S							7,0	6,0
BL								2,0
BS	Incon: 0,02							

Table 5.14 illustrates pairwise comparision of the alternatives with respect to noise pollution criteria.

Table 5.15 : Comparision respect to generation of energy/resource usage

	IE	SX	EW	L	P	S	BL	BS
IE		2,0	5,0	1,0	6,0	7,0	2,0	3,0
SX			4,0	2,0	5,0	6,0	3,0	4,0
EW				5,0	2,0	3,0	6,0	7,0
L					6,0	7,0	2,0	3,0
P						2,0	7,0	8,0
S							8,0	9,0
BL								2,0
BS	Incon: 0,03							

Table 5.15 illustrates pairwise comparision of the alternatives with respect to generation of energy/resource usage

Pairwise comparision matrix for the subcriteria with respect to technological criteria illustrates in Table 5.16, table 5.17 and table 5.18.

Table 5.16 : Comparision respect to operability criteria

	IE	SX	EW	L	P	S	BL	BS
IE		3,0	1,0	2,0	4,0	5,0	3,0	2,0
SX			3,0	2,0	2,0	3,0	5,0	4,0
EW				2,0	4,0	5,0	3,0	2,0
L					3,0	4,0	4,0	3,0
P						2,0	6,0	5,0
S							7,0	6,0
BL								2,0
BS	Incon: 0,02							

Table 5.17 : Comparision respect to reliability criteria

	IE	SX	EW	L	P	S	BL	BS
IE		6,0	7,0	6,0	7,0	7,0	2,0	3,0
SX			2,0	1,0	2,0	2,0	5,0	4,0
EW				2,0	1,0	1,0	6,0	5,0
L					2,0	2,0	5,0	4,0
P						1,0	6,0	5,0
S							6,0	5,0
BL								2,0
BS	Incon: 0,02							

Table 5.18 : Comparision respect to functionality criteria

	IE	SX	EW	L	P	S	BL	BS
IE		2,0	2,0	1,0	2,0	2,0	4,0	3,0
SX			1,0	2,0	3,0	3,0	5,0	4,0
EW				2,0	3,0	3,0	5,0	4,0
L					2,0	2,0	4,0	3,0
P						1,0	3,0	2,0
S							3,0	2,0
BL								2,0
BS	Incon: 0,01							

Table 5.16 illustrates pairwise comparision of the alternatives with respect to operability criteria. Table 5.17 illustrates pairwise comparision of the alternatives with respect to reliability criteria. Table 5.18 illustrates pairwise comparision of the alternatives with respect to functionality criteria.

5.4 Results

When comparision of the alternatives with respect to main criterias; biosorbtion processes has more advantages than other alternatives because of being new, cleaner and ecofriendly technologies. In addition to this, it is efficient due to low capital and operation cost requirement.

The changes that were imposed to the weight coefficients of the social criteria led to the conclusion that criteria political acceptance and social acceptance do not alter the final ranking of the proposed management systems. A low waste technology solution should always be preferred as it minimizes the threat of environmental legislation. The unique change that was noticed was in the values of ranking. The final ranking of the alternative management systems is as follows:

BS>BL>EW>SX>IE>L>P>S.

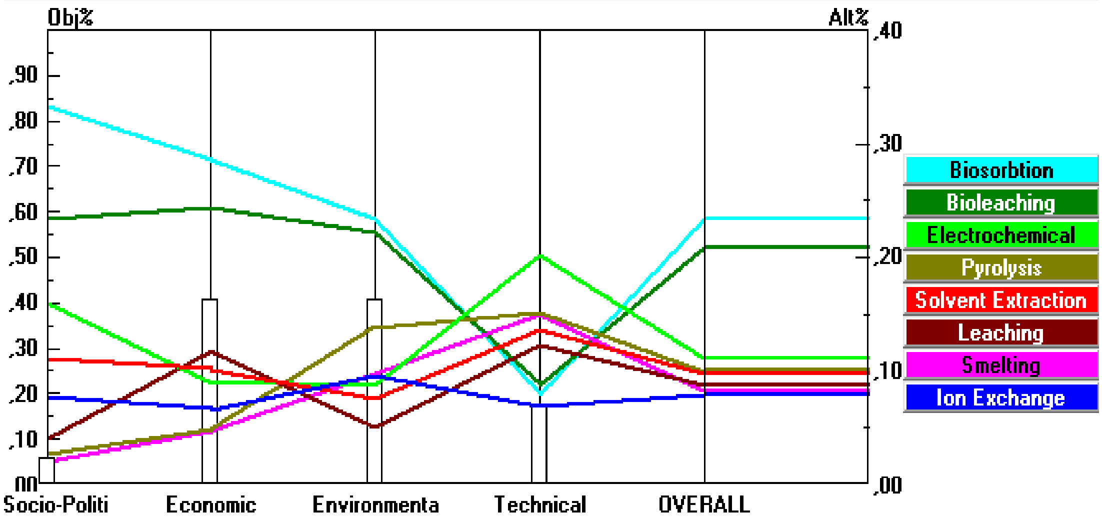

Figure 5.2 : Overall performance results

Concerning the socio-political criteria, biosorbtion is seems to be more preferable than other process. Figure 5.3 is summarized by the final ranking of ExpertChooise that is presented below:

BS>BL>EW>SX>IE>L>P>S.

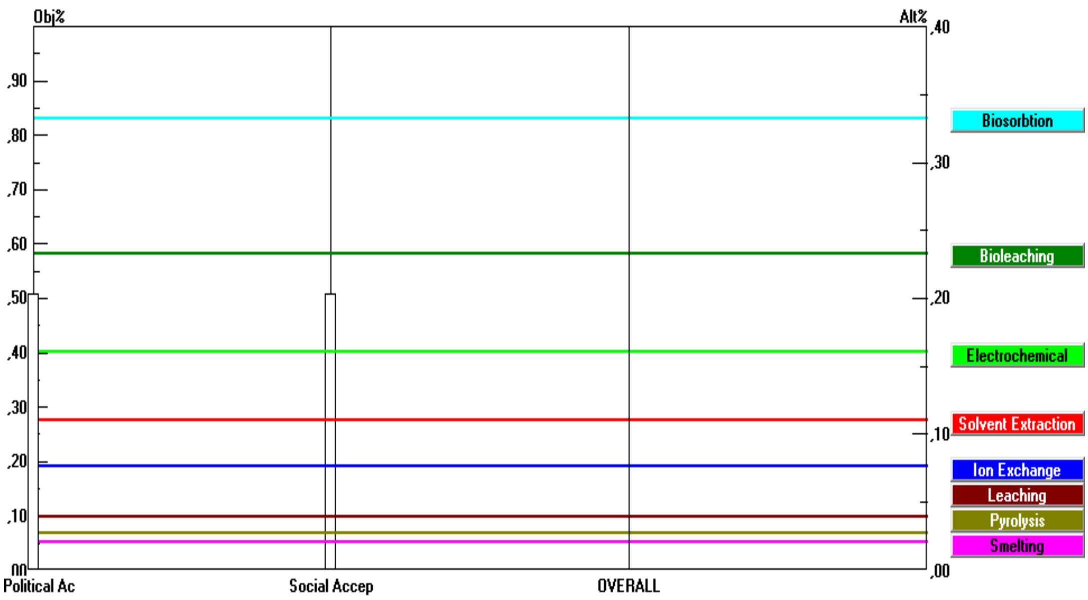

Figure 5.3 : Socio-Political results

Concerning the economic criteria, it was observed that all of them influence the final ranking of the proposed management systems by changing their weight coefficients. BS process is much more than BL process and is rated at 2, then BL must be absolutely less important than BS and is graded as 1 with regard to operation and maintenance cost. Smelting require large capital investment. Also, it requires pollution control equiment which contributes directly to the high cost. Pyrolysis has quite high capital requirement. In addition to this, pyrolysis process generates energy during operation, so it significantly reduces operating costs. Indicatively, the weight coefficient was calculated. Figure 5.2 is summarized by the final ranking of ExpertChooise that is presented below:

BS>BL>L>SX>EW>IE>P>S.

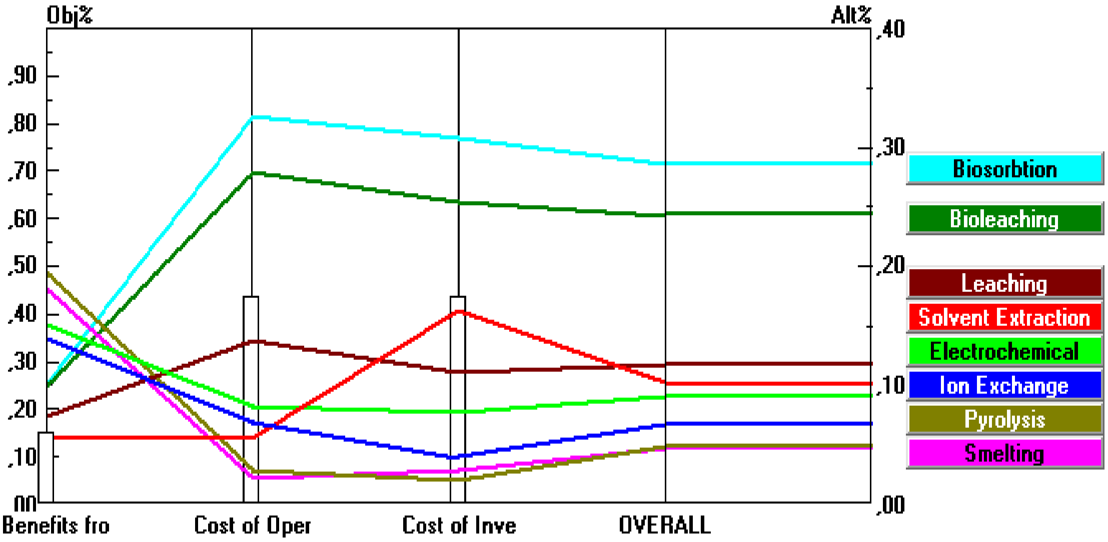

Figure 5.4 : Economical results

The changes that were imposed in the weight coefficients of the environmental criteria led to the conclusion that the criteria which influence the final ranking of the proposed management systems are air emission, wastewater production,solid waste production, hazardous waste generation, noise pollution, energyconsumption/raw material usage. Biosorption is new, cleaner and ecofriendly technologies. So, It is acceptable method because of having low environmental effect. Bioleaching is also often seen as more environmentally sensitive process than hydrometallurgical and pyrometallurgical processes, since the use of strong chemicals, energy and aggressive conditions are reduced lowered. This change resulted in the differentiation of the final ranking. This change is obvious noting the complete ranking of Expert Chooise that is presented below:

BS>BL>P>S>IE>EW>SX>L.

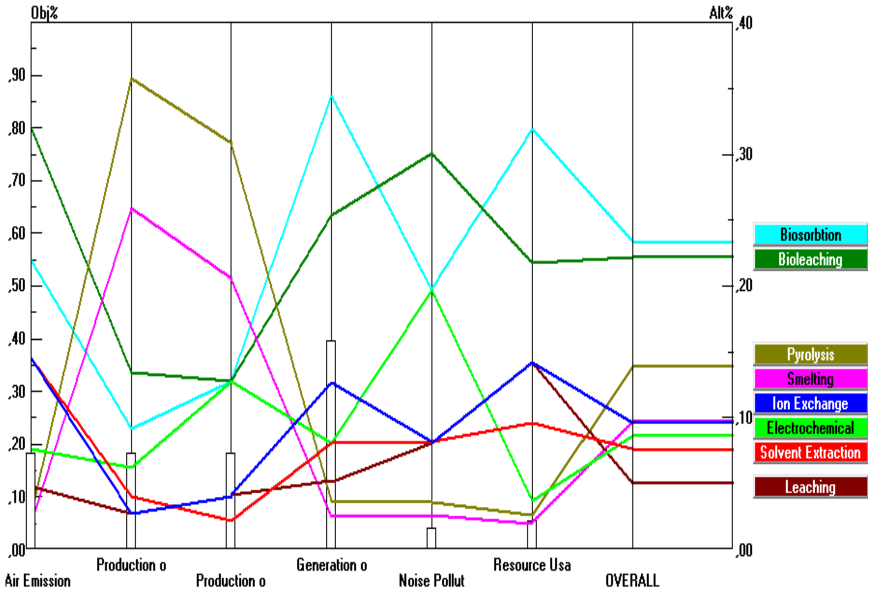

Figure 5.5 : Environmental results

Finally, as far as the technical criteria are concerned, the only criterion that does not alter the final ranking is criterion reliability. Electrochemical process is a clean, closed-loop process. Also, improved safety. Electrochemical plant is reliable. This change is obvious by the final ranking of ExpertChooise presented below:

EW>P>S>SX>L>BL>BS>IE.

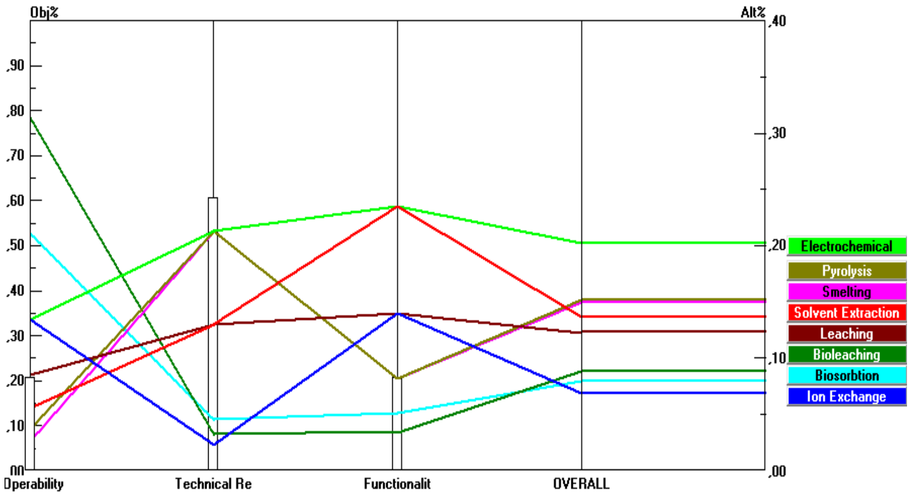

Figure 5.6 : Technical results

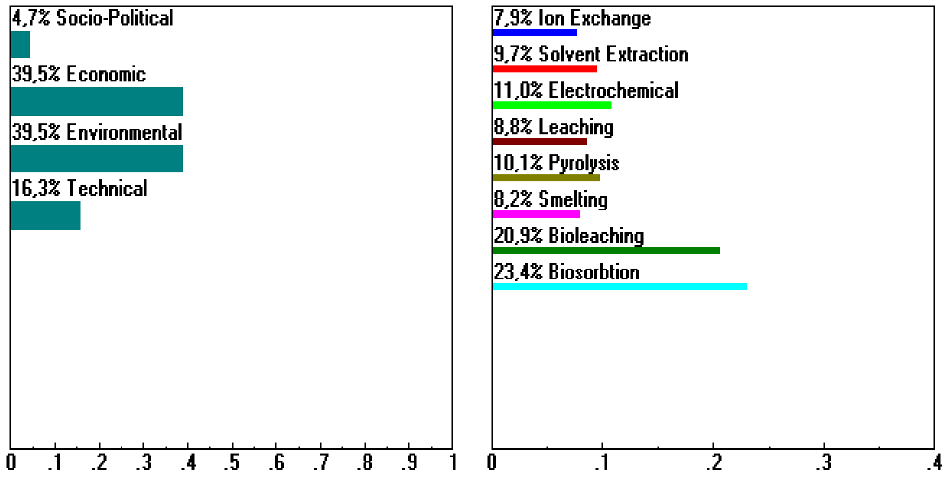

Figure 5.7 : Dynamic sensitivity results

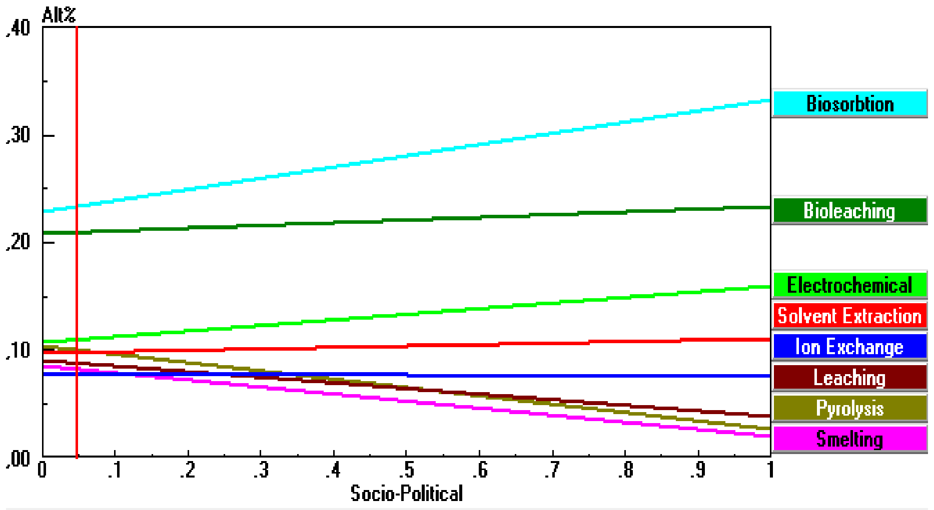

Figure 5.8 : Comparision of socio-political criterias

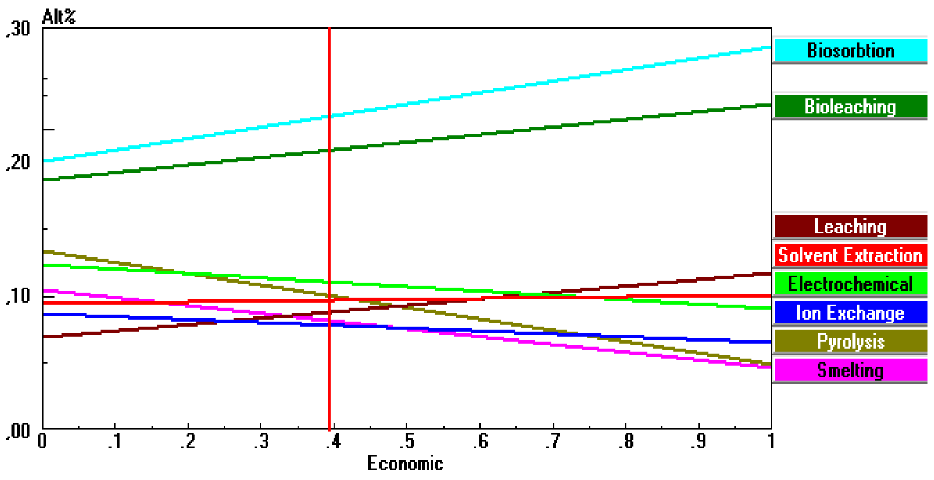

Figure 5.9 : Comparision of economic criterias

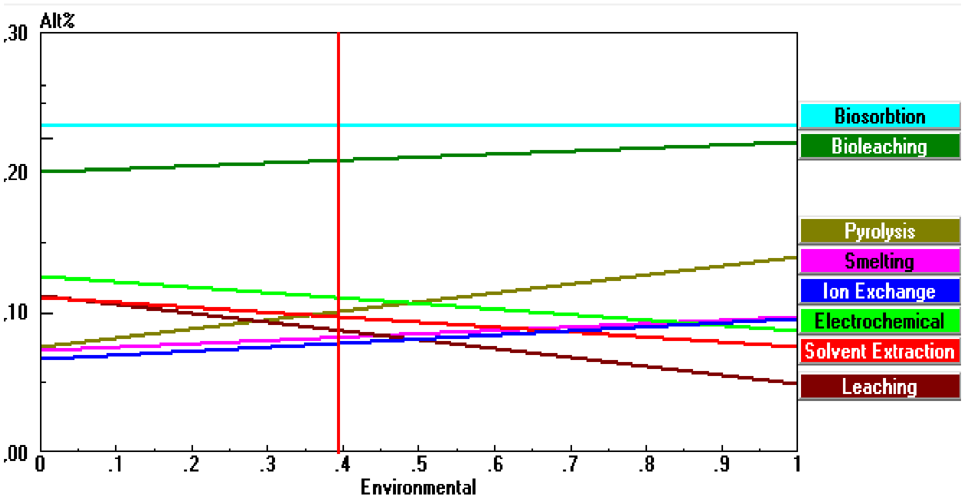

Figure 5.10 : Comparision of environmental criterias

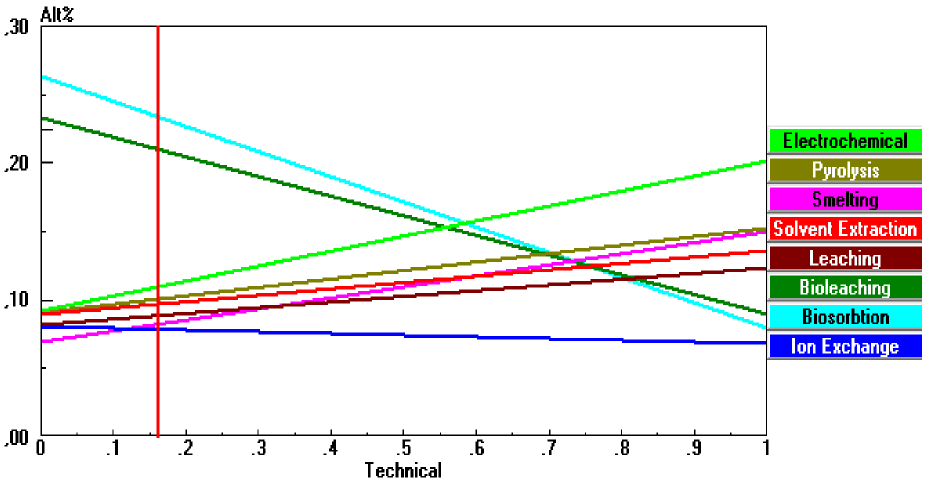

Figure 5.11 : Comparision of technical criterias

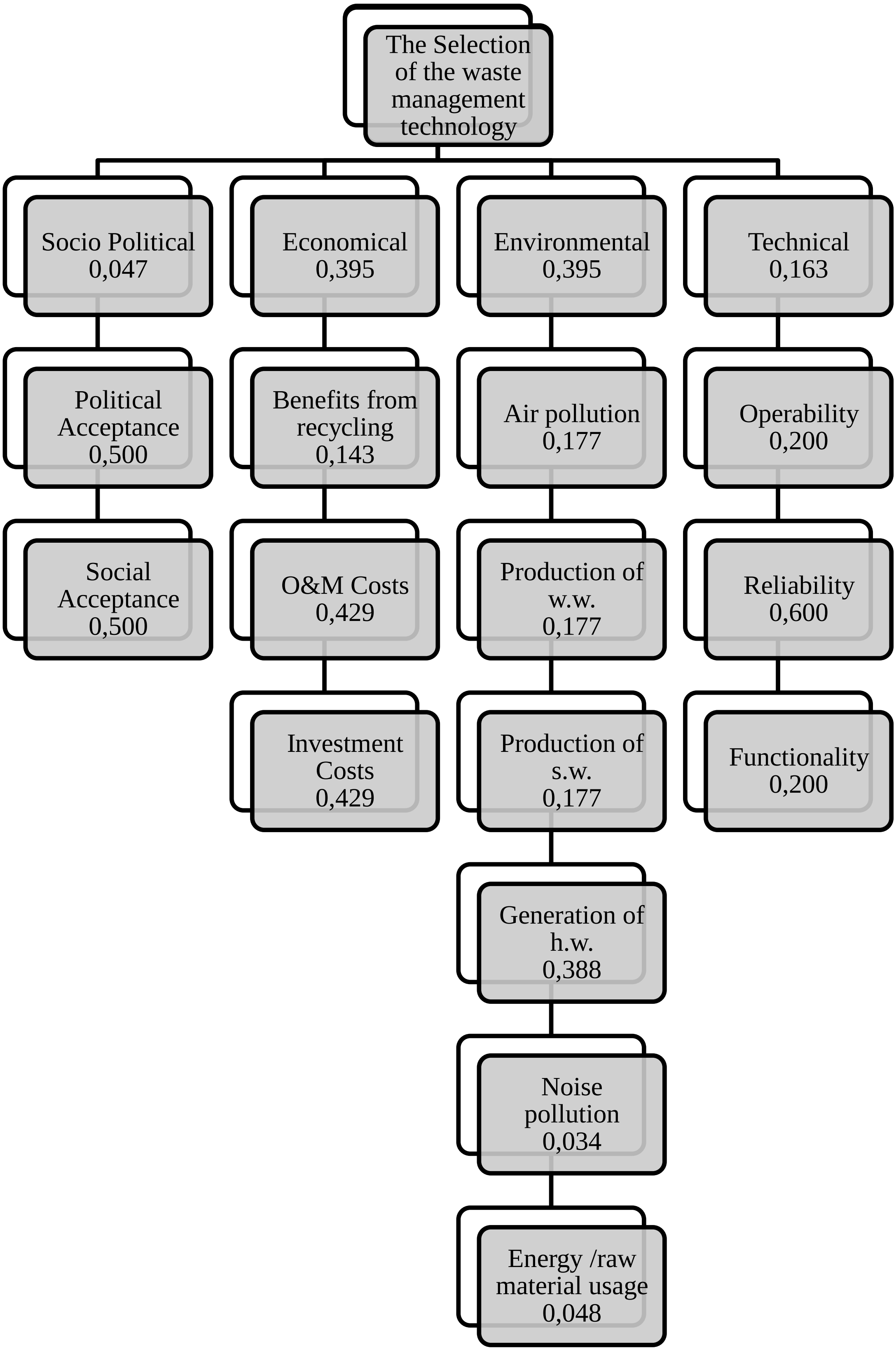

Figure 5.12 : Pairwise comparisation value of attributes

Table 5.19 : Pairwise comparision of alternatives respect to subcriteria

Sub Criteria	Alternatives							
	IE	SX	EW	L	P	S	BL	BS
Socio-Political								
Political Acceptance	0,076	0,11	0,16	0,039	0,028	0,02	0,233	0,333
Social Acceptance	0,076	0,11	0,16	0,039	0,028	0,02	0,233	0,333
Economic								
Benefits from Recycling	0,14	0,57	0,151	0,074	0,196	0,181	0,1	0,1
Cost of O&M	0,069	0,055	0,083	0,137	0,029	0,021	0,28	0,326
Cost of Investment	0,039	0,162	0,077	0,111	0,02	0,028	0,255	0,307
Environmental								
Air emissions	0,145	0,145	0,076	0,048	0,026	0,02	0,32	0,22
Production of w.w.	0,027	0,041	0,061	0,027	0,358	0,259	0,135	0,092
Production of s.w.	0,041	0,022	0,127	0,041	0,308	0,205	0,127	0,127
Generation of h.w.	0,126	0,081	0,081	0,052	0,037	0,025	0,254	0,344
Noise Pollution	0,081	0,081	0,197	0,081	0,036	0,026	0,301	0,197
Resource/Energy Usage	0,142	0,096	0,038	0,142	0,027	0,02	0,217	0,319
Technological								
Operability (Flexibility)	0,134	0,056	0,134	0,085	0,038	0,027	0,314	0,211
Technical Reliability	0,023	0,13	0,213	0,13	0,213	0,213	0,032	0,046
Functionality	0,14	0,235	0,235	0,14	0,082	0,082	0,034	0,051

	Process	Advantages	Disadvantages
Pyrometallurgical Processes	Pyrolysis	The inertization of the waste residue or contamination concentration [33] Uncomplicated and cost effective processes [33] Reduces greenhouse gas emissions and waste going to landfill [99] Produces few air emissions due to limited use of oxygen [99] Fast disposal of plastic waste without flying ash and TCDD [27] Full automatic operation, computer control system during pyrolysis [58]	Technology is still evolving [99] Markets are yet to be developed for char product and pyrolysis liquids [99]
	Smelting	Smelters would require considerable investments in equipment [44] Reliable and proven process and equipment [158] Low investment and operating costs [159] Capability to treat different qualities of raw materials with variable feed rates [159] High recovery of valuable metals [158] The cleanest smelting method available, safe and easy working conditions [159]	Cannot recover certain components, chips, bare fiberglass, aluminum, iron [29] Flame retardants and (PVC) present in e-waste leads to the formation of dioxins [29] Requires special emission controls [29] Exposure to airborne pollutants from metal processing [159] Can lead to various acute and chronic diseases [67] Causes contaminant-laden air emissions and process wastewater, slag wates [159]
Hydrometallurgical Processes	Leaching	Flexibile, ease and low capital requirement [38] Needs simple equipment and operation, low investment and operation costs [75]	Cyanide leaching in Korea have stopped because of high labour costs and env. issues [44]
	Ion-Exchange	Temporary or permanent applications with immediate results [41] Standard tank sizes available for small to intermediate flows, allows quick installati Low-energy demands, Handles dilute feed, Returns metal as metal salt solution [112] High purity, Niche products [125] Minimal effects on the main alumina processing, good yield and selectivity [22] Low energy consumption and low reagent losses [22]	Requires tight operation and maintenance [112] Equipment complex, limited concentration ability [112] Excess regenerate required, feed concentration must be monitored closely [112] Processing small amounts, Discontinuous and Large Volumes [125]
	Electrowinning	Provide continuous operation, controlled safe and eco-friendly operation [43] Ease of harvesting deposited metals [43] Selective electrowinning of metals, and has effective ability to tolerate contaminants Recovers metals that can be recycled or reused in process, up to 90 to 95 percent [112]	Byproduct liquid stream which contains the non-target metals dissolved in sulfuric acid [43] Need of special materials to handle highly corrosive agents such as aqua regia [43] Energy inefficient at very low metal-ion concentrations [112] Segregation of rinsewater is needed to prevent contamination of anode with mixed metals [112]
	Solvent Extraction	Simple, no complex equipment [96] Controlled recovery, large selectivity and flexibility [96] Can usually be followed by back-extraction into aqueous solvents [98] Can be performed with simple equipment, but can also be automated [98]	Emulsion formation, loss of compounds [96] Complicated, laborious, pre-concentration step required [96] Cumbersome for a large number of samples or for large samples [98] Can require costly amounts of organic solvents, generate large volumes of organic waste [9 Not so high efficiency, Expensive and harmful chemicals [125]
Biohydrometallurgy Processes	Bioleaching	No airborne pollutants are produced, solid -liquid wastes are environmentally accept Simple and low cost equipments, apt for treating low grade or waste ores [106] Low energy requirement, and no atmospheric contamination [106] In general simpler and, therefore, cheaper to operate [123] The process is more environmentally friendly than traditional extraction methods [18]	The slow process of bacterial leaching has halted its growth [95] [123] Low reaction rates and productivities, requirement of extensive grounds [106] Current inadequacy for treating primary sulphides [106] Toxic chemicals are sometimes produced in the process [123]
	Biosorbtion	Metals at low concentrations can be selectively removed [6] Low operating costs [10] [125] Minimization of the volume of chemical/biological sludges to be handled [10] [64] [12 Highefficiency in detoxifying [10] [65] Requires minimal energy input, less labour and low investment, very economical [139]	High reaction times and large volumes [125] High possiblity to contact with possible harmfull component [125] High degree of destructivity [125]

Figure 5.13 : Advantages and disadventages of alternatives

6. CONCLUSIONS AND RECOMMENDATIONS

In the last decade many countries have formulated legislations on e-waste management. According to legislative, traditional methods of managing e-waste including disposing in landfills, burning in incinerators or exporting to underdeveloped countries, all of which are not permitted anymore. The disposal of e-waste under ground has multiple disadvantages including the contamination of underground water and soil, and wasting a potential source of valuable metals. Besides, burning in air and acid leaching will deteriorate the environment by spoiling drinking water and releasing toxic gases into the atmosphere. Therefore, recycling of e-waste is crucial from the perspective of minimizing environmental pollution and resource management.

The presence of precious metals in e-waste makes recycling an attractive and viable option both in terms of environment and economics. Industrially, pyrometallurgical, hydrometallurgical, biometallurgical or a combination of both routes is used for recovering PMs from e-waste. Fundamentally, hydrometallurgical routes are similar to those used in the mineral industry, which include leaching and metal extractions from leachates. Pyrometallurgical routes are economical and eco-efficient for the recovery of PMs. However, hazardous emissions should be controlled to minimize environmental pollution. Both processes have advantages and disadvantages, which therefore should be considered for a specific feed materials and final product. There are only limited laboratory studies for e-waste processing through biometallurgical routes, e.g., bioleaching of metals from e-waste. Nevertheless, this route has a potential for further development.

In this thesis, fourteen individual criteria were selected in total, categorized in 4 groups as described following. Environmental, economical, socio-political and technical attributes that may affect an implementation of WEEE management systems is based on the analysis of subcriteria.

Eight alternatives that is used recovery precious materials from WEEE was investigated. The AHP decision-making method has been applied in order to examine alternative scenarios/systems for WEEE management. Implementing an Analitical Hierarchy Process and comparization of socio-political, economical, environmental and technological criteria was evaluated by using ExpertChoise programme. This thesis presents a decision-support framework for decision makers to select electronic waste treatment technologies.

The obtained results, including the sensitivity analysis (i.e., modifications of the weight coefficients of the applied criteria), show that management schemes/systems based on recovery are the most suitable for implementation. More specifically, the optimum scenario/system that can be implemented is that of partial disassembly and forwarding of recyclable materials to the native existing market and disposal of the residues at landfill sites.

As a consequence of this research,

- ✓ Being the best recycling technology is bioleaching to recover procious metals from WEEE,
- ✓ Being a biosorbtion and electrochemical technology are other best alternative to recycle precious metals from WEEE,
- ✓ Being observed the biometallurgical technologies are preferable and effective than traditional methods,
- ✓ Thearmal treatment route is called Pyrometallurgical processes such as pyrolysis and smelting has advantages like production of marketable materials (raw material, energy and electricity etc…).
- ✓ Treatment of e-waste has been done mainly by the pyrometallurgical processes but due to emission of noxious gases and low recovery of metals, researchers are looking towards the hydrometallurgical processes because this route is easily controlled and better predictable.

- ✓ The last but not least, in Turkey, there are any circuit boards recovery centere, we are obligatory to sent these items to Europe for precious metal recovery.

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APPENDICES

APPENDIX A : Tables

APPENDIX A

Table 0.1 : Pairwise comparision of biosorbtion respect to bioleaching

Sub Criteria	Alternatives		Details
	BS	**BL**	
Socio-Political			
Political Acceptance	2	1	A low waste technology should always be preferred (Tamilselvan N. et all, 2011).
Social Acceptance	2	1	Social acceptability of them are high because the use of strong chemicals, energy and aggresive conditions reduced (Virolainen S., 2013).
Economic			
Benefits from Recycling	1	1	BL brings in less profit for being very slow process (Mulligan C. N. et all., 2004)(Masi M. et all., 2013).
Cost of O&M	2	1	BL and BS has low operate and maintain. BS has low O&M costs (Sohaili J. et all., 2012).
Cost of Investment	1	1	BL and BS require low investment costs (Sohaili J. et all., 2012)
Environmental			
Air emissions	1	2	No airborne pollutants and biogas that could be reduce greenhouse gasses (SO2) during the BL. Condition in BS is similar (Özgün Ç., 2008).
Production of w.w.	1	2	Production of detoxified w.w. in BL (Tamilselvan N. et all, 2011). In BS, large volume of w.w. and process water (Tsezos M. et all, 2008).
Production of s.w.	1	1	Minimization of chemical/biological sludge generation in BS and BL process (Qaiser S. et all, 2007)(Karwowska E. et all, 2014).
Generation of h.w.	2	1	Toxic chemicals are sometimes produced in BL process (Majumder D. R.,2013).
Noise Pollution	1	2	Silenced technology to not required to operate complex chemical plants (Karwowska E. et all, 2014).
Resource/Energy Usage	2	1	They has low energy(Jonglertjunya W, 2003).BL require chemicals(Virolainen S., 2013), while BS not require nutrient(Ashraf M.A. et all., 2011).
Technological			

Operability (Flexibility)	1	2	BL is simple process that doesn't require a lot of expertise to operate or complicated machinery (Pradhan N. et all., 2008).
Technical Reliability	2	1	BS is technical reliable than BL (Özgün Ç., 2008).
Functionality	2	1	In BL, metal recovery rate is low (Willner J. and Fornalczyk, 2013). BS technology is effective method (Qaiser S. et all, 2007).

Table 0.2 : Pairwise comparision of pyrolysis respect to bioleaching

Sub Criteria	**Alternatives**		**Details**
	P	**BL**	
Socio-Political			
Political Acceptance	1	7	BL is simple and require low capital cost [Pradhan N. et all., 2008]. Reluctance of some residents (Luyima A. Et all.,2012).
Social Acceptance	1	7	BL has benefits as compared with P: simple, ow cost equipments, low waste, low energy requirement, and no air (Mankhand T.R. et all., 2012).
Economic			
Benefits from Recycling	1	3	BL is very slow process. This brings in less profit. Pyrolysis produce marketable products (electricity) (Mankhand T.R. et all., 2012)
Cost of O&M	1	7	BL process is simple process. Therefore, cheaper to operate and maintain than P. (Karwowska E. Et all, 2014).
Cost of Investment	1	9	The capital cost of a BL is considerably less than that Pyrolysis (Pradhan N. et all., 2008).
Environmental			
Air emissions	1	8	Pyrolysis emit poisonous gases (Zuo X., et all.,2011). BL don't produce airborne pollutants & biogas (Özgün Ç., 2008).
Production of w.w.	1	2	Pyrolysis has low risk of water pollution. The wastewater are environmentally acceptable in BL process (Volesky B. and Naja G., 2003).
Production of s.w.	3	1	The solid wastes are environmentally acceptable in BL process (Neale J.W. et all., 2011). P coke as solid residue (Xakalashe B. S. 2012).
Generation of h.w.	1	6	In P, generates of toxic residues. In BL, toxic chemicals are sometimes produced in the

			process (Willner J. and Fornalczyk, 2013).
Noise Pollution	1	6	Noise from gas and leachate management systems (Luda M.P., 2011). BL doesn't reguire management (Karwowska E. Et all, 2014).
Resource/Energy Usage	1	7	BL is lower energy requirement and raw material requirement than P (Jonglertjunya W., 2003) (Luyima A. et all., 2012).
Technological			
Operability (Flexibility)	1	6	BL is simple process that does not require a lot of expertise to operate while P require qualified personnel (Mankhand T.R. et all., 2012)
Technical Reliability	6	1	P is automatic operation. BL must be carefully planned, since the process can lead to a biosafety failure (Jonglertjunya W., 2003).
Functionality	3	1	Metal recovery in pyrolysis are better yield than metal recovery rate in BL (Willner J. and Fornalczyk, 2013) (Luda M.P., 2011).

Table 0.3 : Pairwise comparision of pyrolysis respect to biosorbtion

Sub Criteria	Alternatives		Details
	P	BS	
Socio-Political			
Political Acceptance	1	8	BS is preferable as being low waste technology (Sohaili J. et all., 2012).
Social Acceptance	1	8	BS is more accebtable than P in terms of public acceptance (Masi M. et all., 2013).
Economic			
Benefits from Recycling	1	3	P is profitable with regard to marketable products. Low economic value because of high reaction times in BS (Masi M. et all., 2013).
Cost of O&M	1	8	M&O costs of P are more expensive than BS (EPA, 2006). Energy generation reduces operating costs in pyrolysis (Lei Z. et all. ,2011).
Cost of Investment	1	9	Pyrolysis has quite high capital requirement. Biosorbtion process requires low capital investment (Kang H.Y. and Schoenung J.M. 2005).
Environmental			
Air emissions	1	7	Poisonous gases were produced in pyrolysis. No gas emissions to atmosphere in BS (Zuo X.

			et all., 2011).
Production of w.w.	5	1	Pyrolysis has low risk of water pollution. In BS, large valume of effluents (Macek T. and Mackova M., 2011).
Production of s.w.	3	1	Toxic residues in pyrolysis. BS minimize of sludges [Sohaili J. et all., 2012].
Generation of h.w.	1	7	In BS, high efficiency in detoxifying. In Pyrolysis, the inertization of the waste residue (Sohaili J. et all., 2012).
Noise Pollution	1	5	In pyrolysis, gas and leachate management systems (Lei Z. et all. ,2011].
Resource/Energy Usage	1	8	There is no additional nutrient requirement. BS is lower energy requirement than Pyrolysis (Ashraf M.A. et all., 2011).
Technological			
Operability (Flexibility)	1	5	Pyrolysis are flexible and easy to operate. Qualified personnel. In BS, skilled/semi-skilled operator (Masi M. et all, (2013).
Technical Reliability	5	1	Full automatic operation, computer control system during pyrolysis (Luyima A. et all., 2012).
Functionality	2	1	Pyrolysis processes are better yield. BS provide active metal recovery rate (Masi M. et all., 2013).

Table 0.4 : Pairwise comparision of smelting respect to bioleaching

Sub Criteria	**Alternatives**		**Details**
	S	**BL**	
Socio-Political			
Political Acceptance	1	8	BL technique, because of its simplicity and low capital cost, is suitable for developing countries[Pradhan N. et all., 2008].
Social Acceptance	1	8	While social acceptability of smelting is low due to high environmental liabilities, social acceptability of BL is high (Virolainen S., 2013).
Economic			
Benefits from Recycling	1	5	Product quality is high. It is profitable because of PMs sale value BL is slow process that brings in less profit (UNEP, 2009).
Cost of O&M	1	8	O&M costs of BL not much as Smelting operation costs (Pradhan N. et all., 2008)

			(Karwowska E. Et all, 2014).
Cost of Investment	1	8	Generally, the capital cost of a BL is approximately 50 percent less than that of S (Namias J., 2013) (Pradhan N. et all., 2008).
Environmental			
Air emissions	1	9	Smelting releases highly poisonous gases (Özgün Ç., 2008). BL could reduce the amount of greenhouse gasses (Sohaili J. et all., 2012).
Production of w.w.	3	1	In S., low water use because of reuse. Liquid wastes are environmentally acceptable in BL process (UNEP, 2009).
Production of s.w.	2	1	The solid wastes are environmentally acceptable in BL (Neale J.W. et all., 2011). Little waste products. Slag to building industry (UNEP, 2009).
Generation of h.w.	1	7	In S, ash is very toxic (Hagelüken Ch., 2006). Toxic chemicals causing environmental damage are sometimes produced in the BL process.
Noise Pollution	1	7	Smelter could have a negative effect on noise levels because of gas & leachate management systems (Hagelüken Ch., 2006).
Resource/Energy Usage	1	8	BL has a less harmful impact because of low usage of raw materials. BL is lower energy requirement than S (Jonglertjunya W., 2003).
Technological			
Operability (Flexibility)	1	7	In smelting, High and medium skilled labour. BL is simple. Therefore, it require reduced need for skilled labour(Karwowska E. Et all, 2014).
Technical Reliability	6	1	Smelting is reliable (automation).In BL, a setup of BL must be carefully planned, since can lead to a biosafety failure (Jonglertjunya W., 2003).
Functionality	3	1	Metal recovery rate is 68,5% in BL process (Willner J. and Fornalczyk, 2013). Metal recovery or yield is >> 90% (UNEP, 2009).

Table 0.5 : Pairwise comparision of smelting respect to biosorbtion

Sub Criteria	**Alternatives**		**Details**
	S	**BS**	
Socio-Political			
Political Acceptance	1	9	BS is more accebtable than S in terms of political acceptance because of requirement less

			energy and material usage (Özgün Ç., 2008).
Social Acceptance	1	9	Social acceptability of smelting is low due to high environmental liabilities, while social acceptability of BS is high because of being ecofriendly, highly effective and mature pollution control methodology (Masi M. et all., 2013).
Economic			
Benefits from Recycling	1	4	Smelting is more profitable business than BS because of product quality and value is high (UNEP, 2009).
Cost of O&M	1	9	Management systems cost od BL not much as smelting operation costs (Holmes I., 2012).
Cost of Investment	1	8	Smelting require significant financial incentives, while BS requires low capital investment (Xakalashe B. S., 2012)(Namias J., 2013).
Environmental			
Air emissions	1	8	Smelter emits poison gases, while biosorbtion does not emit dioxins emissions (Namias J., 2013) (Özgün Ç., 2008).
Production of w.w.	4	1	In S, low water use because of reuse. In BS, effluent problem by acidity and high content of sulfates (UNEP, 2009).
Production of s.w.	2	1	In S, little waste products. Compared with the S, BS offers an advantages minimization of the volume of sludges (Sohaili J. et all., 2012).
Generation of h.w.	1	8	In BS, high efficiency in detoxifying. In smelting, ash is very toxic (Sohaili J. et all., 2012).
Noise Pollution	1	6	Smelter could have a negative effect on noise levels because of gas & leachate management systems(Namias J., 2013).
Resource/Energy Usage	1	9	BS does not require nutrient. In smelter, low material usage. BS is lower energy requirement than Smelter (Yeşilyurt Z. et all., 2007).
Technological			
Operability (Flexibility)	1	6	In smelting, highly skilled labour because of automated process. BS requires less labour (Masi M. et all., 2013).
Technical Reliability	5	1	Process security of smelting is high level of automation (UNEP, 2009).
Functionality	2	1	In S, recovery rates >> 90%. BS technology is effective method (Qaiser S. et all, 2007).

Table 0.6 : Pairwise comparision of smelting respect to pyrolysis

Sub Criteria	Alternatives		Details
	S	P	
Socio-Political			
Political Acceptance	1	2	Health&safety and odor are issues are unknown related to public acceptance. P has lower risk of odours than S (O2)(Hagelüken Ch., 2006).
Social Acceptance	1	2	Social acceptability of S is lower than P due to high environmental liabilities. Reluctance of residents (Beltran M.S., 2009).
Economic			
Benefits from Recycling	1	2	Product quality and value of P products is alittle bit more higher than S.(Hagelüken Ch., 2006).
Cost of O&M	1	2	P require higher operation costs than S (Namias J., 2013).
Cost of Investment	2	1	Smelting require significant financial incentives (Xakalashe B. S., 2012). Pyrolysis has quite high capital requirement (M. Ringer et all., 2006).
Environmental			
Air emissions	1	2	S releases highly poisonous gases (Namias J., 2013). By using less oxygen, fewer air emissions are produced during P (Holmes I., 2012).
Production of w.w.	1	2	In smelting, low water use because of reuse (UNEP, 2009). Pyrolysis has low risk of water pollution (http://www.emrc.org.au/pyrolysis.html).
Production of s.w.	1	2	In S, little waste products. Slag to building industry. Pyrolysis produce ash or a char (Luyima A. et all., 2012).
Generation of h.w.	1	2	In smelting, ash is very toxic. In Pyrolysis, the inertization of the waste residue or contamination concentration (Molto´ J. et all., 2008).
Noise Pollution	1	2	S could have a negative effect on noise levels over P because of gas & leachate management systems (Naminas J., 2013).
Resource/Energy Usage	1	2	In S, low usage of some reagents. In P, energy self-sustain and additives requirement (Luyima A. et all., 2012).
Technological			
Operability (Flexibility)	1	2	In S, High and medium skilled labour. While P require qualified personnel. Pyrolysis plants are flexible (Mankhand T.R. et all., 2012)

Technical Reliability	1	1	Process security of P is high because of auromation level. Security of S is uncertain (UNEP, 2009).
Functionality	1	1	Recovery rates in S >> 90%. Pyrolysis processes are better yielding 92.5% and 96.2%, respectively (UNEP, 2009).

Table 0.7 : Pairwise comparision of leaching respect to bioleaching

Sub Criteria	**Alternatives**		**Details**
	L	**BL**	
Socio-Political			
Political Acceptance	1	6	BL technique, because of its simplicity and low capital cost, is suitable for developing countries (Pradhan N. et all., 2008).
Social Acceptance	1	6	BL is seen as more acceptable than L, since the use of strong chemicals,energy and aggressive conditions are reduced(Yeşilyurt Z. et all., 2007).
Economic			
Benefits from Recycling	2	1	In L, recovering of valuable metals for a economic revenue. BL is very slow process that brings in less profit (Karwowska E. et all., 2014).
Cost of O&M	1	3	Bioleaching has a number of benefits over L, including low operating costs (Namias J., 2013).
Cost of Investment	1	4	L require low capital investment(Kamberoviç Z. et all, 2009).BL reduce investment and operating costs compared to L (Virolainen S., 2013).
Environmental			
Air emissions	1	7	During the leaching reactions hazardous or toxic fumes are generated. Bioleaching could reduce SOx (Namias J., 2013).
Production of w.w.	1	5	L use large amount of water, while BL use low (Holmes I., 2012).
Production of s.w.	1	4	BL has a number of benefits over L, minimization of the volume of chemical and/or biological sludge (Namias J., 2013).
Generation of h.w.	1	5	BL is more effective than L with regard to generation of hazardous waste (Tripathi A. et all., 2012).

Noise Pollution	1	4	In L, noise from management of gas control and treatment measures. In BL, noise from management of chemical plants (Majumder D. R.,2013).
Resource/Energy Usage	1	2	BL has a less harmful impact on the environment than L, because it uses less energy (Jonglertjunya W., 2003).
Technological			
Operability (Flexibility)	1	4	Leaching is flexibility, ease (Kamberoviç Z. et all, 2009). BL is easier to conduct in comparison to L.(Willner J. and Fornalczyk, 2013).
Technical Reliability	5	3	L method is more exact, more predictable, and more easily controlled.But, new promising BL are now under development (Luda M.P., 2011).
Functionality	3	1	Metal recovery rate is 68,5% in BL process (Willner J. and Fornalczyk, 2013). In L, yields for both metals were over 90% (Virolainen S., 2013).

Table 0.8 : Pairwise comparision of leaching respect to biosorbtion

Sub Criteria	**Alternatives**		**Details**
	L	**BS**	
Socio-Political			
Political Acceptance	1	7	A low waste technology solution should always be preferred as it minimizes (Sohaili J. et all., 2012).
Social Acceptance	1	7	BS is seen as more env. sensitive than leaching, since chemical usage, energy and aggressive conditions are reduced (Allison S et all, 2011)
Economic			
Benefits from Recycling	2	1	Recovering brings economic revenue during L. In BL, low economic value and less useful in products (Macek T. and Mackova M., 2011).
Cost of O&M	1	4	The advantages BS has over conventional treatment methods include low cost (Macek T. and Mackova M., 2011).
Cost of Investment	1	4	Leaching require low capital investment (Kamberoviç Z. et all, 2009). BS, low capital and operation cost (Macek T. and Mackova M., 2011).
Environmental			

Air emissions	1	6	During the leaching reactions hazardous or toxic fumes are generated. There is no biogas during biosorption (Özgün Ç., 2008).
Production of w.w.	1	4	Large amount of water used in L (Holmes I., 2012). In BS, the typical problem of the effluents generated.
Production of s.w.	1	4	Compared with the L, BS offers an advantages minimization of the volume of chemical/biological sludges (Sohaili J. et all., 2012).
Generation of h.w.	1	6	In biosorption, high efficiency in detoxifying (Luda M.P., 2011) (Tripathi A. et all., 2012).
Noise Pollution	1	3	In leaching, Off-gas control and treatment measures. In bioleaching, noise from management of complex chemical plants (UNEP, 2009).
Resource/Energy Usage	1	3	Biosorption is seen to be preferable than L , since the use of strong chemicals, energy are reduced (Tsezos M. et all., 2008)(Virolainen S., 2013)
Technological			
Operability (Flexibility)	1	3	Leaching is flexibility, ease (Allison S et all, 2011). BS is simple. It requires less labour (Masi M. et all., 2013).
Technical Reliability	1	4	L method is more exact, more predictable, and more easily controlled. But, new promising BS are now under development (Luda M.P., 2011).
Functionality	3	1	In L, yields for both metals were over 90% (Virolainen S., 2013). BS technology is lower effective than L (Qaiser S. et all, 2007)

Table 0.9 : Pairwise comparision of leaching respect to pyrolysis

Sub Criteria	**Alternatives**		**Details**
	L	**P**	
Socio-Political			
Political Acceptance	2	1	P has been banned, researchers are looking towards the L because it is easily controlled and better predictable (Tripathi A. et all., 2012).
Social Acceptance	2	1	Compared to P, leaching is easier to perform and much less harmful, because no gaseous pollution occurs (Majumder D. R.,2013).
Economic			

Benefits from Recycling	1	3	Compared to leaching operations,pyrolysis has low recovery of metals (Tripathi A. et all., 2012)
Cost of O&M	5	1	Advantages of leaching process is low investment and operation costs (Kamberoviç Z. et all, 2009)(Pradhan N. et all., 2008).
Cost of Investment	6	1	Leaching require low capital investment (Allison S et all, 2011). But, Pyrolysis has quite high capital requirement. (Namias J., 2013).
Environmental			
Air emissions	3	1	Hazardous or toxic fumes are generated in L. Compared to P, L is much less harmful, because no gaseous pollution occurs (Zuo X. et all., 2011)
Production of w.w.	1	8	Large amount of water used in leaching process. Pyrolysis has low risk of water pollution (Holmes I., 2012)
Production of s.w.	1	6	Leaching processes produce sludges. The resulting slag was shown to be very effective in cleaning the pyrolysis gas (Luda M.P., 2011).
Generation of h.w.	2	1	The inertization of the waste residue or contamination concentration in pyrolysis (Tripathi A. et all., 2012).
Noise Pollution	3	1	In pyrolysis, gas and leachate management systems. In leaching, Off-gas control and treatment measures (UNEP, 2009).
Resource/Energy Usage	6	1	Additives were used in P(Luyima A. et all., 2012). In leaching, the use of chemicals is high. L require lower energy than P (Kappes D.W., 2001).
Technological			
Operability (Flexibility)	3	1	Compared to Pyrolysis, Leaching is easier to perform and better predictable (Tripathi A. et all., 2012)(Kamberoviç Z. et all, 2009).
Technical Reliability	1	2	Leaching method is more exact, more predictable, and more easily controlled. Pyrolysis is modular (M. Ringer et all., 2006).
Functionality	7	1	Yields for both metals were over 90% (Virolainen S., 2013) Compared to L, P has low recovery of metals (Luda M.P., 2011)

Table 0.10 : Pairwise comparision of leaching respect to smelting

Sub Criteria	Alternatives		Details
	L	S	

Socio-Political			
Political Acceptance	3	1	Smelting caused much of the ecological damage. L is significant progress toward achieving sustainable ecosystems (Sum E.Y.L,1991).
Social Acceptance	3	1	Both of them harmonize with the legislation. Compared to S, L is much more environmentally friendly (Majumder D. R.,2013).
Economic			
Benefits from Recycling	1	2	In L, recovering of valuable metals for a positive economic revenue. In smelting, product quality and value is high (UNEP, 2009).
Cost of O&M	6	1	Operating costs of S is inexpensive, while Operating costs of L is expensive (Ciocoiu, C. N et all., 2012).
Cost of Investment	5	1	Advantage of the leaching process is its low capital investment requirement relative to the smelting process (Namias J., 2013).
Environmental			
Air emissions	4	1	Compared to P, leaching is much less harmful, because no gaseous pollution occurs (Kaya M., Sözeri A., 2003).
Production of w.w.	1	7	Large amount of water used in L (Holmes I., 2012). In modern S, low water use because of reuse (Howard S.M. et all.,2009).
Production of s.w.	1	5	Leaching processes produce sludge. In smelting, little waste products. Slag to building industry (UNEP, 2009).
Generation of h.w.	3	1	Leaching has been tried to save the environment from the hazardous behaviour of the PCB metals (Tripathi A. et all., 2012).
Noise Pollution	4	1	In L, off-gas control and treatment measures. S could have a negative effect on noise levels (UNEP, 2009).
Resource/Energy Usage	7	1	L have lower energy consumption and agent consumption , when compared to S (Howard S.M. et all.,2009) (Virolainen S., 2013).
Technological			
Operability (Flexibility)	4	1	Compared to S, leaching is flexibility, easier to perform (Allison S et all, 2011).
Technical Reliability	1	2	Smelting method is little bit more exact, predictable, and easily controlled than Leaching (Allison S et all, 2011).
Functionality	2	1	In L, acceptable yields for both metals were over 90% (Luda M.P., 2011). S produce a gold-silver bullion up >95% precious metals.

Table 0.11 : Pairwise comparision of electrochemical respect to bioleaching

Sub Criteria	Alternatives		Details
	EW	**BL**	
Socio-Political			
Political Acceptance	1	2	BL technique, because of its simplicity and low capital cost, is suitable for developing countries (Pradhan N. et all., 2008).
Social Acceptance	1	2	BL is seen as more environmentally sensitive process than EW, since the use of chemicals and energyare reduced (Yeşilyurt Z. et all., 2007).
Economic			
Benefits from Recycling	3	1	BL is very slow process that brings in less profit. In EW, the outcome of recovery can compensate its capital cost (Youssef C. et all, 2012).
Cost of O&M	1	4	EW require low O&M costs. BL has a number of benefits over EW, including low operating costs(Namias J., 2013).
Cost of Investment	1	4	EW require a large capital investment, while BL require low investment costs (Virolainen S., 2013).
Environmental			
Air emissions	1	5	BL if used for all processing could drastically reduce the amount of air pollution. In EW, abatement of gases (Mulligan C. N. et all., 2004).
Production of w.w.	1	3	Large amount of water utilization in L, while liquid wastes are environmentally acceptable in BL (Özgün Ç., 2008).
Production of s.w.	1	1	In EW, minimum of waste production and toxic material (Namias J., 2013). BL reduced amount of sludge production (Tsezos M. et all., 2008).
Generation of h.w.	1	4	EW neither produce any undesired reaction co-products nor use toxic and hazardous materials (P Chandra Mouli, 2004).
Noise Pollution	1	2	In bioleaching, noise from management of complex chemical plants (Sohaili J. et all., 2012).
Resource/Energy Usage	1	6	BL require lesser energy than EW (Jonglertjunya W., 2003). BL reduce chemical usagelower than EW (Virolainen S., 2013).

Technological			
Operability (Flexibility)	1	3	In BL, simple process, low-level operating skills being required. EW are usually simple (Willner J. and Fornalczyk, 2013).
Technical Reliability	6	1	L is more exact, more predictable, and more easily controlled. But, new promising BL are now under development (Luda M.P., 2011).
Functionality	5	1	In EW, up to 90 to 95 percent. Metal recovery rate is 68,5% in BL process (Willner J. and Fornalczyk, 2013).

Table 0.12 : Pairwise comparision of electrochemical respect to biosorbtion

Sub Criteria	**Alternatives**		**Details**
	EW	**BS**	
Socio-Political			
Political Acceptance	1	3	BS is seem to be preferble than EW (Allison S et all, 2011).
Social Acceptance	1	3	BS is seen as more env. sensitive than EW, since chemicals usage, energy and aggressive conditions are reduced (Virolainen S., 2013).
Economic			
Benefits from Recycling	3	1	Recovering brings positive economic revenue during EW. In BS, low economic value and less useful (Macek T. and Mackova M., 2011).
Cost of O&M	1	5	The advantages biosorption has over conventional treatment methods include low cost (Sohaili J. et all., 2012).
Cost of Investment	1	5	EW require a large capital investment (Youssef C. et all, 2012). In BS, low capital and operation cost (Macek T. and Mackova M., 2011).
Environmental			
Air emissions	1	4	No airborne pollutants and no biogas are produced during BS, EW is much less harmful than BS (Montero R. et all., 2012).
Production of w.w.	1	2	EW is closed-loop process that does not produce effluents. In BS, the typical problem of the effluents generated (Tsezos M. et all., 2008).

Production of s.w.	1	1	Compared with EW, BS offers an advantages minimization of the volume of chemical/biological sludges (Macek T. and Mackova M., 2011).
Generation of h.w.	1	5	EW neither produce any undesired reaction co-products nor use toxic and hazardous materials [157].
Noise Pollution	1	1	In BS, noise from management of complex chemical plants (Kıta G. and Skoblewsli P., 2010).
Resource/Energy Usage	1	7	BS is seen as more env.sensitive process than EW, since chemical usage, energy and aggressive conditions are reduced (Namias J., 2013).
Technological			
Operability (Flexibility)	1	2	In EW, controlled safe and eco-friendly (Youssef C. et all, 2012). BS requires less labour (Masi M. et all., 2013).
Technical Reliability	5	1	EW is reliable, but evolution of hydrogen which is highly flammable. New promising BS are now under development (Luda M.P., 2011).
Functionality	4	1	In EW up to 90 to 95 percent (Allison S et all, 2011). BS is effective method (Qaiser S. et all, 2007).

Table 0.13 : Pairwise comparision of electrochemical respect to pyrolysis

Sub Criteria	**Alternatives**		**Details**
	EW	**P**	
Socio-Political			
Political Acceptance	6	1	P has been banned due to emission and low recovery, researchers are looking towards clean tech. such as EW (Tripathi A. et all., 2012).
Social Acceptance	6	1	Researchers are looking towards the EW because it is easily controlled and predictable (Tripathi A. et all., 2012) (Kaya M., Sözeri A., 2003).
Economic			
Benefits from Recycling	1	4	There are concerns regarding the economy of EW compared to P for the extraction of PMs from e-waste (Khaliq A. et all, 2014).
Cost of O&M	4	1	EW has low specific capital costs. P generates energy during operation, so it significantly

			reduces operating costs (Namias J., 2013).
Cost of Investment	5	1	EW require a large capital investment . Also, P has quite high capital requirement (Youssef C. et all, 2012).
Environmental			
Air emissions	4	1	Pyrolysis emit poisonous gases. By using less oxygen, fewer air emissions are produced. EW is much less harmful(Zuo X. et all., 2011).
Production of w.w.	1	6	In, electrochemical, utilization of the leachate in the process. Pyrolysis has low risk of water pollution (Özgün Ç., 2008).
Production of s.w.	1	3	The solid residue remaining from P is typically an inorganic ash or a char, while EW doesn't produce further wastes (Luda M.P., 2011).
Generation of h.w.	3	1	In EW, minimum of waste production and toxic material The inertization of the waste residue in P (Kang H.Y. and Schoenung J.M., 2005).
Noise Pollution	5	1	In pyrolysis, gas and leachate management systems (Kaminsky W., 1993).
Resource/Energy Usage	2	1	EW has a spesific energy consumption and the use of strong chemicals. P generates energy and additives usage (Virolainen S., 2013) .
Technological			
Operability (Flexibility)	4	1	EW are usually simple (Youssef C. et all, 2012). Compared to P , EW is easier to perform and predictable (Tripathi A. et all., 2012).
Technical Reliability	1	1	EW are controlled safe, closed-loop process and eco-friendly (Youssef C. et all, 2012). P is modular (Kaya M., Sözeri A., 2003).
Functionality	3	1	Compared to EW, P has low recovery of metals (Luda M.P., 2011)(Tripathi A. et all., 2012).

Table 0.14 : Pairwise comparision of electrochemical respect to smelting

Sub Criteria	**Alternatives**		**Details**
	EW	**S**	
Socio-Political			
Political Acceptance	7	1	S caused much of the ecological damage. Significant progress toward achieving sustainable ecosystems such as L . (Namias J., 2013).

Social Acceptance	7	1	Social acceptance of smelting is low due to high environmental liabilities while social acceptance of electrochemical is high (UNEP, 2009).
Economic			
Benefits from Recycling	1	3	Smelting leads to higher loss of metals as compared to EW (Neira J. et all., 2006).
Cost of O&M	5	1	Operational cost of EW is high, while S is energy efective process (Holmes I., 2012)(Ciocoiu, C. N et all., 2012).
Cost of Investment	4	1	Electrochemical process has low specific capital costs (Khaliq A. et all, 2014). Smelters require high capital investments (Namias J., 2013).
Environmental			
Air emissions	5	1	Smelting releases highly poisonous gases (Holmes I., 2012). Compared to S, EW is much less harmful, because of gaseous pollution.
Production of w.w.	1	5	While in modern S use low water because of reuse, EW generates wastewater (Özgün Ç., 2008)(Howard S.M. et all.,2009).
Production of s.w.	1	2	EW does not produce further wastes. The solid waste is discarded slag from the smelter (Namias J., 2013).
Generation of h.w.	4	1	In EW, minimum of waste production and toxic material. In S, ash is very toxic (Kang H.Y. and Schoenung J.M., 2005).
Noise Pollution	6	1	Smelter could have a negative effect on noise levels because of gas & leachate management systems (Namias J., 2013).
Resource/Energy Usage	3	1	EW requires acidic or caustic solutions (Virolainen S., 2013). Direct fuel consumption of EW is almost negligible (Howard S.M. et all.,2009).
Technological			
Operability (Flexibility)	5	1	In S, High and medium skilled labour. EW are usually simple. Compared to S, EW is easier to perform (Khaliq A. et all, 2014).
Technical Reliability	1	1	EW are controlled safe andclosed-loop process (Khaliq A. et all, 2014). EW is reliable, while S is not.
Functionality	3	1	Recovering rate is low in S, while recovering rate is high in EW (E Waste Management online book).

Table 0.15 : Pairwise comparision of electrochemical respect to leaching

Sub Criteria	Alternatives		Details
	EW	**L**	
Socio-Political			
Political Acceptance	5	1	A low waste technology solution should always be preferred as it minimizes (Sohaili J. et all., 2012).
Social Acceptance	5	1	EW does not produce further wastes or effluents. L is causing environmental pollution and serious health risks(Tripathi A. et all., 2012).
Economic			
Benefits from Recycling	1	2	Recovering of valuable metals for a positive economic revenue during EW and L (Youssef C. et all, 2012).
Cost of O&M	1	2	L require low operation costs.In EW, require lower O&M cost (Kamberoviç Z. et all, 2009).
Cost of Investment	1	2	EW require a large capital investment (Youssef C. et all, 2012). But,in L, low investment requirement (Allison S et all, 2011).
Environmental			
Air emissions	2	1	EW could generate chlorine gas. During the L hazardous or toxic fumes are generated (Kaya M., Sözeri A., 2003).
Production of w.w.	3	1	large amount of water used in L. In EW, utilization of the leachate in the process (Holmes I., 2012).
Production of s.w.	4	1	Leaching produce residues, while effluent treatment results in sludges. EW doesn't produce wastes(closed-loop)(Ciocoiu, C. N. et all,2011).
Generation of h.w.	2	1	EW neither produce any undesired reaction co-products nor use toxic and hazardous materials (P Chandra Mouli, 2004).
Noise Pollution	3	1	In L, Off-gas control and treatment measures (UNEP, 2009).
Resource/Energy Usage	1	5	L require low energy and acidic/caustic solutions(Virolainen S., 2013). In EW, lesser chemical and energy usage (Habashi F., 1986).
Technological			
Operability (Flexibility)	2	1	In L, flexibility, ease (Allison S et all, 2011). EW is simple, controlled safe, less labour requirement and eco-friendly (Youssef C. et all, 2012).

Technical Reliability	2	1	L is more exact, more predictable, and more easily controlled (Allison S et all, 2011).
Functionality	2	1	In L, yields for both metals were over 90% (Virolainen S., 2013). In EW, up to 90 to 95 percent. Recovers only metals (Youssef C. et all, 2012).

Table 0.16 : Pairwise comparision of solvent extraction respect to bioleaching

Sub Criteria	Alternatives		Details
	SX	BL	
Socio-Political			
Political Acceptance	1	3	BS is seem to be preferable than SX because of its simplicity and low capital cost (Pradhan N. et all., 2008)
Social Acceptance	1	3	Moreover BL found a larger place and a research area because of its high efficiency, low cost against SX processes (Yeşilyurt Z. et all., 2007).
Economic			
Benefits from Recycling	2	1	SX is not efficient, loss of compounds. BL is very slow process.This brings in less profit (Neale J.W. et all., 2011).
Cost of O&M	1	6	Bioleaching has a number of benefits over traditional methods, including low operating costs (Pradhan N. et all., 2008)(Namias J., 2013).
Cost of Investment	1	2	BL is expected to reduce investment and operating costs compared to conventional SX (Virolainen S., 2013) (Roux L. M. et all., 2004).
Environmental			
Air emissions	1	3	Bioleaching if used for all processing could drastically reduce the amount of greenhouse gasses (SO2) in our atmosphere (Habashi F., 1986).
Production of w.w.	1	4	The solid and liquid wastes are environmentally acceptable in BL. Sx is a process that enables reuse of waste liquid (Neira J. et all., 2006).
Production of s.w.	1	6	Solid residue from BL has a number of benefits over SX, minimization of the volume of sludge (Tsezos M. et all., 2008).
Generation of h.w.	1	4	In SX, often requires toxic or flammable solvents that can cause sludges. (Luda M.P., 2011).

Noise Pollution	1	4	In BL, noise from management of complex chemical plants (Namias J., 2013).
Resource/Energy Usage	1	3	BL has a less harmful impact on the environment than SX, because it uses less energy and chemicals (Namias J., 2013).
Technological			
Operability (Flexibility)	1	5	Solvent Extraction is a simpleand flexibility. BL is a fairy simple process that does not require expertise (Willner J. and Fornalczyk, 2013).
Technical Reliability	5	1	SX is relatively efficient and reliable. New promising biological processes are now under development (Luda M.P., 2011).
Functionality	5	1	In SX process, Up to 99% metals[45]. In BL, metal recovery rate is 68,5% in BL process. (Yeşilyurt Z. et all., 2007).

Table 0.17 : Pairwise comparision of solvent extraction respect to biosorbtion

Sub Criteria	**Alternatives**		**Details**
	SX	**BS**	
Socio-Political			
Political Acceptance	1	4	BS is seem to be preferable than SX because of a low waste technology solution (Sohaili J. et all., 2012).
Social Acceptance	1	4	BS is seen as more environmental sensitive process than SX, since the use of strong chemicals, energy are reduced (Allison S et all, 2011).
Economic			
Benefits from Recycling	2	1	In SX, up to 99% metals are adsorbed. In BL, low economic value and less useful in alternative products (Macek T. and Mackova M., 2011).
Cost of O&M	1	7	SX required $28,393,500 Operational Costs. The advantages BS has over SX include low cost[(Sohaili J. et all., 2012)(Roux L. M. et all., 2004).
Cost of Investment	1	3	SX requires relatively inexpensive equipment, while BS requires low capital and operation cost (Roux L. M. et all., 2004).
Environmental			
Air emissions	1	2	SX reduces emission of harmful gases when compared to conventional technologies. No airborne pollutants in BS (Özgün Ç., 2008).

Production of w.w.	1	3	SX is a process that enables reuse of waste liquid. In BS, the typical problem of the effluents generated (Özgün Ç., 2008).
Production of s.w.	1	6	Compared with SX, BS-based process offers an advantages minimization of the volume of chemical/biological sludges (Sohaili J. et all., 2012).
Generation of h.w.	1	5	In SX, often requires toxic or flammable solvents that can cause sludges. In BS, high efficiency in detoxifying (Luda M.P., 2011)
Noise Pollution	1	3	
Resource/Energy Usage	1	4	BS is seen as more environmental sensitive process than SX, since the use of strong chemicals, energy are reduced (Allison S et all, 2011).
Technological			
Operability (Flexibility)	1	4	SX is a simple and flexibility. Biosorption requires less labour and high reaction times (Masi M. et all., 2013).
Technical Reliability	4	1	SX is relatively efficient and reliable. New promising biological processes are now under development (Luda M.P., 2011).
Functionality	4	1	BS is effective method. Number of disadvanteges of BS are not efficient, loss of compounds. SX is very sensitive (Qaiser S. et all, 2007).

Table 0.18 : Pairwise comparision of solvent extraction respect to pyrolysis

Sub Criteria	**Alternatives**		**Details**
	SX	**P**	
Socio-Political			
Political Acceptance	5	1	P has been banned but due to emission of noxious gases and low recovery, researchers are looking towards the SX because it is easily controlled and better predictable (Tripathi A. et all., 2012).
Social Acceptance	5	1	Compared to P, SX is easier to perform and much less harmful, because no gaseous pollution occurs (Kaya M., Sözeri A., 2003).
Economic			
Benefits from Recycling	1	5	There are concerns regarding the economy of SX compared to P for the extraction of PMs from e-waste (Khaliq A. et all, 2014).

Cost of O&M	2	1	SX required low Operational Costs while P require high (Roux L. M. et all., 2004). Energy during operation reduces operating costs.
Cost of Investment	7	1	P has quite high capital investment, while SX requires low capital investment (Youssef C. et all, 2012)(Roux L. M. et all., 2004).
Environmental			
Air emissions	6	1	Compared to P, SX is much less harmful, because no gaseous pollution occurs (Zuo X. et all., 2011).
Production of w.w.	1	7	SX is a process that enables reuse of waste liquid. Pyrolysis has low risk of water pollution (Holmes I., 2012).
Production of s.w.	1	8	The solid residue remaining from P is typically an inorganic ash or a char. In SX, generate large volumes of organic waste (Luda M.P., 2011).
Generation of h.w.	3	1	SX requires e solvents that can cause chemical/ biological sludges. The inertization of the waste residue or contamination concentration in P.
Noise Pollution	3	1	
Resource/Energy Usage	5	1	SX requires solvents, while P requires additives (Luyima A. et all., 2012). SX use low energy, while P is energy efficient (Habashi F., 1986).
Technological			
Operability (Flexibility)	2	1	SX is simple to construct and operate. P is uncomplicated because of full automatic, computer control system (Tripathi A. et all., 2012).
Technical Reliability	1	2	SX is relatively efficient and reliable. Full automatic operation, computer control system during pyrolysis [58].
Functionality	3	1	Compared to SX, P has low recovery of metals [24]. In P, 68.4% Cu, 92.6% Ag and 85.5% Au recovery (Luda M.P., 2011)(Tripathi A. et all., 2012).

Table 0.19 : Pairwise comparision of solvent extraction respect to smelting

Sub Criteria	Alternatives		Details
	SX	S	
Socio-Political			
Political Acceptance	6	1	SX is a low waste technology solution should always be preferred. Smelting caused much

			of the ecological damage (Boerrigter H., 2001).
Social Acceptance	6	1	Compared to S, SX is easier to perform and much less harmful, because no gaseous pollution occurs (Kaya M., Sözeri A., 2003).
Economic			
Benefits from Recycling	1	4	SX are not efficient, loss of compounds. In smelting, product quality and value is high (UNEP, 2009).
Cost of O&M	3	1	SX requires lower operating costs than S (Roux L. M., et all., 2004). In S, management systems contributes to the high cost (Holmes I., 2012).
Cost of Investment	6	1	S require high capital investments. Generally, the capital cost of a SX is considerably less than that of S (Namias J., 2013).
Environmental			
Air emissions	7	1	S releases highly poisonous gases (Namias J., 2013).Compared to S, no gaseous pollution occurs in SX (Kaya M., Sözeri A., 2003).
Production of w.w.	1	6	In modern smelters, low water use because of reuse. In contrast to S, SX also generates wastewater (Howard S.M. et all.,2009).
Production of s.w.	1	7	The solid waste is discarded slag from the smelter. In SX, generate large volumes of organic waste (Howard S.M. et all.,2009).
Generation of h.w.	4	1	In S, ash is very toxic. In SX requires toxic or flammable solvents that can cause chemical/ biological sludges (Toprak A.O. et all.,2013).
Noise Pollution	4	1	Smelter could have a negative effect on noise levels because of gas & leachate management systems (Hagelüken Ch., 2006).
Resource/Energy Usage	6	1	In SX, often requires olvents while S reduce agent consumption (Howard S.M. et all.,2009). SX use low energy, S use high (Holmes I., 2012).
Technological			
Operability (Flexibility)	3	1	SX is a simple and flexibility. Disadvantages of SX, loss of compounds and laborious. In S, High and medium skilled labour (UNEP, 2009.
Technical Reliability	1	2	Smelting can be control with utilizing process control equipment. SX is relatively efficient and reliable (Holmes I., 2012).
Functionality	3	1	Recovering rate is low in smelting, while recovering rate is high in SX (Majumder D. R.,2013).

Table 0.20 : Pairwise comparision of solvent extraction respect to leaching

Sub Criteria	Alternatives		Details
	SX	L	
Socio-Political			
Political Acceptance	4	1	A low waste technology solution should always be preferred (Virolainen S., 2013).
Social Acceptance	4	1	They are easily controlled (Tripathi A. et all., 2012). L is causing environmental pollution and serious health risks (Luyima A. et all., 2012).
Economic			
Benefits from Recycling	1	3	SX are not efficient, loss of compounds. Recovering brings a positive economic revenue during L (Youssef C. et all, 2012).
Cost of O&M	1	4	Reguirement high solvent costs (Gamse T., 2003). Advantages of L process is lower operation costs than SX (Kamberoviç Z. et all, 2009).
Cost of Investment	2	1	Investment cost of SX is a little bit more than L (Allison S et all, 2011).
Environmental			
Air emissions	4	1	SX reduces emission of harmful gases when compared to L. There is no pollution of air in view of L process (Kaya M., Sözeri A., 2003).
Production of w.w.	2	1	SX generates wastewater and enables reuse of waste liquid [49][56]. On the other hand, Large amount of water used in L (Holmes I., 2012).
Production of s.w.	1	3	L produce residues, while effluent treatment results in sludges. In SX, generate large volumes of organic waste [56].
Generation of h.w.	2	1	In SX, often requires toxic or flammable solvents that can cause sludges[89].
Noise Pollution	1	1	In leaching, noise from management of off-gas control and treatment measures (UNEP, 2009).
Resource/Energy Usage	1	2	SX requires solvents, while L require acidic or caustic solutions (Youssef C. et all, 2012). L has lower energy than SX (Virolainen S., 2013).
Technological			
Operability (Flexibility)	1	2	SX is simple to construct and operate and flexibility. L is flexibility, easey controlled (Allison S et all, 2011).
Technical Reliability	1	1	L method is more exact, more predictable, and more easily controlled. SX is relatively

			efficient and reliable (Masi M. et all., 2013).
Functionality	2	1	In SX process, Up to 99% metals are adsorbed (Luda M.P., 2011). In L, yields for both metals were over 90% (Virolainen S., 2013).

Table 0.21 : Pairwise comparision of solvent extraction respet to electrochemical

Sub Criteria	**Alternatives**		**Details**
	SX	**EW**	
Socio-Political			
Political Acceptance	1	2	A low waste technology solution should always be preferred (Virolainen S., 2013).
Social Acceptance	1	2	Researchers are looking towards the hydrometallurgical processes because it is easily controlled and predictable(Tripathi A. et all., 2012).
Economic			
Benefits from Recycling	1	2	SX are not efficient, loss of compounds, while recovering of metals for a positive economic revenue during EW (Youssef C. et all, 2012).
Cost of O&M	1	3	EW has a little bit lower operating cost than SX (Roux L. M. et all., 2004).
Cost of Investment	3	1	EW require a large capital investment than SX (Roux L. M. et all., 2004)(Youssef C. et all, 2012).
Environmental			
Air emissions	3	1	In EW, no gaseous pollution occurs. SX less production emission of harmful gases when compared to EW(Habashi F., 1986).
Production of w.w.	1	2	SX is a process that generates wastewater and enables reuse of waste liquid.In EW, utilization of the leachate in the process (Özgün Ç., 2008).
Production of s.w.	1	6	SX generates large volumes of organic waste, EW is a closed-loop process that does not produce further wastes (Masi M. et all.,2013)
Generation of h.w.	1	1	SX requires toxic or flammable solvents that can cause sludges. EW minimum of waste production and toxic material (Masi M. et all.,2013)
Noise Pollution	1	3	
Resource/Energy Usage	4	1	EW use high energy, while SX use low energy (Habashi F., 1986). EW requires chemicals , SX require solvents (Youssef C. et all, 2012).

Technological			
Operability (Flexibility)	1	3	SX is a simple, no complex equipment and flexibility. EW is cheaper, easier to control (Youssef C. et all, 2012).
Technical Reliability	1	2	SX is relatively efficient and reliable. EW control automation, so its improved safety (Kaya M., Sözeri A., 2003).
Functionality	1	1	In SX, up to 99% platinum group metals are adsorbed. EW is most efficient , yields up to 90 to 95 percent [45].

Table 0.22 : Pairwise comparision of ion exchange respect to bioleaching

Sub Criteria	Alternatives		Details
	IE	BL	
Socio-Political			
Political Acceptance	1	4	BLtechnique, because of its simplicity and low capital cost, is suitable for developing countries (Pradhan N. et all., 2008).
Social Acceptance	1	4	Compared with IE, BL have many advantages, such as low costs, and environmental sustainability (Xakalashe B. S., 2012)
Economic			
Benefits from Recycling	4	1	BL is very slow process.This brings in less profit as well as introducing a significant delay in cash flow for new plants (Sohaili J. et all., 2012).
Cost of O&M	1	5	IE has lower operating costs. BL has a number of benefits over IE , including low operating costs (Namias J., 2013).
Cost of Investment	1	6	BL is expected to reduce investment and operating costs compared to IE processes (Virolainen S., 2013).
Environmental			
Air emissions	1	3	In BL, no airborne pollutants and no biogas are produced (Özgün Ç., 2008). In IE, limited concentration ability (George C Cushnie Jr.,1994).
Production of w.w.	1	5	In IE, savings on regenerant and water consumption. The solid and liquid wastes are environmentally acceptable in BL [76].
Production of s.w.	1	4	BL reduced amount of sludge production for disposal (Tsezos M. et all., 2008).

Generation of h.w.	1	3	BL has a number of benefits over traditional methods, high efficiency in detoxifying effluents (Namias J., 2013).
Noise Pollution	1	4	In BL, noise from management of complex chemical plants[18].
Resource/Energy Usage	1	2	BL requires lesser energy than IE (Jonglertjunya W., 2003). Chemical usage reduce lower in BL, while it is high in L (Virolainen S., 2013).
Technological			
Operability (Flexibility)	1	3	BL is easier to conduct in comparison to IE. Flexibility microorganisms easily adapt to living conditions (Willner J. and Fornalczyk, 2013).
Technical Reliability	1	2	L method is more exact, more predictable and more easily controlled. But, new promising BL are now under development (Luda M.P., 2011).
Functionality	4	1	Metal recovery rate is 68,5% in BL process (Willner J. and Fornalczyk, 2013). Yields for both metals were over 90% in IE (Virolainen S., 2013).

Table 0.23 : Pairwise comparision of ion exchange respect to biosorbtion

Sub Criteria	Alternatives		Details
	IE	**BS**	
Socio-Political			
Political Acceptance	1	5	BS always be preferred with respect to IE because of being low waste technology (Tamilselvan N. et all, 2011).
Social Acceptance	1	5	BS is seen as more env. sensitive than IE, since the use of strong chemicals,energy and aggressive conditions are reduced(Virolainen S., 2013).
Economic			
Benefits from Recycling	4	1	In BS, low economic value and less useful in alternative products (Macek T. and Mackova M., 2011).
Cost of O&M	1	6	IE require high operation costs (Eger P., 2007), while BS requires low operation costs (Sohaili J. et all., 2012).
Cost of Investment	1	7	In IE, installation costs can be quite high (Eger P., 2007). In BS, low capital and operation cost (Macek T. and Mackova M., 2011).
Environmental			

Air emissions	1	2	In IE,Limited concentration ability (George C Cushnie Jr., 1994). No airborne pollutants are produced during BS (Özgün Ç., 2008).
Production of w.w.	1	4	In ion exchange, rinse water and saturated regeneration fluid with harmful ions are released as residue [110]. savings on regenerant and water consumption. In biosorption, the typical problem of the effluents generated. large volume of wastewater and process water very often characterised by acidity and high content of sulfates and metals [130].
Production of s.w.	1	4	Compared with the IE, BS offers an advantages minimization of the volume of chemical/biological sludges (Sohaili J. et all., 2012).
Generation of h.w.	1	4	BS has a number of benefits over traditional methods, high efficiency in detoxifying effluents (Kamberovic et al., 2011)
Noise Pollution	1	3	BS is silenced technology to not required to operate complex chemical plants[Karwowska E. et all, 2014].
Resource/Energy Usage	1	3	BS is seen as more env. sensitive than IE, since the use of strong chemicals,energy and aggressive conditions are reduced(Virolainen S., 2013).
Technological			
Operability (Flexibility)	1	2	BS require less labour, reaction times and volumes (Masi M. et all., 2013). IE is simple, but practical applications are not as widespread [22].
Technical Reliability	1	3	L is more exact, more predictable, and more easily controlled. But, new promising BS are now under development (Luda M.P., 2011).
Functionality	3	1	Biosorption technology is effective method. BS are not efficient than IE because of loss of compounds (Qaiser S. et all, 2007)

Table 0.24 : Pairwise comparision of ion exchange respect to pyrolysis

Sub Criteria	**Alternatives**		**Details**
	IE	**P**	
Socio-Political			
Political Acceptance	4	1	IE is easily controlled and better predictable than P. due to emis-sion of noxious gases and low recovery of metals (Tripathi A. et all., 2012).
Social Acceptance	4	1	Compared to P., IE is easier to perform and much less harmful, because no gaseous pollution occurs (Tripathi A. et all., 2012).

Economic			
Benefits from Recycling	1	3	In P., marketable secondary raw material. IE are slow and time consuming and impact recycling economy (Khaliq A. et all, 2014).
Cost of O&M	3	1	Total M&O costs of pyrolysis are twice as much IE(EPA, 2006) [45].
Cost of Investment	3	1	While installation costs of IE can be quite high. Pyrolysis has quite high capital requirement of P. is a little bit more than IE (Eger P., 2007).
Environmental			
Air emissions	6	1	Pyrolysis emit poisonous gases. Compared to P.,IE is much less harmful, because no gaseous pollution occurs (Zuo X. et all., 2011).
Production of w.w.	1	8	Pyrolysis has lower risk of water pollution than IE (http://www.emrc.org.au/pyrolysis.html).
Production of s.w.	1	6	In IE, residue was shown to be very effective. The solid residue remaining is an inorganic ash or a char (Luda M.P., 2011).
Generation of h.w.	4	1	The inertization of the waste residue or contamination concentration in pyrolysis (Luda M.P., 2011).
Noise Pollution	3	1	In pyrolysis, gas and leachate management systems [27].
Resource/Energy Usage	6	1	While low energy demand in IE, high nergy requirement in P [27]. [33]. Requirement additives in pyrolysis process (Luyima A. et all., 2012).
Technological			
Operability (Flexibility)	4	1	Pyrolysis is easier than IE because of full automatic operation, computer control system [33] [58].
Technical Reliability	1	7	IE has exhaustion risk. But, pyrolysis is modular (http://www.emrc.org.au/pyrolysis.html).
Functionality	2	1	In P., eventually 68.4% Cu, 92.6% Ag and 85.5% Au(Luda M.P., 2011). In IE, the yield generally lies between 80 and 99%. (Khaliq A. et all, 2014).

Table 0.25 : Pairwise comparision of ion exchange respect to smelting

Sub Criteria	Alternatives		Details
	IE	**S**	
Socio-Political			

Political Acceptance	5	1	Efforts by government have eliminated SOx that cause ecological damage, there has been significant progress such as IE (Sum E.Y.L, 1991).
Social Acceptance	5	1	Social acceptance of smelting is low due to high environmental liabilities while social acceptance of ion exchange is high (UNEP, 2009).
Economic			
Benefits from Recycling	1	2	In S., product quality and value is high. Smelting leads to higher loss of metals as compared to IE (UNEP, 2009).
Cost of O&M	4	1	IE has high operational costs (Eger P., 2007). Smelting is extremely expensive, which contributes directly to the high cost (Holmes I., 2012).
Cost of Investment	2	1	In IE, installation costs can be quite high (Eger P., 2007). Smelters require high capital investments (Namias J., 2013).
Environmental			
Air emissions	7	1	Smelting releases highly poisonous gases. Compared to S. , IE is much less harmful, because no gaseous pollution occurs (Holmes I., 2012).
Production of w.w.	1	7	In modern smelters, low water use because of reuse. In contrast to a smelters, IE generates wastewater (Howard S.M. et all.,2009).
Production of s.w.	1	5	In IE, generation residue. Smelting produces solid waste called slag (http://www.emis.vito.be/techniekfiche/ion-exchange?language=en).
Generation of h.w.	5	1	In IE, minimum of waste production and toxic material. In smelting, ash is very toxic, potentially polluting groundwater (Sum E.Y.L,1991).
Noise Pollution	4	1	Smelter could have a negative effect on noise levels because of gas & leachate management systems(Sum E.Y.L,1991).
Resource/Energy Usage	7	1	S. require high energy demand, while IE require low energy demand. Agent consumption and energy efficiency in S (Howard S.M. et all.,2009).
Technological			
Operability (Flexibility)	5	1	In IE, simple to construct and operate , so it require less skilled labour.In smelting, High and medium skilled labour (Majumder D. R.,2013).
Technical Reliability	1	7	In smelting, automated process. Excess regenerate required, feed concentration must be monitored closely in IE (UNEP, 2009).
Functionality	2	1	IE do offer a genuine treatment alternative to smelting and the possibility of realising somewhat higher metal-recovery yields (EWMOB).

Table 0.26 : Pairwise comparision of ion exchange respect to leaching

Sub Criteria	Alternatives		Details
	IE	L	
Socio-Political			
Political Acceptance	3	1	Both of them are low waste technology (Habashi F., 1986). Cyanide L. in Korea have stopped (UNEP,2009).
Social Acceptance	3	1	Cyanide L. in Korea have stopped because of env. issues (UNEP,2009). IE is environment friendly process (Luyima A. et all., 2012).
Economic			
Benefits from Recycling	1	1	IE brings in high purity, niche products, while metal bring positive economic revenue during L. (Masi M. et all., 2013)(Youssef C. et all, 2012).
Cost of O&M	1	3	In L., low investment and operation costs (Pradhan N. et all., 2008). In IE, high operational costs(Eger P., 2007).
Cost of Investment	1	4	In IE, installation costs can be quite high [112]. Leaching requires low investment and operation costs (Namias J., 2013).
Environmental			
Air emissions	4	1	During the L. hazardous or toxic fumes are generated (UNEP, 2009). In ion exchange,Limited concentration ability (George C Cushnie Jr. 1994).
Production of w.w.	1	1	In IE, high volumes of leachate that can be corrosive and toxic (Gramatyaka P. Et all., 2007). Large amount of water used in L. (Holmes I., 2012).
Production of s.w.	1	1	Leaching processes produce residues that results in sludges (Zhang Y. et all, 2012). In IE, generation residue.
Generation of h.w.	3	1	In IE, minimum of waste production and toxic material. In L., cyanide in leaching process are released as residue.
Noise Pollution	1	1	In leaching, Off-gas control and treatment measures [44].
Resource/Energy Usage	1	1	They require lower energy consumption. Leaching require strong acidic or caustic solutions. IE require reagent losses (Virolainen S., 2013).

Technological			
Operability (Flexibility)	2	1	In L.,simple, flexibility, acceptable yields and easy controlled. In IE, simple to construct and operate (Allison S et all, 2011).
Technical Reliability	1	6	IE has exhaustion risk, while leaching is more exact, more predictable, and more easily controlled (Zhang Y. et all, 2012).
Functionality	1	1	IN IE, yield generally lies between 80 and 99% (Luda M.P., 2011). In leaching, yields for both metals were over 90% (Virolainen S., 2013).

Table 0.27 : Pairwise comparision of ion exchange respect to electrochemical

Sub Criteria	Alternatives		Details
	IE	EW	
Socio-Political			
Political Acceptance	1	3	A low waste technology solution should always be preferred as it minimizes the threat of environmental legislation (Habashi F., 1986).
Social Acceptance	1	3	Electrochemical process is a clean, closed-loop process. Ion exchange is environment friendly process (Kamberoviç Z. et all, 2009)
Economic			
Benefits from Recycling	2	1	Recovering of valuable metals for a positive economic revenue during EW. IE brings in high profit (Youssef C. et all, 2012)
Cost of O&M	1	2	Annual O&M costs of EW twice as much IE (Eger P., 2007).
Cost of Investment	1	3	In EW, Installation and equipment are simple and inexpensive(Youssef C. et all, 2012). Installation costs of IE can be high (Eger P., 2007)
Environmental			
Air emissions	3	1	In IE, Limited concentration ability. Solution could generate chlorine gas during EW (George C Cushnie Jr. 1994).
Production of w.w.	1	3	In IE, generation fluid with harmful ions. In EW, utilization of the leachate(Özgün Ç., 2008)
Production of s.w.	1	4	EW is closed-loop process that does not produce further wastes or effluents. In IE, generation fluid with harmful ions (Özgün Ç., 2008)

Generation of h.w.	2	1	In EW, minimum of waste production and toxic material. In IE, minimum of waste production and toxic material (Khaliq A. et all., 2014).
Noise Pollution	1	3	EW is closed-loop process that does not produce noise (Khaliq A. et all., 2014).
Resource/Energy Usage	5	1	In EW, high electrical energy consumption and corrosive agents such as aqua regia (Virolainen S., 2013). In IE, Low-energy demands [112].
Technological			
Operability (Flexibility)	1	1	EW are usually simple and easy (Youssef C. et all, 2012). In ion exchange, simple to construct and operate (Tripathi A. et all., 2012).
Technical Reliability	1	7	IE has exhaustion risk, while EW is improved safety (Youssef C. et all, 2012).
Functionality	1	2	In EW, recovery sometimes up to 90 to 95 percent [112].The yield pf IE generally lies between 80 and 99% [110].

Table 0.28 : Pairwise comparision of ion exchange respect to solvent extraction

Sub Criteria	Alternatives		Details
	IE	SX	
Socio-Political			
Political Acceptance	1	2	Both of them harmonize with the legislation because of being a low waste technology (Habashi F., 1986).
Social Acceptance	1	2	Hydrometallurgical processes could easier to perform and better predictable (Tripathi A. et all., 2012). SX is much less harmful than IE because no gaseous pollution occurs (Kaya M. And Sözeri A., 2003) (Kamberoviç, Z. et all., 2009)
Economic			
Benefits from Recycling	3	1	While IE brings in high profit, SX are not efficient because of loss of compounds (96).
Cost of O&M	2	1	IE reguires is the relatively high operational costs.SX: $28,393,500. Requirement high solvent costs (Gamse T., 2003) (Roux L. M., 2004).
Cost of Investment (Implementation Cost)	1	5	SX is relatively inexpensive (Roux L. M., 2004), while installation costs of IE can be quite high (Eger P., 2007).
Environmental			
Air emissions	1	1	In IE, limited concentration ability (George C Cushnie Jr.,1994). There is no production of

			the gas and dust (Habashi F., 1986).
Production of w.w.	1	2	In SX, reuse of waste liquid. IE generate rinse water with harmful ions(http://emis.vito.be/techniekfiche/ion-exchange?language=en)
Production of s.w.	3	1	IE generates residue. In SX, generate large volumes of organic waste (http://emis.vito.be/techniekfiche/ion-exchange?language=en)
Generation of h.w.	2	1	SX produce chemical/ biological sludges because of solvents. In IE, minimum of waste production and toxic material (Masi M. et all., 2013).
Noise Pollution	1	1	IE and SX could have a negative effect on noise levels (Masi M. et all., 2013).
Resource/Energy Usage	2	1	IE, low energy consumption and low reagent losses (Virolainen S., 2013). SX requires solvents and low energy (Habashi F., 1986).
Technological			
Operability (Flexibility)	3	1	SX and IE is a simple to construct and operate and flexibility (Eger P., 2007). SX process can be complicated, not efficient. IE is suitable than SX process. Practical applications of IE are not as widespread, but SX has been applied to seperate precious metals(Virolainen S., 2013).
Technical Reliability	1	6	IX has exhaustion risk, while SX is efficient and reliable(EPA, 2000)
Functionality	1	2	In IE, yield generally lies between 80 and 99%, while SX has up to 99% platinum group metals (R,R,R from metallurgical wastes).

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- Packacging waste license application and recertification.

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