YAŞAR UNIVERSITY
GRADUATE SCHOOL

MASTER IN INTERNATIONAL LOGISTICS MANAGEMENT

E-WASTE AND REVERSE LOGISTICS: FORECASTING AND CAUSE AND EFFECT ANALYSIS FOR AN EMERGING ECONOMY

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PRESENTATION DATE: 11.06.2020

BORNOVA / İZMİR
JUNE 2020

ABSTRACT

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Reverse logistics activities based on circular economy perspective including recycling, reuse, remanufacturing, and reconditioning gain more attention. Moreover, circular economy is an essential approach for waste management, and it provides economic, environmental and social benefits. Recently, with the changing technology and increasing population, the usage times of electrical and electronic products are also shortening and the inability to adapt these products to the circular economy causes electronic waste generation especially in emerging economies because reverse logistics activities based on circular economy cannot be carried out effectively due to the shortcomings experienced and the fact that wastes that can be utilized become garbage. For this purpose, the thesis is structured around mobile phones which the most emerging electronic waste in Turkey. First of all, the future state analysis of electronic wastes in Turkey is made to show the electronic waste increase status with Grey Prediction method as a case study. After that, the challenges affecting the recycling of electronic waste especially mobile phones are gathered under 7 main headings such as ecological, social, economic, infrastructural and technological, legal, managerial and business, supply chain management dimensions with 25 criteria totally. These challenges are analysed by 8 experts with the implementation of Fuzzy DEMATEL. It is aimed to create a road map for companies and governments based on sustainable and circular solutions by researching the reasons that affect the recycling of mobile phones.

This way, it has been determined that legal deficiencies generally affect the recycling process of electronic waste. Accordingly, problems such as

environmental pollution, damage to human health, and valuable waste that could not be recycled to the economy have been identified.

Keywords: Circular Economy, Reverse Logistics, E-Waste

ÖZ

ELEKTRONIK ATIKLAR VE TERSINE LOJISTIK: GELIŞMEKTE OLAN BIR EKONOMIDE TAHMINLEME, SEBEP VE ETKI ANALIZI

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2020

Günümüzde geri dönüşüm, yeniden kullanım, yeniden üretim ve yenileme gibi döngüsel iktisat bakış açısına dayalı tersine lojistik faaliyetleri dikkat çekmektedir. Döngüsel iktisat, atık yönetimi için önemli bir yaklaşımdır ve ekonomik, çevresel ve sosyal faydalar sağlar. Son zamanlarda, değişen teknoloji ve artan nüfusla birlikte, elektrikli ve elektronik ürünlerin kullanım süreleri kısalmaktadır ve bu ürünlerin döngüsel iktisat bakış açısı ile değerlendirilememesi özellikle gelişmekte olan ekonomilerde elektronik atık üretimine neden olmaktadır çünkü döngüsel ekonomiye dayalı tersine lojistik faaliyetleri, yaşanan eksiklikler ve kullanılabilecek atıkların çöp haline gelmesi nedeniyle etkin bir şekilde gerçekleştirilemez. Bu amaç doğrultusunda, Türkiye'de en çok ortaya çıkan elektronik atık olan cep telefonlarının geri dönüşüm faaliyetleri analiz edilmek istenmiştir. Öncelikle, Gri Tahmin yöntemi ile Türkiye'de elektronik atıkların gelecekteki durum analizi yapılmıştır. Daha sonra elektronik atıkların özellikle cep telefonlarının geri dönüşümünü etkileyen toplam 7 ana kriter (ekolojik, sosyal, ekonomik, alt yapı ve teknolojik, yasal, işletme yönetimi, tedarik zinciri yönetimi) ve 25 alt kriter belirlenmiştir ve bulanık DEMATEL uygulamasıyla 8 uzman tarafından analiz edilmiştir. Bu çalışma doğrultusunda, cep telefonlarının geri dönüşümünü etkileyen nedenleri araştırarak şirketler ve hükümetler için sürdürülebilir ve dairesel çözümlere dayalı bir yol haritası oluşturulması hedeflenmiştir. Bu şekilde, yasal eksikliklerin genellikle elektronik atıkların geri dönüşüm sürecini etkilediği tespit edilmiştir. Bu doğrultuda, çevre kirliliği, insan sağlığına zarar verme ve değerli atıkların ekonomiye kazandırılamaması gibi sorunlar tespit edilmiştir.

Anahtar sözcükler: Döngüsel İktisat, Tersine Lojistik, Elektronik Atıklar

ACKNOWLEDGEMENTS

I am sincerely thankful to my advisor, Prof. Yigit Kazancoglu for supporting me at every stage of my work and sheds light on my way with his knowledge and experience. I would like to thank my dear colleagues, Yesim Deniz Ozkan Ozen and Deniz Sezer who always guiding me with help and contributions. I am very much thankful to life partner, Oskay Pala, who is always with me when times I needed. In addition, a thank to my lovely sister, Zeynep Ozbiltekin who trying to help me by taking her own time. Lastly, I am grateful to my family for their love and moral support.

Melisa OZBILTEKIN PALA
İzmir, 2020

I dedicate this thesis to my beloved uncle Mustafa Halit EVCİM, whom I have always admired with the energy of life, but I recently lost.

TEXT OF OATH

I declare and honestly confirm that my study, titled “E-Waste and Reverse Logistics: Forecasting and Cause and Effect Analysis for an Emerging Economy” and presented as a master’s thesis, has been written without applying to any assistance inconsistent with scientific ethics and traditions. I declare, to the best of my knowledge and belief, that all content and ideas drawn directly or indirectly from external sources are indicated in the text and listed in the list of references.

MELİSA ÖZBİLTEKİN PALA

Signature

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June 30, 2020

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LIST OF ABBREVIATIONS

EEE: Electrical and Electronic Equipment

E-WASTE: Electronic Waste

WEEE: Waste of Electrical and Electronic Equipment

INTRODUCTION

Circular economy is a production model based on sustainability and innovation, where every waste generated in a production system is recycled, so raw material costs are minimized, resource efficiency and environmental benefits are kept to a maximum (Ellen MacArthur, 2013). In other words, circular economy can be defined as an industrial economy in which it is governed and the concept of circular economy, society to get maximum value from resources and resource consumption according to real and future needs provides adaptation (Wautelet, 2018). Waste prevention, reuse, recycling and recovery (material and energy) to get maximum value from the resources of society and consumption according to real needs makes it possible to adapt. In this way, the demand for primary resources is optimized (Lahti et al., 2018).

Recently, organizing the reverse logistics of products has become an imperative for consumer electronics manufacturers, which can be realized within the framework of the circular economy (Reike et al., 2018). Reverse logistics is a structure related to the entire production industry that creates waste in steel production, aircraft, computers, cars, chemicals, electronic products, medical items and is responsible for the flow of the used product from the consumer to the manufacturer (Julianelli et al., 2020). In this respect, the reverse logistics is one of the most important parts of waste management when it comes to recyclable waste (Guarnieri et al., 2020). Therefore, it is essential to integrate circular economy with reverse logistics operations to have sustainable solutions in waste management.

The electronic waste is very important in reverse logistics and circular economy approaches (Ottoni et al., 2020). Electronic wastes and electronic waste policies should not only support the structural improvements to be made in the recycling and collection stages (Nnorom and Osibanjo, 2008), but also should support the circular economy, and arrangements should be made in the reuse, renewal and reproduction stages of the end of life electronic wastes (Sharma et al., 2020). Moreover, electronic waste is the fastest growing type of waste worldwide (Srivastava et al., 2020). While electronic logistics wastes reverse logistics activities can be implemented more systematically in developed countries, the implementation of these operations in emerging economies remains insufficient (Ottoni et al., 2020). This situation causes electronic waste generated in emerging economies to be transformed to the circular economy (Srivastava et al., 2020). Therefore, it is of utmost importance for emerging economies to know the amount of electronic waste in the present and future, to determine the criteria that prevent reverse logistics activities and to create solutions in line with the results obtained (Demajorovic et al., 2016). For this purpose, this thesis covers electronic waste management based on reverse logistics operations under the circular economy concept.

To best of our knowledge, this is the well-organized study that focus on the prediction of amount of electronic waste to be generated in the coming years within emerging economies, determining challenges for recycling of electronic waste in emerging economies and the ways of analysing causal relationship among these challenges. barriers and challenges of urban mining in emerging economies both theoretically and empirically. Therefore, as a result, three research questions of this thesis can be summarized as;

- RQ1: How shall we predict amount of electronic waste to be generated in the coming years within emerging economies?
- RQ2: What are the challenges for recycling of electronic waste in emerging economies?
- RQ3: How shall we analyse the causal relationship among the challenges to recycling of electronic waste?

In order to find answers to first research question, prediction of amount of electronic waste to be generated in the coming years within emerging economies are analysed with Grey Prediction method. After detailed literature review, seven main challenges about recycling activities of electronic waste are determined for an emerging economy to find answers of second research question. Furthermore, to find the impacts of these challenges, fuzzy DEMATEL method is applied and causal relationship among the challenges are determined for third research question. By the implementation of Fuzzy DEMATEL, the importance order of challenges is specified for an emerging economy.

Thesis study is organized as follows. After the introduction, section one reviews the theoretical framework of circular economy approach and reverse logistics, circular economy, the importance of reverse logistics, benefits of reverse logistics, reasons for product returns, reverse logistics in the supply chain management, reverse logistics activities based on circular economy approach and the role of reverse logistics in supply chain. Section two discusses electronic waste, and section three explains e-waste in reverse logistics as a theory. In section four, the research framework and methodology are reviewed. In section five, the e-waste problem in Turkey is explained. Then, the prediction e-waste in an emerging economy and challenges in e-waste recycling activities in emerging economies are explained respectively. After determining challenge set, the implementation of the study is explained in section eight. The last parts will include results, discussions, and conclusions.

1. CIRCULAR ECONOMY & REVERSE LOGISTICS

Traditional economy is based on the 'take, make, dispose' approach that follows a linear direction (Genovese et al., 2017) and this approach may contain hazards that could harm the business sector. This one-way pattern has caused unique growth throughout history but has also paved the way for the risk of resource depletion which can cause surging price volatility and supply disruptions for companies (Ellen MacArthur, 2013). In these risky situations, leverage becomes more ineffective. The presence of such troubles leads to the idea of a circular economy, causing the need for materials and energy use to decline again (Reike et al., 2018). The circular economy follows a path which considers the boundaries of the world that reduce resource consumption by targeting the renewability and recyclability of raw materials and energy resources (WBCSD, 2019). This economic approach, which transforms the end-of-life concept into restoration, also distinguishes revenue from material input (Genovese et al., 2017).

Reverse logistics and circular economy are similar in many ways, such as repair, renewal, remanufacturing (Ellen MacArthur, 2013). Some principles of the circular economy, such as leakage minimization, are more extensive than reverse logistics, and circular economy has wider primary objectives that contribute to the global economy (Geissdoerfer et al., 2017). Moreover, reverse logistics contributes to transition to a circular economy and the close loop of product life cycles (Tom, 2018).

Logistics is a crucial activity for companies in supply chain management. Generally, logistics is defined as “a part of the supply chain process, planning, implementing and controlling the efficient flow and storage of goods, services, and related information from the point of origin to the point of consumption” (Li, 2014; USAID Deliver, 2011). Logistics of goods includes material flow, production, packaging, inventory, transportation, and warehousing (Elmas & Erdogmus, 2011; Li, 2014). The logistics concept is not only about goods, but services as well. Council of Supply Chain Management Professionals states the meaning of logistics as “the process of planning, implementing, and controlling the efficient, effective flow and storage of goods, services, and related information from the point of origin to the point of consumption to conform to customer requirements.” The definitions show that the concept of logistics includes goods and services as inbound, outbound, and internal, external activities (Chain, n.d.).

The meaning of green logistics is a logistics activity that includes green storage, green packaging, green transportation with advanced technology based on logistics which aims to decrease environmental pollution caused by logistics activities and resource consumption (Li, 2014; Zhang & Zhao, 2012; Zheng & Zhang, 2010). Sustainability is the basis of green logistics. Moreover, green logistics is defined as logistics activities management considering economic, social, and environmental sustainability. Besides, green logistics includes city logistics, green supply chain management, decreasing freight transport externalities, logistics about environmental issues, and reverse logistics (Paridah et al., 2016; Piecyk & McKinnon, 2010).

Reverse logistics is a part of green logistics which consists of the return of waste products and reusing materials, remanufacturing, refurbishing, recycling, and disposal. In reverse logistics activities, companies not only seek to reduce environmental damage and improve social sustainability, but they also explore opportunities to gain value in these activities (Elmas & Erdogmus, 2011; Nallusamy et al., 2015).

Reverse logistics include marketing returns, secondary markets, and product returns (Rogers & Tibben-Lemke, 2002). Reverse logistics also includes processes i.e., product re-stocking, seasonal organization inventory, and hazardous material programs (Elmas & Erdogmus, 2011).However, green logistics include environmental factors such as reducing air and noise emissions, reducing packaging waste, and unharmful mode selection (Teixeira et al., 2018). The common point of green logistics and reverse logistics is remanufacturing, recycling, and reusable packaging (Rogers & Tibben-lembke, 2001).

To increase the complexity of logistics activities, there are many reasons to take into consideration as reverse logistics steps. According to Gandolfo & Sbrana, 2008; Krykawskyy & Fihun, 2015, product return reasons can be listed briefly as below;

1- Having a defect of a product
2- Recalling of a product because of some technical problems
3- The dissatisfaction of consumers about the product
4- Having a long-term maintenance process about the product
5- Overstock in warehouses.

To sum up, reverse logistics and circular economy are two interconnected concepts and the circular economy even includes the concept of reverse logistics (Reike et al., 2018). The circular economy serves a broader purpose than reverse logistics, as it includes reverse and forward flows (Ellen MacArthur, 2015). However, in this thesis, reverse logistics is studied in electronic waste management based on circular economy approach.

In the following sections, firstly, circular economy concept, meaning of reverse logistics, literature review and importance of reverse logistics, benefits of reverse logistics, reasons to prefer reverse logistics, reverse logistics in the supply chain management, reverse logistics activities, and the role of reverse logistics in supply chain are explained. After that, electronic waste and electronic waste in reverse logistics as a theory are discussed. First analysis of this thesis, which is “Grey Systems”, is implemented in the following section. Moreover, electronic waste problem in Turkey is explained. After determining challenge set, the implementation of the study is explained. The last parts will include results, discussions, and conclusions.

1.1. Circular Economy

Circular economy is a global economic model to minimize limited resource consumption that focuses on smart material, product and system design (Shen et al., 2020). While everything is produced from scratch in the traditional linear economy, recycling is at the forefront in the circular economy and he main goal in this process is to recycle the waste materials into the economy (Scheel et al., 2020).

The circular economy describes the restorative and productive industrial economy (WBCSD, 2019). Contrary to the linear economy, the circular economy refuses to use the 'take it' system and aims to minimize the use of resources and raw materials in production besides ensuring that the restored contents are returned to the production point (Ghilsellini et al., 2016).The main purpose of the circular economy approach is to create a regenerative system that can ensure optimum reuse, renewal, regeneration and recycling by processing products, materials and wastes in closed loops (Julianelli et al., 2020).

There is a relationship between reverse logistics and circular economy terms. Both approaches have goals such as contributing to sustainable socio-economic developments, obtaining environmental and economic solutions in used products, and bringing products back to production through methods such as reuse and repair (Isernia et al., 2019). Circular economy is a broader approach that also includes reverse logistics principles (Julianelli et al., 2020).

Therefore, in this thesis, the focused issue is accepted as reverse logistics operations in waste management. In the following part, the definitions of reverse logistics and literature review are given.

1.2. Definition of Reverse Logistics and Literature Review

Due to the increase in the world population, the need for raw materials has emerged. The concept of reverse logistics involves recycling the materials that can be used instead of raw materials (Pinna & Carrus, 2003). Especially since 1970, the environmental dimension of sustainability has been endangered. Therefore, in recent days, reverse logistics has become a crucial issue for studies. There is a recognition about the importance of reverse logistics in the world.

Considering the literature review, there are many studies defining reverse logistics. The definition of reverse logistics is stated that “the purpose of all activities related to service or a product after-sales points, the best final sales activity or effective after-sales activities, in this way protecting environmental resources and avoiding loss of money” (“Reverse Logistics Magazine,” 2009). In the business dictionary, reverse logistics is defined as “flow of surplus or unwanted material, goods, or equipment back to the firm, through its logistics chain, for reuse, recycling, or disposal” (“Reverse Logist.,” n.d.). Reverse logistics is also defined as “the process of planning, implementing, and controlling the efficient, cost-effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin to recapture value or proper disposal” by more than one researcher (Brito, Dekker, & Flapper, 2003; Elmas & Erdogmus, 2011; Rogers & Tibben- lembke, 2001; Senthil & Sridharan, 2014). In addition, Stock (2001) explained the reverse logistics as a system that includes processes such as substitution, recycling, reuse, and disposal in order to ensure the recycling of logistics, recycling of waste, waste management and resource reduction. Moreover, Kroon & Vrijens (1995) described the term “reverse logistics” as a logistic activity involving the reduction, management and disposal of harmful or harmless wastes caused by products and packaging materials. For Sarkis (1998), reverse logistics includes waste collection, transportation and reintegration of a product into the production environment. Furthermore, Dowlatshahi (2000) defined reverse logistics as the supply chain designed backwards to organize the management of the product flows used for recycling, disposal, or efficient use of resources. Škapa & Klapalová (2012) analysed reverse logistics with three approaches. Besides, Lourenço et al. (2002) studied on the definition of reverse logistics. According to Grant et al. (2013), reverse logistics is a concept that provides general supply chain optimization, including supply chain design, product design, and product recovery.

In the next part, the importance of reverse logistics is explained in detail.

1.3. The Importance of Reverse Logistics

Reverse logistics has become a necessary operation since the logistics system changed. Reverse logistics is an essential method in environmental issues, such as companies developing quarterly designs, focusing on life cycle analyses, and green supply chain management (Uriarte-Miranda et al., 2018). The primary purpose of companies is to create cost and competitive advantage compared to other companies. This advantage can be created by reverse logistics applications (Vaz et al., 2013). Defects in products, recalling products by factories because of some problems, overstock in the warehouses, dissatisfaction in after-sales service operations, the return of products or containers due to some delivery problems are the reasons why reverse logistics is needed (Eeva-Liisa Kauhanen, 2016). In addition to being needed, reverse logistics also provides excellent benefits to companies if it is applied. According to Abdullah & Yaakub (2014) and Agrawal (2003), reverse logistics provides revenue gain and competitiveness. Moreover, it helps to decrease stock and operating costs, and to increase customersatisfaction. Customers are becoming more sensitive to the environment. In addition to this, the economic factors cause a change in the purchase of products, because used products provide cheaper resources than new ones (Agrawal, 2003). Therefore, if reverse logistics management is applied successfully, it provides better management in the logistics process.

In the reverse logistics system, the products can be reused, transformed into the same or different products, thus they protect the resources, and ensure sustainability (Dias & Braga, 2016). In addition, reverse logistics reduce the consumption of resources and provides an economic value by helping to recover waste. Reverse logistics is an increasingly important system, as it provides benefits such as saving energy and reduction of environmental pollution (Rubio et al., 2019). The significance of reverse logistics and the economic return vary from sector to sector. Especially in the product groups where the product value and the return rate is high, reverse logistics is more critical (Rogers & Tibben-lembke, 2001). In summary, reverse logistics have advantages from the point of sustainability such as increasing the productivity of the assets, product retrieval practices, contributing to profitability by reducing the cost, recycling of assets in economic view, contributing to environmental protection in an environmental view and customer satisfaction in a social view (Abdullah & Yaakub, 2014; Agrawal, 2003; Rogers & Tibben-lembke, 2001).

Reverse logistics play an active role in all areas including factors such as financial returns, returns under warranty, faulty product returns, packaging returns, return on maintenance and customer returns. If these returns are managed well, reverse logistics will provide a competitive advantage to companies and institutions as it will reduce customer loss (Fleischmann, 2000).

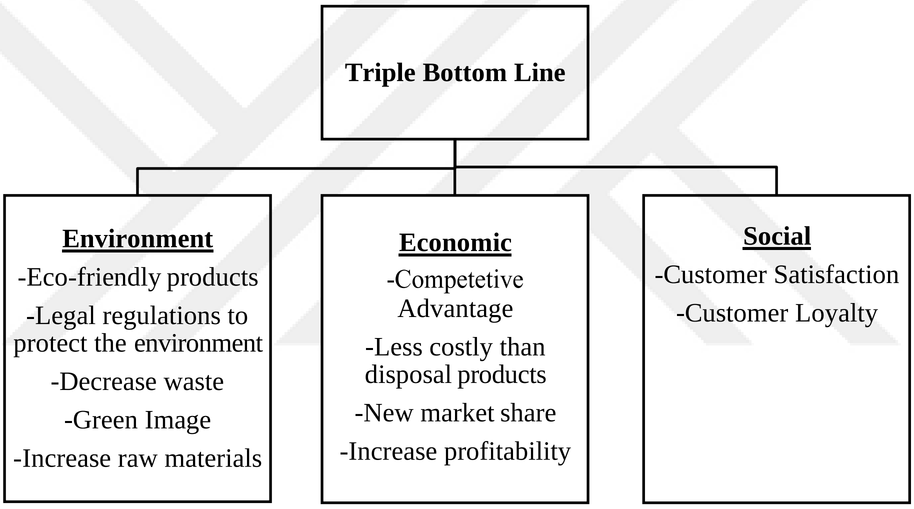
1.4. Benefits of Reverse Logistics with Alignment Circular Economy

Although logistics has a complex structure worldwide, it can direct the circular flow of products, connect markets and provide transparency in supply chains (Ellen MacArthur, 2015). It is an extremely important issue for companies and countries to adopt reverse logistics activities to participate in the circular economy and to design the supply chains to return products and materials used for recycling (Pan et al., 2015).

In addition, regulations applied for the recycling of products; It enables companies to reduce the losses that the products can cause to the environment during the recycling process. However, these laws are addressed not only from an environmental perspective, but also from an economic and a social perspective. While economic profitability from returns is economically essential, customers' commitment to firms is socially essential even if they can return their products at any time (Torabi et al., 2016). Companies that want to benefit from these are making efforts to incorporate reverse logistics practices into their organizations based on circularity and sustainability.

According to Sarkis (1998), reverse logistics has benefited from the sustainability concept. Therefore, these benefits can be analysed using the “triple bottom line (TBL)”. In Figure 1 (Sarkis, 1998), the benefits of reverse logistics from the point of TBL view are shown.

Figure 1 TBL Based Benefits of Reverse Logistics



As mentioned before, according to Rogers & Tibben-lembke (2001), benefits of reverse logistics can be analysed using a sustainability approach. Thanks to reverse logistics activities, the significance of producing environmentally friendly products has increased. This way, damage to the environment is decreasing. Likewise, in the reverse logistics applications, the assessment of the end-of-life consumption products minimize the damage to the environment. In order to increase the importance given to the process in reverse logistics, legal regulations have been introduced to protect the environment and to increase the sensitivity of the companies to it. (Rogers & Tibben-lembke, 2001). In addition, the importance given to reverse logistics increased with the rules brought to the producers. As a result, the volume of waste generation was reduced and the usage of recycled materials increased. Another environmental advantage of reverse logistics is the “green image” (Stock, 2001). Companies are trying to see the concept of the green image as a marketing element. That way, the companies attach more significance to reverse logistics activities. They pay attention to implementing activities such as reduction of consumption, effective use of reuse, and recycling processes (Vaz et al., 2013). Furthermore, the reverse logistics resulting from the shortage of resources and raw materials provides an increase in the amount of raw materials available as it obtains raw materials from returned products (Altug et al., 2012). The benefits mentioned can be explained under environmental dimensions through the concept of sustainability.

In addition to the environmental benefits of reverse logistics activities, there are also economic benefits on companies. In reverse logistics activities, recycling and reuse operations applied to products provide new business opportunities, and thus provide a competitive advantage to companies (Dowlatshahi, 2000). Besides, the return policies implemented by the firms and the use of these policies as a marketing tool increase the competitive advantage (Rogers & Tibben-Lemke, 2002). Moreover, repairing or reusing products rather than disposing returned products greatly reduces company costs. Since repaired products can be sold at higher prices in different markets, this benefit allows companies to have low-cost production and new markets (Brito et al., 2003). These benefits are under economic dimensions of sustainability.

From the social perspective, as the competition increases, the biggest desire of the companies is to provide high-quality products and services to their customers by preventing customer loss (Akdoğan & Coşkun, 2012; Fernandes et al., 2017). The most effective way to ensure the satisfaction of customers is to carry out a quick recovery of damaged products. In order to realize the take-back operations of the companies in an organized way, it increases customer satisfaction and ensures the trust of the customers (Fernandes et al., 2017). Therefore, customer satisfaction and customer loyalty increase when there are well-organized reverse logistic activities.

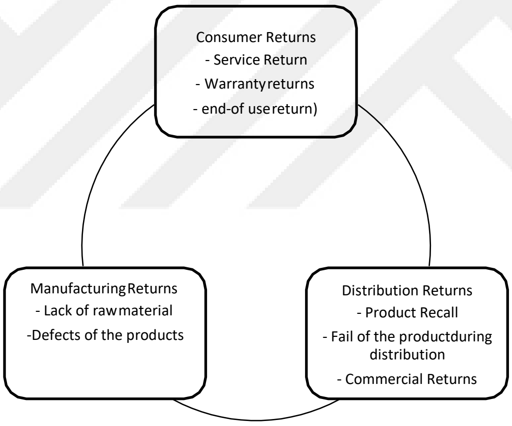
In summary, the benefits of reverse logistics are financial gain, customer satisfaction, increasing credibility of the company, and compliance with the law. There are 3 main objectives in terms of sustainability in reverse logistics applications (Fidlerová & MÍkva, 2016). These objectives are to improve customer satisfaction (social), to increase the profitability of the company (economic) and to eliminate the defects of the old products in the form of waste which have been collected from the customer, or to eliminate these products (environmental) (Rogers & Tibben-lembke, 2001).

The following section addresses the reasons to prefer reverse logistics activities.

1.5. Reasons for Product Returns

There are product returns in all sectors worldwide. The reasons for return may be the inability of the products to function correctly, the defects in quality, and the problems arising from the production stage (Panigrahi et al., 2018). According to Brito et al., (2003), product returns can occur in the manufacturing, distribution, and consumption process as shown in Figure 2 (Brito et al., 2003).

Figure 2 Reasons to Product Returns



Manufacturing reasons include product failure caused by the lack of a raw material or production process (Ahmad et al., 2018). If there are any problems or damages related to the product, it can be recovered in the production stages. On the other hand, product returns can occur in distribution stages as product recalls, which means that products are collected from the market and consumers because of some problems or because products may have been damaged during the distribution (Brito et al., 2003). In addition to manufacturing and distribution stages, consumer stages have product returns because of some product problems related to service, warranty returns, or end-of-use returns (Douthit et al., n.d.). There may be many different reasons for customer returns, and the product may not meet the customer's expectations (Brito et al., 2003).

1.6. Reverse Logistics in Supply Chain Management

Before reverse logistics became important, logistics systems included processes from the manufacturer to the end-user in the classical material flow. Recently, the importance of logistic processes supporting the recovery of used goods has increased. Reverse logistics can be defined as a logistics concept that includes product returns, resource recovery, material substitution, recycling, reuse of materials, repair, waste disposal and renewal, and remanufacturing (Uriarte-Miranda et al., 2018). Since the traditional logistics involves the movement of the material from the origin to consumer, reverse logistics should include the movement of the material from the consumer to origin (Rubio et al., 2019).

Reverse logistics, which involves collecting goods, moving them to a specific location and applications such as refurbishing, reuse or recycling, benefits the economy with a circular economy approach (Isernia et al., 2019). Moreover, logistics processes include both forward (traditional) and reverse logistics (Duigou, 2014). Reverse logistics in the supply chain is crucial for companies since it provides better performance in logistics management, increasing competitiveness, and revenue gain (Agrawal, 2003). The reverse logistics process is a complicated process to have control in supply chain management. Accurate planning, integration of information systems, the process of products, and the packaging are essentialfor such stages (Krykawskyy & Fihun, 2015). The centres, which are usually located in reverse logistics cycles, are places such as recycling facilities, external return centres (Krykawskyy & Fihun, 2015).

In forward (traditional) logistics, there is one-way flow from the raw material process to end consumers (Rogers & Tibben-Lemke, 2002). The forward (traditional) logistics supply chain starts with sending the raw materials from the supplier to the manufacturer. After the manufacturer part, the new products are distributed to resellers or customers. The process is about forward (traditional) logistics (Larson & Halldorsson, 2004). In other words, forward logistics includes processes about the supply of raw material, production process, finished goods, and finished goods supply process to customers (Yin, 2011). The forward logistics is simpler than reverse logistics because of having a standardized channel for the flow of products, uniform product quality and product packaging, being more natural to forecast, having specific routes, being more comfortable to see cost situation, and having a stable price i.e. (Rogers & Tibben-Lemke, 2002).

On the other hand, in reverse logistics, products return from consumer to reseller with a reason such as damages in the product, the dissatisfaction of consumers etc. Contrary to the simplicity of the forward logistics, reverse logistics is more complex due to having a non-standardized channel for the flow of products, non-uniform product quality and packaging, being hard to forecast, including unknown routes, difficulties in cost calculation, price fluctuations owing to operation on products, etc (Rogers & Tibben-Lemke, 2002; Soleimani& Govindan, 2014). Moreover, reverse logistics includes product returns from downstream members that need to be recycled, refurbished, reused, remanufactured, or repaired (French, 2001). According to product type, the reverse process starts with testing the returned product. After testing the product, the next processes can be reuse, refurbishment, remanufacturing, repair, recycling, or disposal. According to Figure 3, which is above, the complexity of processes increases from bottom-left to top-right. For example, it is easier to test a product than disassemble it (Rogers & Tibben-Lemke, 2002).

In the next part, reverse logistics and its activities are explained in detail.

1.7. Reverse Logistics Operations Based on Circular Economy

Although the circular economy and reverse logistics concepts seem similar, circular economy is a term that includes the reverse logistics approach (Reike et al., 2018). In other words, the concept of circular economy is wider than reverse logistics, because it covers both reverse and forward side such as the type of materials specific to process, leakage minimization, etc. (Ellen MacArthur Foundation, 2013). Adopting the principles of the circular economy within reverse logistics operations enables reverse logistics applications to be implemented more effectively (Tjahjono and Ripanti, 2020). Although the operations, which will be explained in detail below, are seen as the operations of circular economy in the literature with varying time and studies, these operations are also used for reverse logistics (Govindan et al., 2015; Reike et al., 2018). In this thesis, it is adopted that reverse logistics is a sub approach under circular economy and the study is focused on reverse logistics.

A great deal of attention is given to returning products, and manufacturers have serious responsibilities for end-of-life products in reverse logistics activities. The laws in countries require the collection of a specific part of the products (Elmas & Erdogmus, 2011). Reverse logistics includes disposal options for return products such as reusing, refurbishing, repairing, remanufacturing, reconditioning, cannibalization, and recycling activities (Akdoğan & Coşkun, 2012).

Product recovery activities consist of reusing, repair, reconditioning, refurbishing, cannibalization, remanufacturing, and recycling. Disposal, incineration, and landfilling processes are used for non-recyclable products in waste management (King et al., 2006). Repair, reconditioning, refurbishing, and remanufacturing are related to the renewal or repair of the product. These processes differ depending on the quality of the worn or used product, and they are used for product upgrade (Andrew-Munot et al., 2015). Cannibalization is about using a small portion of used products. Moreover, recycling is about the reuse ofmaterials that could be the raw material of another product. These are used for product recovery (Mahapatra et al., 2013). Disposal means that the product can be recycled to a waste state. In addition, incineration and landfilling are other disposal methods (Andrew-Munot et al., 2015). The aim of these processes is to use parts of the worn or used product in another product. The processes are used for waste management (Mahapatra et al., 2013). While flow is approaching from consumer to raw material, damage to the environment is increasing and its contribution to the companies is decreasing. Reuse is the best method in terms of environmental damage (Andrew- Munot et al., 2015).

The reverse logistics processes are separated into three categories which are direct reuse, product recovery and waste management (Brito & Dekker, 2004). Table 1 shows the reverse logistics activities (Brito & Dekker, 2004).

Table 1 Reverse Logistics Activities based on Circular Economy

Direct Reuse	**Product Recovery Management**	**Waste Management**
a. Reuse	b. Repair	h. Incineration

	c. Reconditioning d. Refurbishing e. Remanufacturing f. Cannibalization g. Recycling	i. Landfilling

As shown in Table 1, direct use includes the first step of the returned products. If reuse is not enough for returned products, the other processes are covered under the product recovery management process. Product recovery management includes repairing, reconditioning, refurbishing, remanufacturing, cannibalization and, recycling. Waste management includes incineration and landfilling processes (Assamoi & Lawryshyn, 2012; Brito & Dekker, 2004). It is essential to apply appropriate operations by achieving circularity.

The reverse logistics activities based on circular economy are explained in detail below.

1.7.1. Reuse

Reuse processes require simple operations such as cleaning and checking (Amit Kumar & Holuszko, 2016). There should be no difference between the original product and the partin the re-use process. This method is an environmentally sensitive approach and may also lead to an increase in the company's profitability ratio (Defra, 2018). In summary, re-use means re-use of the product without any action.

1.7.2. Repair

Repair process includes the repair of broken or damaged parts of the used product. (Aneesh & Kumar, 2019). Repairs to the product are usually carried out by replacing damaged parts. The process for the re-functionalization of damaged products is called repair. The quality of the finished product is lower than the new product (Amit Kumar & Holuszko, 2016).

1.7.3. Reconditioning

It is the process of re-calibrating materials to make a used product new or original (Ifrassen et al.,2019). Refurbished goods are the top model compared to the original product and are generally better than the refurbished ones.

1.7.4. Refurbishing

It is similar to the reconditioning phase. Parts are renewed for the used products by product addition. It is the process of restoring the used product to the specified quality standard (Amit Kumar & Holuszko, 2016). The parts are replaced by technologically better-quality ones. This process is usually applied to expensive products such as aircraft. Not only broken parts, but the old parts of the product can also be replaced with better parts (Ifrassen et al., 2019).

1.7.5. Remanufacturing

The remanufacturing strategy is the most environmentally and economically feasible way for sustainability (Amit Kumar & Holuszko, 2016). The remanufacturing process starts with disassembling and inspection, and then completed by the assembly and final inspection. For each part, the technical team decides to repair or destroy the product. Remanufacturing is a comprehensive examination of the used parts of a used product, and the product is completely disassembled to perform the necessary operations to obtain a quality product as a new product (Amit Kumar & Holuszko, 2016). On the other hand, it is one of the most complicated steps in the reverse logistics process as the reproduction process requires much more labour than other processes (Soleimani & Govindan, 2014).

1.7.6. Cannibalization

Contrary to the reuse, repair, refurbishing, and remanufacturing, in the cannibalization process, only a small portion of the product can be reused. The parts which can be used from the obsolete product are obtained and used in the repair, remanufacturing or refurbishing of other products or components (Aneesh & Kumar, 2019).

1.7.7. Recycling

Recycling is the exploitation of original products or the production of them outside the original product by separating usable products and parts from used ones (King et al., 2006; Amit Kumar & Holuszko, 2016). In the recycling process, the material is recovered without preserving the structure of the product (Zhou et al., 2019). Materials suitable for recycling can be recycled into the economy with recyclable materials (Amit Kumar & Holuszko, 2016). In addition to the economic benefit, one of the most important benefits of recycling is the reduction of environmental pollution (Fleischmann, 2000; Yang et al., 2020).

There are steps to be followed in the recycling process in order to reduce environmental impact and make economic contributions based on circular approaches. These stages are collection, separation, evaluation, and introduction of a new product into the economy (Yang et al., 2020). Collection phase involves the collection of wastes in a particular area, regardless of the process (Isernia et al., 2019). At this stage, the waste can be brought to the consumer, taken from the consumer, or firms. In separation phase, the products and parts collected in the collection phase must be separated. In addition, undesired substances mixed into the collected products and parts are eliminated at this stage (Thi et al., 2019). Evaluation phase is a process of recycling materials to contribute to the circular economy of the enterprise. Lastly, the process of introducing a new product into the economy is the start-up phase of a recycled product (Fleischmann, 2000).

1.7.8. Disposal & Incineration & Landfilling

At the disposal stage, the necessary processes are made for the products which cannot be reused. The invalidity of a waste or scrap results from the fact that its technical or economic reuse does not create any value or is not worth processing (Wilson et al., 2006). In addition, incineration is another disposal method when there is a non-recyclable product and provides energy recovery (Yi & Ma, 2019). If a product is to be destroyed, incineration should be preferred. On the other hand, the landfilling process is the last way to be preferred. This method is the greatest damage to the environment (Assamoi & Lawryshyn, 2012).

Electrical and electronic products are one of the most important parts of the global economy and are affected by technological developments in the world (PACE, 2019). With the inclusion of these products in the circular economy and the lack of proper recycling operations, these products fall into the category of products that have become the most waste. Therefore, in the following chapter, electronic waste, problems caused by electronic wastes, and global electronic waste problems are explained in detail.

2. ELECTRONIC WASTE

Today, the population of the world is almost 7,7 billion, and it is predicted to increase in the future. The expected world population is 8.6 billion in 2030 and 11.2 billion in 2100 (Worldometers, 2019a).

Electrical and electronic equipment (EEE) is inseparable from the global economy (PACE, 2019). In a globalized world, the life of electronic products has been shortened due to reasons such as technological developments (automation, i.e.) and changes in consumer wishes (ILO, 2014). Electrical and electronic products that reach the end-of-life phase are changed very frequently because they are considered old (PACE, 2019). Therefore, EEE waste, whose abbreviation is “e-waste”, is the fastest-growing municipal solid waste type with innovations and consumer demands (Needhidasan et al., 2014). For example, recently, it has been announced that more than 237130 billion computers has been sold worldwide, and the rate is increasing day by day (Worldometers, 2019a). Based on the development of a country, the life of a personnel computer is between 2 and 5 years.

E-waste includes toys, entertainment and sporting equipment, monitoring-control equipment, medical equipment, and vending machines, as well as large household appliances, small home appliances, telecommunication and consumer equipment, telecommunication equipment, EEE, and lighting equipment (Forti et al., 2018). The number of unused computers, telephones, televisions, and devices was expected to be doubled between 2009 and 2014, reaching 42 million tons worldwide (Needhidasan et al., 2014). E-waste is the fastest-growing type of waste in terms of environmental effects on the world (Mmereki et al., 2016; Monika & Kishore, 2010). There are many valuable materials that can be gained from recycling activities of e-waste. However, the harmful substances in the e-waste need to be treated before the e-waste is destroyed (Kumar et al., 2017).

2.1. Definition and Categories of E-Waste

E-waste does not have any specific definitions (Widmer et al., 2005). It can be defined as “all electronic and electrical devices at the end of their life” (European Commission, 2014). In other words, e-waste means that “all EEE and parts disposed of by the owner without re-use” (Khan, 2017). Moreover, e-waste is defined as unwanted by their users. E-waste is called WEEE (Waste of Electrical and Electronic Equipment). E-waste covers all electronic and electrical gadgets e.g., computers, televisions, washing machines, mobile phones, refrigerators, air conditioners, photocopiers, etc.

On the other hand, EEE is devised to produce, transmit, measure and, has 1500 Volt direct current limitation or 1000 Volt alternating current, which requires an electric current or electromagnetic field to perform its actual function (EU, 2002).

WEEE has 10 different waste categories (EU,2002). Moreover, according to EU WEEE directives, e-waste can be divided into six different categories. In Table 2, 10 different categories of e-waste are shown.

Table 2 WEEE categories

Label	Categories	Examples
LARGE HH	Large Household Appliances	Refrigerators, Washing Machines, Freezers etc.
SMALL HH	Small Household Appliances	Microwaves, Vacuum Cleaners, Ventilation Equipment, Video Cameras, Electric Kettles etc.
ICT	Telecommunication and Information Technology Equipment	Personnel Computers, Telephones, Global Positioning Systems etc.
CE	Consumer Equipment	Televisions etc.
LIGHTING	Lighting Equipment	LED, Fluorescent etc.

E AND E TOOLS	EEE	Handheld Drills, Saws, Screwdrivers
TOYS	Leisure, Sports Equipment and Toys	PlayStation etc.
MEDICAL EQUIPMENT	Medical Equipment	Radiotherapy equipment, Cardiology Equipment
M&C	Controlling and Monitoring Equipment	Smoke detector, Heat regulators, Thermostats
DISPENSERS	Automatic Dispensers	Cash Dispensers, Hot and cold bottle dispensers

The lifetime profile of each product shows differences based on their waste quantities, environmental impacts, economic values, etc. Moreover, the logistics operations and recycling activities are different for each type of e-waste. Therefore, the collection, recycling, and logistics processes should be managed appropriately for e-wastes (Balde et al., 2017). The Large HH, Small HH, ICT, and CE constitutes almost %90-%95 of all produced e-waste (Balde et al., 2017).

The classification of e-waste is based on the end-of-lifecharacteristics, the similarity in functions, and comparable material composition (Balde et al., 2017). Recently, a WEEE classification listing has been created by UNU, and named as UNU-KEYS (Balde et al., 2017; Forti et al., 2018). The UNU-KEYS consists of all EEE in the list with codes. Some examples of UNU-KEYS are: 0102 Dishwashers (large household equipment), 0104 Washing Machines (large household equipment), 0403 Music Instruments (consumer equipment), 0505 LED Lamps (lighting) (Forti et al., 2018).

E-waste, which is heterogeneous complex structure, consists of more than 1000 components (Widmer et al., 2005). These components are separated as ‘hazardous’ and ‘nonhazardous'. E-wastes consist of plastics, ceramics and concrete, plywood and wood, and others (Chatterjee, 2012; Ding et al., 1998). While steel and iron are composed of about 50% of e-waste, plastics constitute 21% of e-waste, and nonferrous metals which include aluminium (Al), precious metals, e.g. gold, palladium, silver, copper (CU) contain about 13% and others (Ding et al., 1998; Needhidasan et al., 2014; Widmer et al., 2005). If e-waste includes hazardous materials e.g., arsenic, selenium, mercury, cadmium, etc., it is classified as hazardous waste (Chatterjee, 2012).

2.2. Environmental Problems Caused by E-Waste

Most of the e-waste is hazardous because of its components such as mercury (Hg), chromium (Cr), arsenic (As), flame retardants, etc. and if sustainable recycling or disposal system is not implemented, it has a great environmental impact (Drahansky et al., 2016; Vetrivel & Devi, 2012). The collecting, and disposal of e-waste are crucial problems for the environment. Especially in emerging economies, e-waste is one of the most significant issues due to the lack of an insufficient recycling system and knowledge about the process of the system (Drahansky et al., 2016). This improper recycling system can cause a high toxic release in the atmosphere, ecosystems, and water (Khan., 2017). For example, according to the ECCC (2016) Report, only 1 gram of lead makes almost 20.000 litres of water unusable.

Effect on water:

- Keeping e-waste in storage areas causes valuable elements to leak into the environment (*E-Waste Training Manual*, 2018).

Effect on air:

- E-waste pollutants are emitted by dust in the air. It is the most dangerous and comprehensive way of exposure. Therefore, living beings are exposed to these pollutants through their mouth or nose (Valley & Coalition, 2014).

Effect on soil:

- Each pollution ends in soil and, improper e-waste management damages the natural mineral structure of the soil (Adesokan et al., 2016).

Therefore, recycling or disposal of e-waste using insufficient technologies and lack of knowledge to gain more profit is harmful to soil, air, water, and directly to human health, which makes it a social problem (Heacock et al., 2016; Khan., 2017).

2.3. Social Problems Caused by E-Waste

All substances are not hazardous for society, such as electronic components including only metals and alloys and free of active glass or hazardous capacitors (Friege, 2012). However, e-waste can have the most hazardous components as shown in Table 3. These substances affect human health directly (Perkins et al., 2014). The examples of the effects of heavy metals and substances in e-waste on people are shown in Table 3 (Ikhlayel, 2018; Ohajinwa et al., 2017).

Table 3 Health Problems Caused by E-Waste

Substances	Effects on People
Cadmium (Cd)	Kidney Diseases
Lead (Pb)	Brain Damage
Mercury (Hg)	Brain Damage & Kidney Diseases
Chromium (Cr)	Asthma & DNA Damage
Phosphorus (P)	Risky in breath when the substance occurs
Barium (Ba)	Muscle Weaknesses & Cardiac and Liver Diseases
Beryllium (Be)	Carcinogenic

Furthermore, improper management systems of e-waste affect not only society but also workers in e-waste or similar sectors (Wolf et al., 2018). These workers may have tuberculosis, infant mortality, blood and brain damages, cancer, etc.

Moreover, the social impacts of lack of proper management of e-waste (recycling, collection, disposal, treatment) are increasing the informality of disposal centres, lack of knowledge about technology opportunities, etc.

2.4. Economic Problems Caused by E-Waste

E-waste does not only have environmental and social impact but it also has economic impacts on the communities and the world. Since the rapid increase in economic growth, the consumption and production of EEE have gone up (Needhidasan et al., 2014). Therefore, proper e-waste management have become an economic problem in the world. One of the biggest problems in e-waste management (recycling, collection, treatment etc.) is the need for high financial investment (Mmereki et al., 2016). Therefore, especially in emerging economies, e-waste management is organized in an illegal way.

Furthermore, e-waste includes valuable metals such as Silver (Ag) and Gold (Au) substantially (Drahansky et al., 2016). Most of these precious materials are contained in consumer equipment, communication equipment and entertainment equipment, etc. For example, a personal computer includes 1 g of gold (Bleiwas & Kelly, 2001).

As mentioned before, EEE, which is a crucial secondary source with precious metal contents, includes gold, the most precious metal (Sarja, 2015). Nowadays, in the production process of EEE, the rate of gold used in EEE has decreased by 4 times compared to the old EEE such as computers (Charles et al., 2017). Therefore, it is essential to adopt the circular economy approach to deal with e-waste problem in the EEE industry.

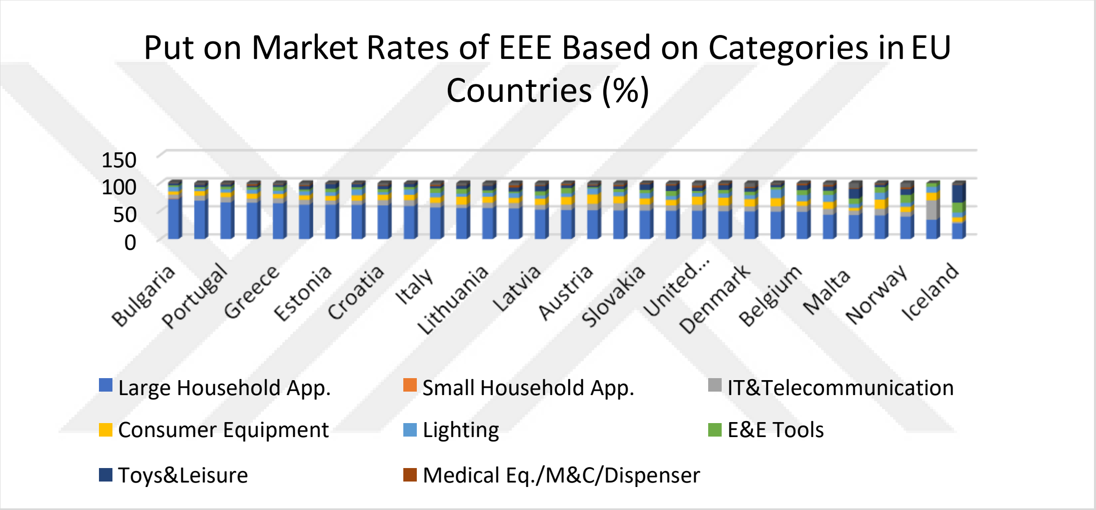
2.5. Global E-Waste Problem

EEE provides a practical and straightforward life for humans. Recently, with the globalization and increasing technological environment, the consumption and production of EEE have increased. In the world, approximately 45 million tons of WEEE are generated (Balde et al., 2017). Furthermore, 44.7 million metric tons of these devices are disposed of, and

20% of them are recycled (Balde et al., 2017). For example, according to statistics, while 57% of the world used mobile phones in 2015, in 2019, 63% did. In addition, the number of mobile phone users in the world was 5.1 billion in 2018 (Kemp, 2019). WEEE generation has astrong relationship with the gross domestic product, and especially in emerging economies, the amount of generation per capita is increasing continually (Işıldar et al., 2019).

In the following figure, the total put on the market rate of EEE is shown.

Figure 3 Total Put on Market Rate of EEE (Eurostat (env_waselee))



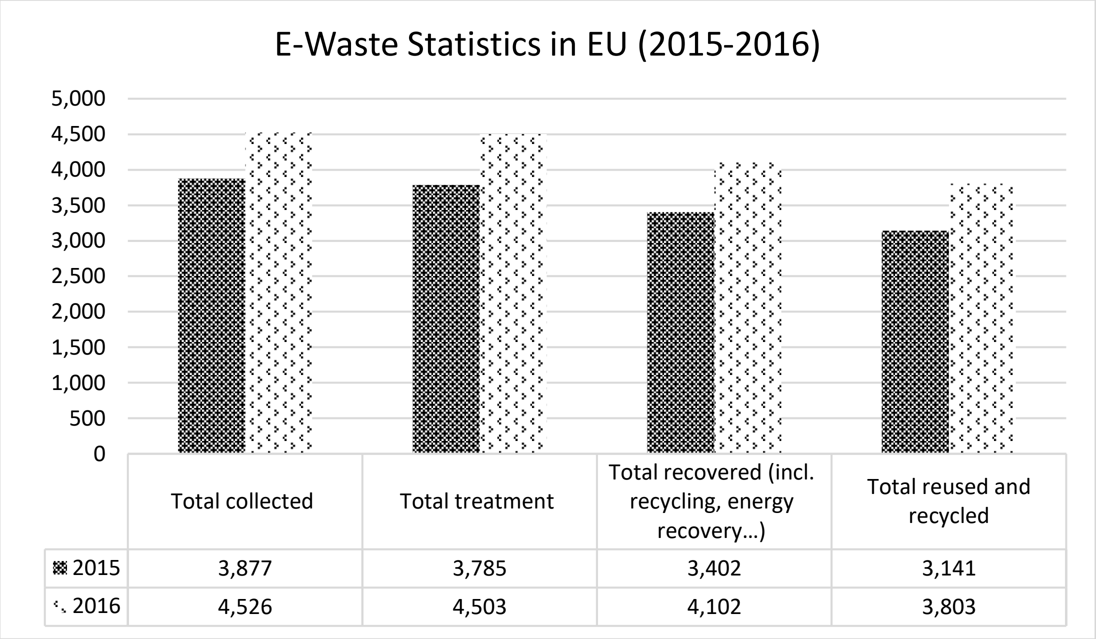
As shown in Figure 3, the total put on the market rate of EEE is 10095 tonnes in 2016. The most widely introduced product category is the large household appliances in 2016. It is calculated that in all EU countries, the most significant proportion of large household appliances belongs to Bulgaria with 74.4% in 2016 (European Commission, 2019). The average EU level was 53%. Moreover, the second-largest category about put on the market rate is calculated as IT and Telecommunication category in EU countries and the average of the category corresponds with almost 11%. The rates continue to go up in the world (European Commission, 2019).

Furthermore, besides increasing consumption and production of EEE, the proper management of this equipment became a crucial issue since it consists of toxic substances. It is accepted that proper management of e-waste is a global challenge (Mihai & Gnoni, 2016; Perkins et al., 2014). Therefore, the process of collection, treatment, recycling and disposal of WEEE need consideration to avoid hazardous consequences (Zeng et al., 2015). Furthermore, the amount of approximately 50 million tons of e-waste generated every year in the world is only 5% of the total solid waste, but 70% of the hazardous waste accumulated in landfills (Mmereki et al., 2016).

In this respect, the perspective should be developed. The improper management systems of e-waste, including collection, treatment, recycling, and, disposal are applied by many countries in the world and threatening human health and environment (Heacock et al., 2016). In other words, when WEEE is not recycled correctly, it releases hazardous substances that have contrary effects on the human health and environment (Needhidasan et al., 2014).

In Figure 4, from the reverse logistics perspective under the circular economy approach, the amount of total collected waste in EU countries was 4526 tonnes in 2016 with a 17% increase while the amount of total treatment rate of waste was 4503 tonnes with almost a 20% increase (European Commission, 2019). Moreover, recovery processes increased from 2015 to 2016, with a total amount of 4102 tonnes in 2016 and with a 20% increase. In addition, the total reuse and recycling rate has increased by 20% percent (European Commission, 2019).

Figure 4 E-Waste Statistics in EU (Eurostat (env_waselee))



	Total collected	Total treatment	Total recovered (incl. recycling, energy recovery…)	Total reused and recycled
▩ 2015	3,877	3,785	3,402	3,141
⁘ 2016	4,526	4,503	4,102	3,803

Therefore, statistics show that reverse logistics activities remained from 2015 to 2016. Moreover, according to statistics in Table 5, as aforementioned above, the rate of collected waste is increasing year by year.

Figure 5 Waste Collected in EU Countries (kg/capita) (Eurostat (env_waselee))

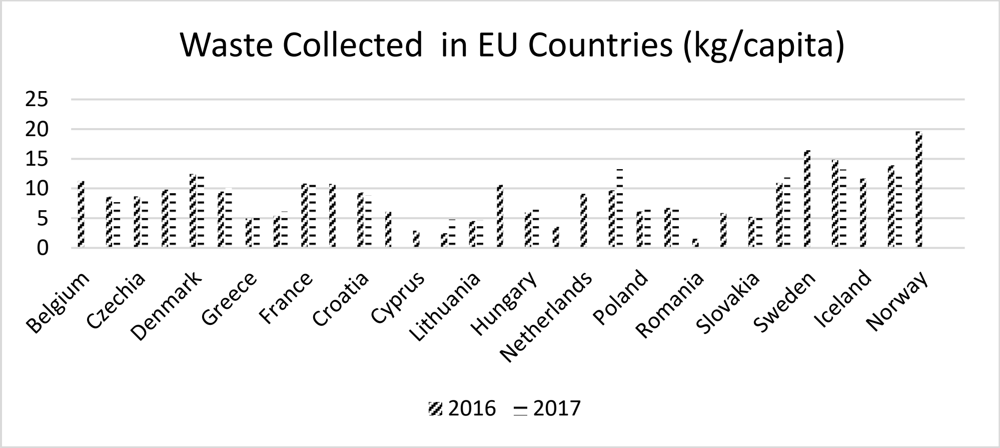
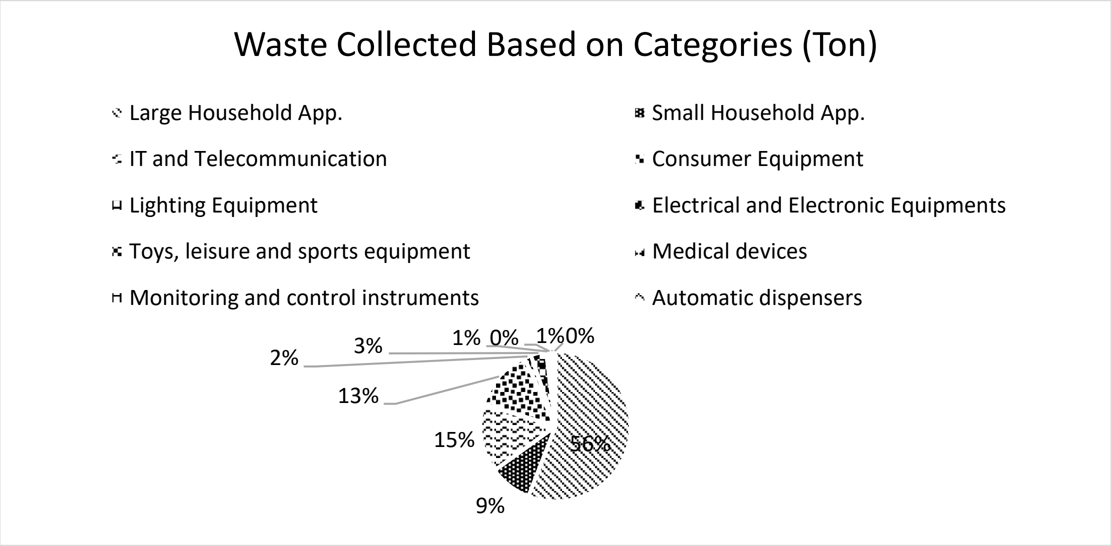


Figure 5 indicates the amount of collected waste (kg/capita) in EU countries between 2016 and 2017. Countries without 2017 data are shown as single columns. Among the EU countries, Norway (19,6 kg/capita), Sweden (16,45 kg/capita) and Liechtenstein (13,1 kg/capita) are shown as the countries having the most collected waste in 2016, respectively. Moreover, although the amount of waste collected from some countries such as the UK and Iceland decreased in 2017, it has almost doubled in some countries such as Austria.

Figure 6 Waste Collected Based on Categories (ton) (Eurostat (env_waselee))



Considering the categories of WEEE, Figure 6 shows the amount of waste collected by the equipment category. The total amount of collected waste is calculated by almost 4.5 million tons overall in EU countries. According to the data, in the total number of wastes, there are 2342109 tons of large household appliances. This number corresponds to 56% of total waste. Moreover, IT and Telecommunication category is the second most collected waste category with a share of 15%. Furthermore, for other categories, the ranking continues as consumer equipment (13%), small household appliances (9%), EEE (3%), lighting equipment (1,5%), monitoring (0,76%), toys, leisure and sports equipment (0,56%), automatic dispensers (0,35), and medical equipment (0,32%).

Especially in emerging economies, the current policies created by emerging economies have failed in the informal recycling process (Perkins et al., 2014). In this process, emerging economies continue to carry out informal practices taking the economic return into consideration. This results in environmental consequences, toxic release, human health problems, and economic losses (Heacock et al., 2016; Zeng et al., 2015). Therefore, it is important to embark on reverse logistics operations based on circular economy approach.

Furthermore, due to market share growth, improvements in features of EEE and new marketing strategies, the lifetime of EEE is decreasing day by day. As mentioned before, the EEE becomes scrap for different reasons such as reaching the end-of-life phase, being fusty, breaking down, etc. and it becomes WEEE (Forti et al., 2018). Moreover, the useful life of EEE is different from the technological life of EEE. For example, the functional life of a desktop computer is 10 years, but the technological life of it is 2 years; or the functional life of a washing machine is 10 years, but the technological life of it is 6 years (Bauer et al., 2020). These differences cause waste of these pieces of equipment due to “marketing strategies” although their life continues.

In addition, due to the continuous increase in the number of e-wastes, the most commonly used recycling methods for filling are incineration, burning, and reuse of the solid and usable ones (Ferronato & Torretta, 2019). However, e-waste use as a filling material causes pollution of groundwater, damages on people, and air pollution. In the US, only 10% of e-waste is recycled (Needhidasan et al., 2014). Therefore, most developed countries prefer to export or donate their hazardous e-waste to poor Asian and African countries (Ferronato & Torretta, 2019).

As mentioned before, e-waste is a crucial global problem related to the environment, society and economy. Therefore, it is vital to create new policies and adopt circular economy approach to avoid environmental, social and economic problems caused by improper management of WEEE.

3. LITERATURE REVIEW ABOUT E-WASTE IN REVERSE LOGISTICS

E-waste is a global problem, and it gains more attention due to environmental and economic concerns. In Global E-Waste Monitor Report (2017), it is stated that almost 45 Mt of E-Waste were produced in 2016 and only 20 percent of these wastes could be collected (Balde et al., 2017).

The tremendous environmental and economic effects lead to the importance of end-of-life phase treatment of products. From this point, reverse logistics activities based on circular economy perspective including recycling, reuse, remanufacturing, and reconditioning gain more attention. Circular economy is an essential approach for waste management, and it provides economic, environmental and social benefits (Tjahjono and Ripanti, 2020). As mentioned before, reverse logistics is an approach under the circular economy concept. Reverse logistics starts with the collection of products from the end users and management of these returned products through the activities i.e. recycling, remanufacturing, repairing, and disposing (Govindan et al., 2015). Therefore, e-waste recycling industry is mainly based on reverse logistics activities.

One of the most fundamental elements of waste management is the recovery or recycling of WEEE (European Commission, 2015). Recovery of WEEE represents recovery of waste, reuse of waste or processing for the purpose of creating a new product/raw material applying various processes of reverse logistics (Cole et al., 2019). The purpose of recovery and recycling processes is to eliminate the possible toxic components of WEEE’s recyclable parts and precious metals (Sarja, 2015). Moreover, recycling means the recycling of WEEE into a product or raw material through a physical or chemical process (Needhidasan et al., 2014; Sarja, 2015).

Recently, there have been serious problems in the management of WEEE in the world, especially in collection and recycling processes (Zhao & Yang, 2018). Therefore, new practices for collection and transportation systems, recovery and recycling of WEEE should be developed considering human health and environment (Cole et al., 2019).

3.1. Literature Review

E-waste in reverse logistics is one of the crucial working areas to understand the e-waste processes under the reverse logistics activities. It is crucial to know the current status of e-waste in countries to provide solutions for reverse logistics problems in e-waste management (Ceballos & Dong, 2016). Therefore, there are many studies to analyse current status and management process of e-waste in different countries. These studies are focused on e-waste management, reverse logistics activities for e-waste, and global e-waste status as shown in Table 4.

Table 4 Literature Review about E-Waste in Reverse Logistics

Author(s)	**Methods**	**Focused Area in Reverse Logistics**
Terazono et al. (2006)	Desk Research	E-Waste Issues in Asia
Mou et al. (2006)	Fuzzy Multi Factor	Regional E-Waste Status
Babu et al. (2007)	Desk Research	Global E-Waste Problem
Kahhat et al. (2008)	Desk Research	E-Waste Management in US

Lau & Wang (2009)	Case Study	Electronic Product Manufacturers in China
Chatterjee (2012)	Proposed Model – Holistic Approach	Recycling Processes of E-Waste
El-nakib (2012)	Exploratory Methodology	Electronic Waste Recycling
Li & Tee (2012)	Integer Multi-Objective Linear Programming	Two E-Waste Sectors
Dat et al. (2012)	Mathematical Programming Model	Reverse Logistics Costs in E-Waste Operations
Kiddee et al. (2013)	Life Cycle Assessment (LCA), Material Flow Analysis (MFA), Multi Criteria Analysis (MCA), Extended Producer Responsibility (EPR)	Global E-Waste Problem
Kang (2014)	Desk Research	E-Waste Management in Supply Chain
Elbadrawy et al. (2015)	Genetic Algorithm	Reverse Log. Optimization
Gupt & Sahay (2015)	Case Study	Regulations and Legal Policies of

Extended Producer Responsibility

Fernando & Rupasinghe (2016)	Qualitative Research & Case Study	E-Waste in Reverse Logistics
Demajorovic et al. (2016)	Qualitative and Exploratory Research	Industrial Economies
Telecommunications Management Group Inc. (2017)	Desk Research	E-Waste Management Policies
Balde et al. (2017)	Report	Global E-Waste Statistics
Doan et al. (2017)	Mixed Integer Linear Programming	Reverse Supply Chain in E-Waste Operations
Aneesh and Kumar (2019)	Network Design	Used Refrigerators
Asante et al. (2019)	Desk Research	E-Waste Recycling
Isernia et al. (2019)	The Probability Transition Matrix	E-Waste Management in Reverse Logistics
Kumar (2019)	Extended Theory of Planned Behaviour	E-Waste Recycling Behaviour
O’Farrell & Wright (2019)	Case Study	Data Centres
Sabbaghi et al. (2019)	Estimation	E-Waste Recovery Systems

Shevchenko et al. (2019)	Literature Review	Consumer Behaviour in E-Waste

Thi et al. (2019)	Network Design	Reverse Supply Chain in E-Waste Operations
Wang et al. (2019)	Modelling	Pricing Strategy & Government Subsidies
Bolat et al. (2019)	Artificial Neural Network (ANN)	WEEE in Turkey

To start with, Terazono et al. (2006) analysed the current e-waste status in Asia based on 3R (reduce, reuse, recycle) concepts. For sustainable development, future researches are considered. Moreover, Babu et al. (2007) discussed e-waste generation and classification using the recycling concept and the recycling activity was analysed for India. In this study, environmental problems caused by e-waste are focused on to find proper management of e-waste. Furthermore, Telecommunications Management Group Inc. (2017) prepared a report about e-waste management regulations which includes personal computers (desktops and laptops), mobile phones, TV sets, cathode-ray-tube (CRT), and flat panel display monitors for Saint Lucia.

Balde et al. (2017) prepared “Global E-Waste Monitor, 2017” with the collaboration of International Solid Waste Association (ISWA), International Telecommunication Union (ITU) and United Nations University. “Global E-Waste Monitor 2017” report includes guidelines on e-waste management for countries. What is more, Kiddee et al. (2013) analysed e-waste management based on collection process of e-waste, recycling or other activities that are less hazardous for society and other e-waste policies. In this study, extended producer responsibility is proposed to find solutions to e-waste problems.

On the other hand, there are various studies about e-waste in reverse logistics using different mathematical models. For example, Isernia et al. (2019) analysed e-waste management processes from the sustainability and circular economy perspectives. With the study, they tried to determine the current management system in Italian organizations. Moreover, Chatterjee (2012) examined the ways of sustainable recycling processes and e-waste management in emerging economies. In this study, it is stated that a sustainable recycling method is needed for e-waste management. Therefore, a proposed recycling model is organized in the study.

Furthermore, Li and Tee (2012) used an integer multi-objective linear programming about reverse logistics for recovery options in terms of economic, health and environmental issues caused by e-waste. In this study, two main waste sectors are taken into consideration, which are informal waste sector and formal waste sector. Moreover, Mou et al. (20016) with fuzzy multi factor analysis and Elbadrawy et al. (2015) with genetic algorithm and Bolat et al. (2019) with ANN made crucial contributions to the literature.

Besides, there are different studies about the same issue using qualitative and exploratory research. Demajorovic et al. (2016) studied on reverse logistics in e-waste for industrial economies. In this study, challenges and opportunities are analysed for a Brazilian model. In addition, in this study, emerging economies are discussed with the help of qualitative and exploratory research. At the end of the study, it is analysed that programs which are organized for RL activities provide advantages not only economical but also environmental and social for emerging economies. Similarly, El-Nakib (2012) analysed disposal of end-of-life products in Switzerland and Egypt to compare collection and financing processes for recycling. In this study, exploratory research is used to compare e-waste recycling processes in these two countries. In addition, Gupt and Sahay (2015) analysed the policies of extended producer responsibility (EPR) for returned products. They used exploratory research to make an analysis of three aspects of EPR such as taking back responsibility, regulatory systems, and financial situations. Similarly, Fernando and Rupasinghe (2016) prepared a paper about e-waste generation under the concept of reverse logistics using qualitative research method and case study.

E-waste in reverse logistics is an important issue since the amount of e-waste is increasing and world conditions are changing. Considering literature, there are several studies addressing the e-waste in reverse logistics from different perspectives such as government subsidies (Wang et al., 2019), regulations and policies (Kahhat et al., 2018), data centres in e-waste management (O’Farrell & Wright, 2019), electronic product manufacturers (Lau and Wang, 2009), consumer behaviours about e-waste (Shevchenko et al., 2019) and supply chain processes of e-waste in reverse logistics (Kang, 2014; Thi et al., 2019). Moreover, Aneesh and Kumar (2019) prepared a network design for e-waste in reverse logistics processes. Besides, Doan et al. (2017) analysed risk conditions in reverse supply chain for e-waste recycling process and Dat et al. (2012) examined the reverse logistics costs in e-waste operations. Kumar (2019) analysed e-waste recycling behaviour of consumers using extended TPB model and cross-cultural analysis. In addition, Sabbaghi et al. (2018) made a contribution to the literature by estimating and mapping global flow of electronic products in e-waste recovery system.

3.2. Problem Definition

E-waste has rapid increase in the worldwide and as mentioned before, every year approximately 45 million tons of WEEE are generated in the world (Silveria et al., 2020). While some of the e-wastes generated in developed countries are recycled to the circular economy, some are sent to some of the emerging economies (such as Pakistan, India) for disposal (Park et al., 2017).

Emerging economies, which already generate a lot of e-waste, also suffer environmental, social and economic damage with the e-waste they receive from abroad (Garlapati, 2016). As well as emerging economies, recycling of e-waste, reuse, repair is unsatisfactory for reasons such as technological infrastructure and state regulations for such applications transition into circular economy (Ghilsellini et al., 2016). In addition, while operations such as repair and reuse, which are among the highest levels of reverse logistics operations, are implemented in developed countries (Namias, 2013), emerging economies are unable to implement the recycling activities, which is the previous stage before disposal (Ferranota and Torretta, 2019). Generally, e-wastes of economic value are seen as scraps and sent to the trash or burning facilities in emerging economies. The utilization of these wastes under the concept of reverse logistics and their recycling into the circular economy is extremely important for the country's economic development, environmental and social improvement (Preston and Lehne, 2017).

In order to find permanent and sustainable solutions, firstly, the size of the e-waste in emerging economies should be analysed in the coming years, and then challenges that affect the failure of the recycling activity, which is the previous stage of disposal from reverse logistics activities, should be determined.

This study is a generic model that can be applied to all emerging economies. However, to find answers of the mentioned research question, Turkey, which is one of the emerging economies and mobile phone, which is one of the types of e-waste are discussed in this thesis.

Three important issues are emphasized as a research question. First of all, the future state analysis of an emerging economy will be analysed. Secondly, the challenges for recycling of e-waste in emerging economies will be determined and lastly, the causal relationship among the challenges to recycling of e-waste will be analysed.

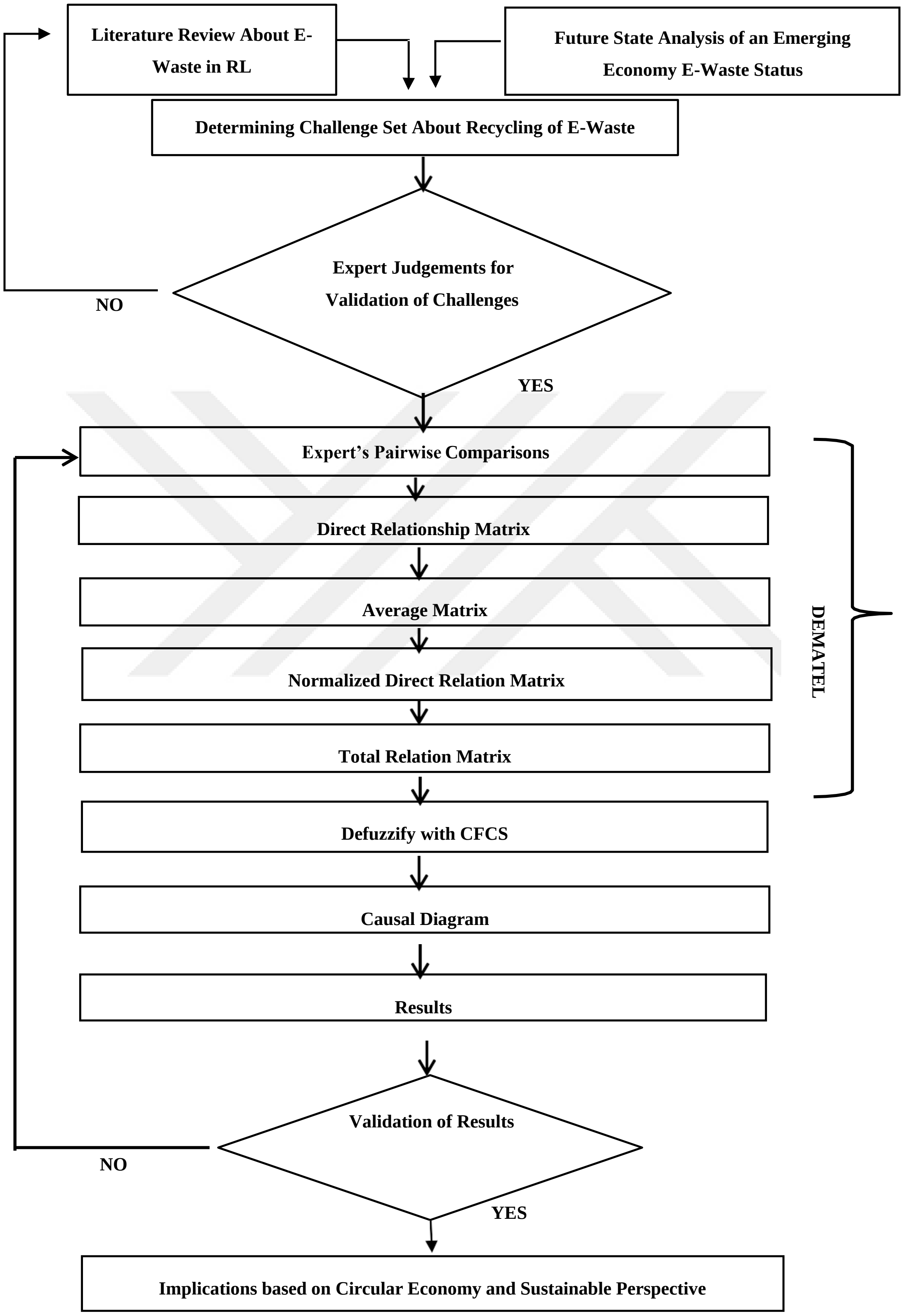
In the following section, proper research framework and methodology of the study are explained in detail.

4. RESEARCH FRAMEWORK AND METHOLODOGY

As mentioned before, e-waste problem is critical issue for emerging economies. With the globalizing world order and technological developments, the amount of e-waste continue to increase day by day. Therefore, it is important to know the amount of e-waste in emerging economies in the coming years in order to find sustainable solutions based on the integration with the circular economy and reverse logistics operations.

For this purpose, the methodology of this thesis covers future state analysis of an emerging economy with Grey Prediction, determining challenge set, verification and refining these challenges, determining final version of challenge set, implementation of Fuzzy DEMATEL as a case study and sustainable based implications as shown in Figure 7 as a flow chart. First of all, a prediction has been made in order to determine the future situation, which is the first of the research questions. After that by analysing the future e-waste status of an emerging economy by Grey Prediction and considering literature review, the challenges of e-waste recycling activities are determined to find answer second research question of this thesis. After verification and refining of the challenge set, final version of it is determined. Moreover, Fuzzy DEMATEL is implemented for challenges of recycling activities of a specific product which is mobile phone in this thesis. After validation of the results, at the end of the study, circular economy and sustainable based implications are given based on results of the implementations.

Figure 7 Flowchart of the Study



According to flow chart, firstly, Grey systems are analysed to find answer for first research question. After that, Fuzzy DEMATEL is explained respectively.

4.1. Grey Systems

The grey system theory was proposed by Ju-long Deng in 1982 for limited data and uncertain systems (Hsu, 2011; Slavek and Jovic, 2012). In 1982, Ju-Long Deng published “Control Problems of Grey Systems” article to mention grey system theory. The article was the first article which explained grey system theory (Liu et al., 2012). For complex systems, i.e. lack of information, limited data, lack of operational mechanism, grey system is practical for a solution (Liu and Forrest, 2007). Agriculture, economy, government data, human body etc. are included in grey system theory (Deng, 1989). Grey systems can be applied in industry, ecological systems, education, economy, management problems, geography, history, ecology, and military conditions etc. (Huang, 1994; Liu and Forrest, 2007; Hui et al., 2013; Köse and Taşçı, 2015). Furthermore, The Grey method has several applications that can be used for multi-criteria decision making (MCDM) problems. The main aim of the theory is to analyse the relation between proposed models and complex conditions i.e. uncertainty, lack of data, chaotic environments.

After development of grey system theory, in 1989, “The Journal of Grey System” was published in England. Moreover, in 1996, Chinese grey system society was founded in Taiwan. After that, “Journal of Grey System Association” was published in Taiwan. Following this, the “Journal of Grey System Association” was translated into English in 2004. Furthermore, “Grey Systems: Theory and Application” which was a new article, was published in England in 2011 (Liu et al., 2012).

Grey system is defined by grey number which defines known and unknown information with the term of white, grey and black (Deng, 1989). Where “white” means fully known information, “black” means unknown information and “grey” means partially known information which includes limited data and uncertain conditions (Deng, 1989). Grey numbers are represented with $\otimes$ (Deng, 1989).

Grey system theory encompasses 6 fields of the grey systems which are grey generating, grey relational analysis (GRA), grey model (GM), grey prediction, grey decision making, and grey control (Liu & Lin, 2010). The systems are explained briefly below.

4.1.1. Grey Generating

The grey generating involves converting irregular raw data into a regular series (Deng, 1989). The model covers 4 parts which are grey relational generating operation, accumulated generating operation, inverse accumulative generating operation, and localization generating. Grey relational generating operation consists of adding new information based on system needs and in accumulated generating operation, data accumulated operation is used to decrease randomness of data. Inverse accumulative generating operation is the anti-operation of accumulated operation. Localization generating is used to reconstruct data when there is missing data.

4.1.2. Grey Relational Analysis (GRA)

Grey relational analysis (GRA) which determines the indefinite relations between all given factors and a main factor in the system is an impressive measurement method (Fang et al., 2018). With using small procedures, the approximate correlation between sequences can be measured by the GRA (Tsao, 2009). The method can be applied to many fields such as traffic and education to select the appropriate input variables (Jangra et al., 2010).

4.1.3. Grey Prediction

Traditional prediction methods based on i.e. multivariate regression, simple regression, time series analysis often require statistical analysis as to follow a certain distribution of data (Liu and Yang, 2017). Moreover, it is often impractical to use large sample sizes or comply with statistical assumptions. Therefore, the methods are not preferred to use when there is limited data set and uncertain data. In other words, Grey prediction is more practical for prediction when there is uncertain and complex systems and small sample size (Deng, 1989; Hu et al., 2017). The method requires only four datato predict (Köse and Taşçı, 2015; Şen and Demiral, 2016; Liu and Yang, 2017; Hu et al., 2017). Moreover, grey prediction is appropriate prediction due to reduce randomness of data since using accumulated generating operation

(AGO) its ability to an unknown system using a limited number of data points (Hu et al., 2017). Grey prediction can be used in social sciences, management, engineering, agriculture, geography, economy and other fields (Tien, 2009; Delcea and Scarlet, 2010; Hsu, 2011; Zhou, 2013).

The main characteristics of grey prediction methods that needs small sample size and to be practical for chaotic and non-linear problems (Liu and Forrest, 2007; Tien, 2009; Köse and Taşçı, 2015). As mentioned before, another crucial characteristic of grey prediction method is using AGO since AGO helps to decrease randomness (Hu et al., 2017).

4.1.4. Grey Model: GM

The grey system theory was developed by Ju-long Deng in 1982 (Slavek et al., 2012). Grey system defines incomplete and missing information. Grey system theory provides a multidisciplinary approach that can work in cases where information is incomplete and inadequate (Taşçı et al., 2016). The grey model has demonstrated the practicality of using an inadequate database because it can identify such an unknown system and predict efficiently based on a few variables (Zeng et al., 2016). Therefore, it is more practical than other traditional methods (Liu et al., 2007; Taşçı et al., 2016).

GM model has different model constructions such as GM (1, N), GM (0, N) and GM (1,1) (Li & Li, 2019). There are different prediction models in the literature such as GM (0, N), GM (1,1), remnant GM (1,1) (Zeng et al., 2016). However, GM (1,1) model is the most widely used model to estimate sequences in grey system theory (Yang et al., 2018).

4.1.4.1. GM (1,1)

Avariable of 1st degree shown as GM (1,1) which is called as “Grey Model First Order One Variable” is used to predict the Grey model (Yang et al., 2018). The variation within the system is used by GM (1,1) model to find relationships between consecutive data and then construct the prediction model (Forrest, 2013).

There are six main steps in GM (1,1) model and those are presented below:

Step 1: The utilization of initial dataset.

The original dataset is shown as:

$$x_0=(x_1^0,x_2^0,\ldots..x_n^1) \qquad (1)$$

Where x_0 refers to a non-negative sequence and n is accepted as sample size of dataset. x_0 k≥ 0$k = 1,2,\ldots..,n$

The presented sequence is referred to the Accumulating Generation Operation (AGO), that refers to the cumulative sum of x_0 series, where in the sequence x_1 is found as below.

Step 2: x_0 series changes monotonically to going up x_1 series by using AGO in the second step. Sigma is utilized in the equation, which is shown below, in order to calculate x_1.

$$x_k^1 = \sum_{i=1}^{k} x_i^0 \qquad (2)$$

x_1 is found as below, after implementing AGO formula:

$$x_k^1 = x_1^1, x_2^1, \ldots., x_n^1 \qquad (3)$$

Step 3: After obtaining x_k^1 series, z_k^1 should be found. The generated mean sequence z_k^1 of x_k^1 is presented as follow.

$$z_k^1 = 0.5x_k^1 + 0.5\,x_{(k-1)}^1 \qquad (4)$$

k = 1,2,…..,n

By using the given formula, z_k^1 is found as following:

$$z_k^1 = 0.5x_k^1 + 0.5\,x_{(k-1)}^1 \qquad (5)$$

Step 4: The corresponding grey equation may be calculated by using parameters a and b, after structuring the required GM model (Yang et al., 2018). In this study, Least Square Method is used to calculate a and b. Equations are given below:

Using Equation 6, all values are substituted as Equation (7).

$$b = x^{0}_{(k)} + a z^{1}_{k} \tag{6}$$

$$x^{0}_{(2)} = a z^{1}_{2} + b$$

$$x^{0}_{(3)} = a z^{1}_{3} + b$$

……………………

$$x^{0}_{(n)} = a z^{1}_{n} + b \tag{7}$$

In order to find a and b, below matrices should be structured by using given formula:

$$Y = \begin{matrix} x^{0}_{2} \\ x^{0}_{3} \\ x^{0}_{n} \end{matrix} \qquad B = \begin{matrix} -z^{1}_{2} & 1 \\ -z^{1}_{3} & 1 \\ -z^{1}_{n} & 1 \end{matrix} \tag{8}$$

After that the matrix method is used to calculate a and b parameters by Equation (9).

$$\alpha = [a, b]^{T} = (B^{T}B)^{-1}(B^{T}.Y) \tag{9}$$

Step 5: Grey differential equation is needed to calculate the predicted value of the initial data at time (k + 1).

$$x^{1}_{(k+1)} = \left[x^{0}_{1} - \frac{b}{a}\right] e^{-ak} + \frac{b}{a} \tag{10}$$

Inverse Accumulating Generation Operation is essential in order to control the calculated data by using Equation 11 (Kayacan et al., 2010).

Step 6: For the 6th step of GM (1,1) model, predicted values of the initial data set are found.

$$x^{0}_{(k+1)} = x^{1}_{(k+1)} - x^{1}_{k} \tag{11}$$

$k = 1,2,.....,n$

Step 7: Error Analysis in GM (1,1) Model

For calculating the error rate between the predicted and the actual value, error analysis is needed in GM (1,1) model. Given equation must be used when k=l, l+1,…,n-1 (Yılmaz et al., 2013) for calculating percent error average, where, x^0_k shows the initial value and $\hat{x}^0_k$ shows the predicted value of the dataset (Yılmaz et al., 2013).

$$e(k+1) = \left|\frac{x^0_{(k+1)} - \hat{x}^0_{(k+1)}}{x^0_{(k+1)}}\right| x\ 100\% \qquad (12)$$

4.1.5. Grey Decision Making

Grey decision making provides to make decision in “whitening” of status by using decision models (Wang et al., 2007). It is crucial to form a satisfactory strategy through impact measurement maps that transfer instances of mismatch from different objects to the same scales (Forrest, 2013). There are three decision making models such as grey rules of situation, grey decision-making group and grey programming.

4.1.6. Grey Control

The grey control system tries to develop behaviour by considering the data of system behaviours and predicting future behaviour (Slavek & Jovíc, 2012). The specified value can be fed back to the system to ensure control of the system.

To find answer for second research question of this thesis, Fuzzy DEMATEL is applied for challenges about recycling e-waste. Therefore, in the following par, the methodology of the Fuzzy DEMATEL is explained.

4.2. Fuzzy DEMATEL

DEMATEL technique is a multi-criteria decision-making method developed by Fontela and Gabus in 1973 (Pamucar et al., 2018). DEMATEL, like other multi-criteria decision-making methods, is used in the analysis of the problem of experts' opinions and experiences (Si et al., 2018). It deals with the relationship between cause and effect and provides an evaluation of the strength of the relationship between the criteria (Yazdi et al., 2020). In this method, the complex relationship between the criteria is visualized on the graph and it is possible for decision makers to evaluate the relations between the criteria more easily (Si et al., 2018).

In the method, the criteria are divided into two as the affecting and the affected group (Falatoonitoosi et al., 2014). In this way, it is possible to analyse what criteria decision makers can indirectly improve other criteria (Zhang et al., 2019). Therefore, the criteria that have more impact on the problem solution can be determined and the number of criteria in the problem can be reduced to a lesser extent (Pamucar et al., 2018).

The uncertainties in the structure of real-life problems and the difficulty in digitizing the verbal assessment methods are resolved by applying fuzzy methods (Gharakhani, 2012; Ziemba et al., 2020). Here, the relationship values that the decision makers evaluate with verbal expressions can be translated into numerical expressions by expressing them with the help of fuzzy numbers (Yazdi et al., 2020). The triangular fuzzy number method is a fairly common method to apply the fuzzy DEMATEL and the data can be used by converting it into net values (Wu & Lee, 2007).

The steps of fuzzy DEMATEL are listed as follows;

Step1: Determination of Factors, Creating Fuzzy Scale and Determination of the linguistic scale with fuzzy numbers

At this stage, n factors which are evaluated by m decision makers to solve the problem are determined (Wu & Lee, 2007). Depending on the type of problem, which factors should be chosen should be decided by taking the opinions of the decision-makers or using the literature (Yazdi et al., 2020). Significant relationships between determined factors are created by decision makers (Feng & Ma, 2020).

When making binary comparisons between factors by decision makers, it is not possible to determine exactly how effective one factor is on another factor (Wu & Lee, 2007). Therefore, linguistic expressions of the comparisons using fuzzy scale is more practical. Fuzzy scale is arranged using triangular or trapezoidal fuzzy numbers corresponding to linguisticexpressions (Yazdi et al., 2020). Linguistic expressions are shown as in Table 3.

Table 3. Linguistic Scale with Fuzzy Numbers

Linguistic Expression	Triangular Fuzzy Numbers
No	(0,0,0.25)
VL	(0,0.25,0.5)
L	(0.25,0.5,0.75)
H	(0.5,0.75,1.0)
VH	(0.75,1.0,1.0)

Step 2: Creating a Fuzzy Direct Relationship Matrix

In order to create a fuzzy direct relation matrix, binary comparisons are made between factors by using linguistic expressions. Therefore, a factor the effect on another factor is tried to be measured (Tsai et al., 2015). Since there are p decision makers, p direct relationship matrix is obtained (Lin, Wang, & Tseng, 2009). The direct relation matrix is denoted by "Z" and it is obtained by averaging these matrices as shown in Equation 1.

$$\tilde{Z} = \begin{bmatrix} 0 & \tilde{z}_{12} & \dots & \tilde{z}_{14} \\ \tilde{z}_{21} & 0 & \vdots & \vdots \\ \vdots & \ddots & \vdots & \vdots \\ \tilde{z}_{41} & \dots & \dots & 0 \end{bmatrix}$$

$$\tilde{Z} = \frac{\tilde{Z}^1+\tilde{Z}^2+\tilde{Z}^3+\cdots+\tilde{Z}^P}{P} \quad (1)$$

Step 3: Creating a Normalized Direct Relationship Matrix

By the use of Equations 2 and 3, the fuzzy direct relationship matrix is normalized. $\tilde{X}$ refers to the normalized direct relationship matrix (Falatoonitoosi et al., 2014).

$$\tilde{X} = \begin{bmatrix} \tilde{X}_{11} & \dots & \tilde{X}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{X}_{n1} & \dots & \tilde{X}_{nn} \end{bmatrix}$$

$$\tilde{X}_{ij} = \frac{\tilde{z}_{ij}}{r}\left(\frac{l_{ij}}{r}, \frac{m_{ij}}{r}, \frac{u_{ij}}{r}\right) \quad (2)$$

$$r = max_{1\le i\le n}\left(\sum_j^n u_{ij}\right) \quad (3)$$

Step 4: Total Relationship Matrix

After obtaining the normalized direct relationship matrix, the total relationship matrix will be created by using equation 4. As shown below, Equation 4 is done by treating fuzzy triangular numbers (l, m, u) as a separate matrix for each and combined in a single total relationship matrix, denoted by $\widetilde{T}$. (Başhan and Demirel, 2019).

$$\tilde{T} = \tilde{X} + \widetilde{X^2} + \widetilde{X^3} + \cdots = \sum_{i=1}^{\infty} \widetilde{X^I} = \tilde{X}\left(I - \tilde{X}\right)^{-1} \quad (4)$$

$$X_l = \begin{bmatrix} 0 & \dots & l_{1n} \\ \vdots & \ddots & \vdots \\ l_{n1} & \dots & 0 \end{bmatrix} \quad X_m = \begin{bmatrix} 0 & \dots & m_{1n} \\ \vdots & \ddots & \vdots \\ m_{n1} & \dots & 0 \end{bmatrix} \quad X_u = \begin{bmatrix} 0 & \dots & u_{1n} \\ \vdots & \ddots & \vdots \\ u_{n1} & \dots & 0 \end{bmatrix}$$

Step 5: Defuzzification

The total fuzzy relationship matrix, consisting of triangular numbers, is defuzzied. Therefore, the following matrix $\widetilde{T^{def}}$ is attained (Kang et al., 2019).

$$\widetilde{T^{def}} = \begin{bmatrix} t_{11}^{\widetilde{def}} & \dots & t_{1n}^{\widetilde{def}} \\ \vdots & \ddots & \vdots \\ t_{n1}^{\widetilde{def}} & \dots & t_{nn}^{\widetilde{def}} \end{bmatrix}$$

In this thesis, the CFCS method is used to rinse the total fuzzy relationship matrix. This method will be described below. The CFCS method was developed by Opricovic and Tzeng (2003) for multi-criteria decision making. As shown below, this method reaches certain value in four steps.

Normalization:

$R = max_j\, u_{ij}, L = minl_{ij}$ and $\Delta = R - L$

The following equation will be calculated for each alternative:

$$x_{lj} = \frac{l_{ij}-L}{\Delta},\ x_{mj} = \frac{m_{ij}-L}{\Delta}, x_{uj} = \frac{u_{ij}-L}{\Delta} \quad (5)$$

Calculation of Left (ls) and Right (rs) Normalized Values:

$$x_j^{ls} = x_{mj}/(1 + x_{mj} - x_{lj}) \text{ and } x_j^{rs} = x_{uj}/(1 + x_{uj} - x_{mj}) \quad (6)$$

Calculation of Total Normalized Values:

$$x_j^{crisp} = \frac{\left[x_j^{ls}\times\left(1-x_j^{ls}\right)+x_j^{rs}\times x_j^{rs}\right]}{\left[1-x_j^{ls}+x_j^{rs}\right]} \quad (7)$$

Calculation of Certain Value for $\tilde{f}_{ij}$:

$$\tilde{f}_{ij}^{crisp} = L + x_j^{crisp} \times \Delta \quad (8)$$

Step 6: Determining $D_i + R_i$ and $D_i - R_i$ values

From the values of the total relationship matrix: the sum of the row elements gives D_i while the sum of the column elements gives R_i. Thus, $D_i + R_i$ and $D_i - R_i$values are calculated. The $D_i + R_i$ value indicates the degree of significance that the i factor plays in the system. The factor that has the greater value of the $D_i + R_i$ is in more relation (Kang et al., 2019). On the other hand, criteria with $D_i - R_i$ positive values are in the sender groups and affect the other criteria. On the contrary, criteria with $D_i - R_i$ negative values are in the recipient groups and are affected by the other criteria (Başhan and Demirel, 2019).

As mentioned before, although this thesis is organized to applied on all emerging economies, Turkey is discussed as an emerging economy in this thesis. Therefore, in the following part, Turkey is discussed.

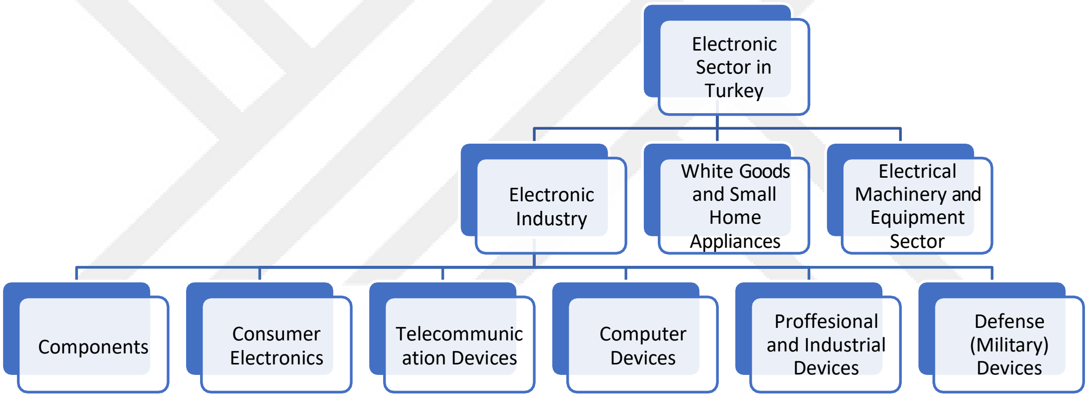
1. E-WASTE PROBLEM IN TURKEY

Turkey's current population was calculated as more than 83 million in 2019 (Worldometers, 2019b) . GDP in Turkey was calculated as 771.27 billion $ in 2018 (Republic of Turkey - Ministry of Trade, 2018) and GDP per capita in Turkey was calculated as 8,957.89 $ in 2019 (Statista, 2019). The electronics sector in Turkey has begun to develop with the introduction of colour TV and the increase in investments on telecommunication industry in the 80s (Republic of Turkey - Ministry of Trade, 2018).

With R&D studies and the demand of export markets, the export rate of the electronics sector is increasing in Turkey. Turkish electronic industry had 10.25 billion $ of export and 26,5 billion $ of import in 2017 (*Turkish Trade Ministery Report*, 2019). The countries with the largest share in the exporting countries are England, Germany and France, respectively (*Turkish Trade Ministery Report*, 2019). The main products exported are electrical machinery and energy group, white and brown goods, and panels. Moreover, China, Germany and Vietnam are the most importing countries and the most imported product were components, integrated circuits and telecommunication equipment in 2017 (*Turkish Trade Ministery Report*, 2019).

In Turkey, electrical and electronic sector are dealt with 3 main headlines which are electronic industry, white goods and small home appliances, electrical machinery and equipment sector. Sub-sectors are shown in Figure 8 (Republic of Turkey - Ministry of Trade, 2018).

Figure 8 Electrical and Electronic Sector in Turkey



5.1. Electronic Industry

Electronic sector of Turkey is divided in three main groups; electronic industry, white goods and small home appliances, electrical machinery and equipment sector.

5.1.1. Component Sub-Sector

Component is a sub-sector that includes all kinds of products used in device manufacturing. Components that are relevant to all sub-sectors of electronics are also important parts of the sectors such as automotive, measuring instruments, medical and analytical instruments, watches, photography devices, optical instruments and transportation (*Turkish Trade Ministery Report*, 2019). Circuit components (resistance, capacitor, etc.), print circuits, tuners, remote control devices, fasteners, thick film circuits, relays, and device cables are some of products of component sub-sector.

5.1.2. Consumer Electronic Sub-Sector

Audio and visual products and accessories used by end-users of consumer electronics are the products and product groups of this sub-sector (Republic of Turkey - Ministry of Trade, 2018). Televisions, video devices, audio devices, antennas and amplifiers, satellite receivers, cash register, POS devices, electronic calculators, and monitors are the main products and product groups that constitute the consumer electronics sub-sector (Republic of Turkey - Ministry of Trade, 2018).

5.1.3. Telecommunication Devices Sub-Sector

With its rapid development, the telecommunications sector is one of the most important driving forces of the information and automation era (Bakanli et al., 2017; Deloitte, 2012). Main power stations, wireless telephone systems such as GSM and DECT, telephone machines, multiplex devices, radio link systems, fibre optic line equipment, data modems / radio modems, mobile and fixed radios, fibre telecom cables, distribution frames, information technology are the main products and product groups that make up the telecommunication devices sub-sector (Solsvik & Dao, 2014).

5.1.4. Computer Devices Sub-Sector

Computer devices cover the devices forming the processor side of information technologies (Rouse, 2019). Computing machines and related units, accessories, software, data centre infrastructure hardware and software are the main products and product groups that constitute the sub-sector of computer devices (Rouse, 2019).

5.1.5. Professional and Industrial Devices Sub-Sector

Professional and Industrial Devices consist of devices used to ensure the realization and control of production processes, together with information technologies (Republic of Turkey - Ministry of Trade, 2018). Uninterruptible power supplies, converters, inverters, motor speed control devices, rectifiers, automation systems, automotive electronics, taximeters, tachometers, signalling and alarm systems, vehicle tracking systems, medical electronics, measurement and test instruments sound and display systems, security systems are the members of professional and industrial devices (Republic of Turkey - Ministry of Trade, 2018).

5.1.6. Defence (Military) Electronic Sub-Sector

For the armed forces, in addition to the human element, the defence industry constitutes the biggest driving force and force multiplier that develops and manufactures tactical, strategic and defence weapon systems and hardware and software for the armed forces (Armed & Foundation, 2016). Radio communication systems, electro-optic equipment, radars, fire control and guidance systems, electronic warfare, friend / enemy recognition devices, navigation devices, command control terminals, simulator and training systems, mine search detectors, defence software, crypto, defence electronics sub are the main products of the sector (Republic of Turkey - Ministry of Trade, 2019).

5.2. White Goods Sector & Small Home Appliances

The sector produces electrical household appliances. White goods sector has 25-million-unit production capacity and 21-million-unit production in Turkey (Ozkul, 2011). Therefore, in the last 10 years, the sector has become a very important production base, and Turkey has become the leading country in the European white goods industry (Durables, (n.d.). White goods sector in Turkey which has an innovative structure, advanced technology, and employment performance of the economy with the support it provides to the country is located in the locomotive industry (Ozkul, 2011). Turkey serves foreign trade surplus by exporting two-thirds of the production of white goods sector. 95% of white goods sold in Turkey are produced in our country (Republic of Turkey - Ministry of Trade, 2019). Nearly 75% of white goods produced in 2018 were exported (Republic of Turkey - Ministry of Trade, 2019).

White goods sector mainly includes refrigerator, oven, washing machine, dishwasher, and air conditioning (Ozkul, 2011). The main products in the electrical appliances sector are electric kitchen appliances, water heaters, food robots, grinders, cutters, and conditioners, hair dryers, vacuum cleaners, ventilators, irons, electric heaters, electric ovens and electric stovetops (Uppal, 2020).

5.3. Electrical Machine Devices Sub-Sector

The sector of electrical machinery and equipment consists of machines operating with one of the effects of electric power, electric field and magnetic field, which function in the production, transmission, distribution and use of electric power, and electrical energy transport units and their auxiliary units (Eurostat, 2013).

Main products of this sector are electric motors and generators, transformers, insulated wires and cables, batteries, accumulators, electrical distribution and control equipment, lighting equipment, and electric lamps (Eurostat, 2013).

In the following part, e-waste problem in Turkey is explained in detail.

5.4. E-Waste Problem in Turkey

Every year approximately 50 million tons of e-waste is generated in the world (Balde et al., 2017). In Turkey, 539 thousand tons of e-waste, especially mobile phones, televisions are created every year and this number is increasing every year by 10 percent. According to statistics, Turkey is ranked the 17^{th} for generating 503 thousand tons of e-waste (Balde et al., 2017). However, as a result of developing technology and changing consumer needs, the ratio is increasing day by day like some other emerging economies (Needhidasan et al., 2014). Furthermore, while electronics sector in the world and Turkey is growing, the proportion of e-waste in the garbage is increasing rapidly. In developed countries, e-waste accounts for an average of 1% solid waste (Bhutta et al., 2011).

As shown in Table 5, 503000 tons of e-waste occurred in 2014, 523000 tons in 2015, 528000 tons in 2016 and 539000 tons in 2017. The amount of collected e-waste was 22000, 28000, 55000, 58000 tons in 2014, 2015, 2016, 2017, respectively (TUBISAD, 2019).
Moreover, 6817, 11596, 23027 and 19224 tons of the collected e-waste could be recorded in 2014, 2015, 2016 and 2017, respectively (TUBISAD, 2019). Financial insufficiencies of municipalities, low regulatory targets, insufficient existing collection of infrastructure and lack of awareness of consumers are important obstacles in the low rate of registered collection.

Table 5 The Amount of Generated, Recorded and Collected E-Waste in Turkey

	2014	2015	2016	2017
Generating	503000	523000	528000	539000
Recorded	6817	11596	23027	19224

Collected	22000	28000	55000	58000

70 units in total, 52 of which are licensed, including WEEE processing plant have received a temporary operating certificate (*Republic of Turkey Ministry of Environment and Urbanisation,* 2016). Currently, there are no licensed WEEE processing facilities in high-populated and industrialized provinces such as Adana, Gaziantep, Kayseri and Konya (*Republic of Turkey Ministry of Environment and Urbanisation,* 2016). Furthermore, only 5-10% of the e-waste produced in Turkey are recycled at licensed facilities (Balde et al., 2017).

The amount of generated e-waste according to e-waste categories in 2014 in Turkey is given. E-waste is mostly composed of e-waste of mobile phones, small household devices, large appliances, televisions and monitors, coolers and heaters such as refrigerators and air conditioners, small software appliances and lighting equipment in Turkey (Ozturk, 2014). According to a research conducted by TUBISAD in 2018, e-wastes kept at home were determined as television, computer, mobile phone, camera, respectively (TUBISAD, 2019). This shows that consumers are not conscious of recycling e-wastes.

5.5. Regulations About E-Waste in Turkey and Stakeholders

As in the whole world, the demand of EEE has also been increasing in Turkey for the last 20 years. Policies about e-waste management are inadequate in high population and emerging economies, and also too much waste is generated (Ferronato & Torretta, 2019). The lack of government policies around the world prevents sustainable reverse logistics activities for e-waste (Garlapati, 2016).

5.5.1. Regulations

There are various regulations about WEEE in Turkey. The first attempt on the WEEE management in Turkey in 2004 began to take shape with Matra Project prepared by joint efforts with Dutch government. Subsequently, the Ministry of Environment and Urbanization prepared a draft regulation in parallel with RoHS Directive which was published in the Official Gazette no.26891 in 2008 under the name of “Regulation on the Restriction on Hazardous Substances in EEE” and entered into force in 2009. This regulation aimed to limit the harmful and toxic substances in the content of the produced or imported EEEs and to keep domestic production and importation of EEEs under control with the principle of protecting the human health and environment.

Moreover, in 2012, within the scope of the harmonization of the European Union with the national legislation of the RoHS (2002/95/EC) and the WEEE Directives (200/96/EC), "Regulation on Control of WEEE" was published in the Official Gazette no. 28300 and entered into force. In the following stages, the Ministry of Environment and Urbanization updated the 2012 regulation in line with WEEE Directive 2012/19/EC.

In the following part, stakeholders of e-waste in Turkey are explained in detail.

5.5.2. Stakeholders

The purposes of the waste policies carried out in Turkey are to minimize damage to the environment and society, and to produce and implement new solutions for waste management etc. (Report, 2007). The Ministry of Environment and Urbanization is mainly responsible for all the legal regulations about e-waste.

There are many stakeholders with responsibilities of management of WEEE. The Ministry of Environment and Urbanization is responsible not only for managing the coordination of enterprises, producers, and organizations, but also for supervising the documents prepared by the receiving centres, recycling and recovery for the management of WEEE ("EEE Producers," n.d.).

The metropolitan municipalities are responsible for ensuring the coordination of the activities carried out by the municipalities and contributing to the information and training activities (Report, 2007). Furthermore, municipalities are responsible for the preparation of a plan about e-waste management, presenting it to the Ministry of Environment and Urbanization and providing cooperation between stakeholders for the collection of WEEE (*Sector Operational Programme for Environment and Climate Action*, n.d.).

Authorized Institutions and the Coordination Center are non-profit organizations that are established by the Ministry of Environment and Urbanization (TUBISAD, 2018). The authorized institutions are obliged to prepare and submit a waste management plan to the Ministry of Environment and Urbanization in order to provide recycling, and collection objectives specified in the regulation, to monitor the activities carried out within the framework and to take back all of the WEEE collected in the receiving centres in the municipalities to recycle or have them recycled (Report, 2007; TUBISAD, 2018). Turkey has three Authorized Institutions: Association of Lighting Equipment Manufacturers (AGID), Association of Electronic Equipment Producers and Recyclers (ELDAY) and Turkey Informatics Industry Association (TUBISAD) (Kurtagic et al., 2015).

The biggest responsibility for the separate collection processes belongs to EEE producers. Producers are responsible for taking the financial burden of transporting, recovering or disposing of these wastes from collection centres which will be established by municipalities, and where consumers can leave WEEE free of charge, import and disposal (Report, 2007).

The EEE producers are defined in the regulation as follows:

- Producing and selling electrical and electronic product under its own brand,
- Producing electrical and electronic products by other suppliers and selling under its own brand,
- Real or legal persons importing electrical and electronic products for commercial purposes (TUBISAD, 2018).

Furthermore, processing plants are facilities that are responsible for purification, dismantling, shredding, and waste recovery activities.

Lastly, consumers are the institutions and individuals that use EEE to create e-waste (TUBISAD, 2018). Consumers are obliged to separate WEEE from household waste according to the principles set out by municipalities and producers, and to take the WEEE to the collection points/dispatch centres of distributors, producers or processing facilities (Kahraman, 2014).

With growing e-waste in Turkey, it is essential to find solutions to reduce and manage generated e-waste. Therefore, first of all, it is important to understand current reverse logistics operations for e-waste in Turkey. In the following part, e-waste in reverse logistics in Turkey is explained in detail.

5.6. E-Waste in Reverse Logistics in Turkey

With the rapidly increasing population, the level of consumption is rising, and production is also increasing. As a result, the sustainability of natural resources has become very important for industrialized societies (Ferronato & Torretta, 2019). This increase in production creates waste. One of the released hazardous waste categories is the WEEE, which is increasing with population and technological developments. These wastes contain materials that can threaten human health and the environment. They contain recyclable materials; however, they are not disposed of properly. In Turkey, the number of firms that consider reverse logistics activities are very little (Altug et al., 2012).

In emerging economies, e-waste is collected separately, and instead of disposing them together with other wastes, they are disposed of in other ways (Abdel-Shafy & Mansour, 2018). Separate waste collection system in Turkey are not fully spread and all waste goes to the same place. In some provinces, recycling with a separate collection system is installed in directly in homes, and all kinds of waste are separated and evaluated in central garbage collection centres (Report, 2007). On the other hand, in some other provinces and districts, the garbage is sold by tender method and the garbage that is useful for reverse logistic operations is separated and evaluated by the companies/responsible organizations.

After WEEE is collected, it is sent to processing facilities (TUBISAD, 2018). Although these facilities are defined as recycling facilities, they disassemble WEEE and decompose the disassembled parts according to the components they contain, such as copper, iron, and chromium (Kahraman, 2014). WEEE, which is separated into production materials in these facilities, is sent to production facilities for recycling (TUBISAD, 2018). Separation in some branches of WEEE is a process that can be called easy for materials such as iron and copper (Report, 2007). However, it is difficult to access rare items in the parts of mobile phones and electronic boards and this process requires high investment and high technology (TUBISAD, 2018). Turkey's efforts in this area are inadequate, so e-waste cannot be evaluated within the country and particularly the parts that cannot be recycled back into the economy in Germany, and France are exported to different countries including Belgium (Report, 20017).

To find answer of the first research question, the amount of e-waste in Turkey is forecasted to have knowledge about future status of e- waste in Turkey in the following section.

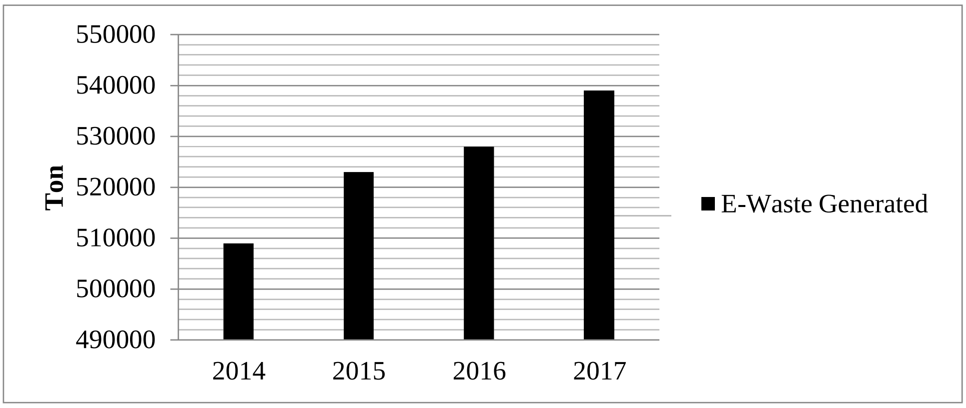
2. PREDICTION E-WASTE IN EMERGING ECONOMIES: CASE OF TURKEY

As mentioned before, Turkey is an emerging economy and there are deficiencies due to factors such as the country's technological infrastructure for waste management, legal arrangements, lack of consumer awareness. E-waste, is rapidly increasing in Turkey as well as in the world. Management of e-waste, recycling, collection and sorting out is a complicated issue in Turkey. In addition, data such as e-waste amounts, product-based waste rates are not kept regularly in the country. This situation creates difficulties in obtaining and analysing data for the researches to be conducted. In this study, the amount of e-waste produced in 4 years could be reached sequentially. For this reason, in this study, GM (1,1) model, which can work in complex and complex structures and with only 4 data, was applied.

In order to understand the future state of e-waste in Turkey and how much to increase in the coming years, the amount of e-waste generated in Turkey, which are the answers of the first research question are calculated. Therefore, the GM (1,1) method is used.

As shown in the Figure 1, the amount of e-waste generated in Turkey is increasing from 2014 to 2017. While the amount of e-waste generated was 503000 tons in 2014, it calculated 523000 tons in 2015 and 528000, 539000 in 2016 and 2017 respectively (Ministry of Environment and Urbanization, 2017) as shown in Figure 8 (Ministry of Environment and Urbanization, 2017- National Waste Management and Action Plan, 2016-2023).

Figure 9 The Amount of E-Waste Generated in Turkey (ton)



In the following, the amount of e-waste generated in Turkey is predicted by GM (1,1) model for next 8 years after 2014.

The steps of the implementation of the model are explained in detail.

The actual non-negative data series, which is “ $X_{(0)}$”

$X_{(0)} =$ (503000, 523000, 528000, 539000)

The new $X_{(1)}$ series is calculated with AGO.

$X^{(1)}$ = (503000, 1026000, 1554000, 2093000)

In thefollowingsequence z_k^1 of x_k^1 is found as;

$Z^{(1)}_{(\bar{k})} =$ (764500, 1290000, 1823500)

The Least Square Method is obtained to find a and b values by using Equation (7) in GM(1,1) model. In the following part X, Y and B matrices are found with Equation (8) in GM(1,1) model.

$$Y = \begin{vmatrix} 523000 \\ 528000 \\ 539000 \end{vmatrix} \qquad B = \begin{vmatrix} -764500 & -1 \\ -1290000 & -1 \\ -1823500 & -1 \end{vmatrix}$$

Before using Equation (9) in GM(1,1) model, (BT.B)-1 is calculated.

$$(BT.B) = \begin{vmatrix} 3926253500000,00 & -2717000,00 \\ -2717000,00 & 30 \end{vmatrix}$$

(BT.B)-1 = $\begin{vmatrix} 0 & 0{,}00000062 \\ 0{,}00000062 & 0{,}89300588 \end{vmatrix}$

Equation (9) in GM(1,1) model is calculated to find a and b values and the results are as below:

a = -0,01

b = 523324,72

e = 2.7183

After implementation of the GM (1,1) model, the predicted values are calculated with Equation (11) in GM(1,1) model. The results are shown in Table C. As shown in Table 6, it is expected that the amount of e-waste generated increases further.

Table 6 Predicted Values of Amount of E-Waste Generated in Turkey (ton)

2018	2019	2020	2021	2022	2023	2024	2025
540806	544807	548837	552897	556988	561108,14	565259,10	578188

Table 7 shows actual and predicted values of an amount of e-waste generated in Turkey between 2014-2025 and the error analysis for these years.

Table 7 Actual and Predicted Values of an Amount of E-Waste in Turkey

Years	Actual Value X^0_k	Predicted Value X^1_k

2014	503000	503000
2015	523000	528979
2016	528000	532892
2017	539000	536895
2018	-	540806
2019	-	544807
2020	-	548837
2021	-	552897
2022	-	556988
2023	-	561108,14
2024	-	565259,10
2025	-	578188

As shown in Table 7, the amount of e-waste generated in Turkey continues to go up until 2025. While the amount of e-waste generated in 2017 was 539000, it is expected that the amount of e-waste generated in 2025 will reach 578188 tons.

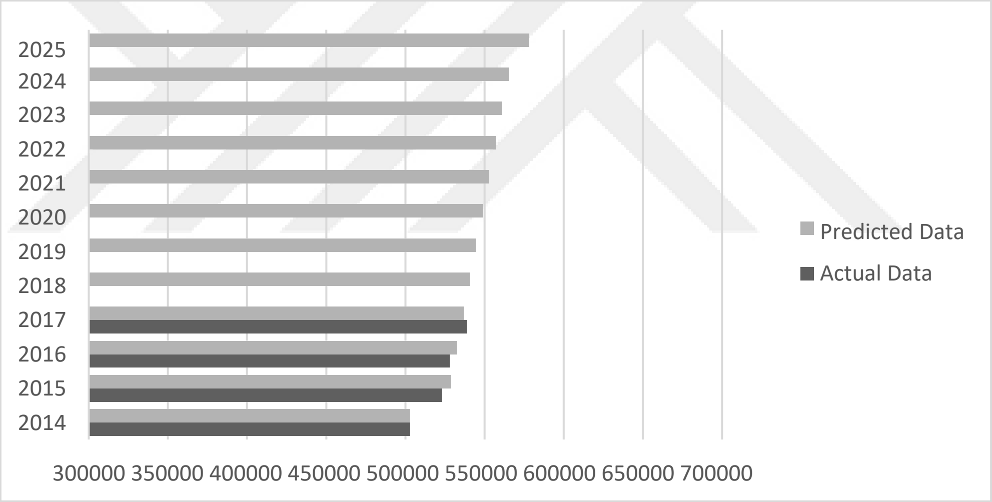
In the following part, Table 8 shows that traditional error results which is defined as Equation (12) in GM(1,1) model. The error analysis represents the difference between actual values and predicted values which is error rate.

Table 8 Traditional Error Analysis (Δ_k)

2014	2015	2016	2017
0% (Accepted)	1,14%	0,93%	0,40%

After calculated traditional error analysis for 2014-2017, average relative error is found as 0,01%. Moreover, Figure 10 shows the comparison between actual and predicted data for 2014-2025.

Figure 10 Comparison between Actual and Predicted Data for 2011-2020



As stated in Figure 10, the amount of e-waste generated in Turkey is increasing year by year. Therefore, to prevent the rapid increase in the amount of e-waste generated, permanent solutions should be taken into consideration.

However, especially in emerging economies, permanent solutions for the reduction of e-waste are insufficient, and recycling activities cannot be carried out effectively for these wastes. Therefore, the challenges of e-waste recycling activities are determined by considering literature review in the following section.

Forecasting based on e-waste situation in Turkey is reaching very serious consequences. For this reason, it is a remarkable issue to examine the difficulties regarding the evaluation of e-waste. Appropriate recycling activities should be implemented in emerging economies, although they are difficult due to lack of infrastructure and information for operations such as reuse and repair of e-wastes. For this reason, determining the challenges that prevent recycling activities in emerging economies is of utmost importance. These challenges are identified and addressed generally for each emerging economy. In the following sections, the results will be specified for Turkey.

3. CHALLENGES IN E-WASTE RECYCLING ACTIVITIES IN EMERGING ECONOMIES

According to forecasted results, the future status of Turkey similarly other emerging economies is alarmingly increasing. Emerging economies are insufficient about managing and recycling of e-waste generated and they confronted many challenges in recycling. In order for these wastes to be transformed into a circular economy, an effective and robust e-waste recycling system should be developed, and the challenges affecting this process should be determined processes. For this purpose, the challenges affecting the recycling of e-waste are specified with expert opinions and literature review.

The challenges affecting the recycling of e-waste are gathered under 7 main headings. These dimensions which are ecological, social, economic, infrastructural and technological, legal, managerial and business, supply chain management dimensions are shown in Table 9.

Table 9 Challenge Set

Challenges of Recycling of E-Waste Products	Author(s)	Explanations
ECOLOGICAL DIMENSIONS		
Environmental hazards because of the toxins contained within electronic products	Needhidasan et al. (2014); Sankhla et al. (2016)	The precious metals contained in the electronic products cause toxic damage by being spread to the environment as a

		result of improper process of recycling.
Insufficient government regulations to prevention the release of toxic substances during the recycling process	Schamne and Nagalli (2016); Lines et al. (2016)	Failure by the government to prevent the release of toxic substances in the recycling process causes recycling activities to be undertaken by ignoring the environment. The release of toxic chemicals from electronic products into the environment cannot be prevented without governmental regulations.
SOCIAL DIMENSIONS		
Health Problems (cancer, liver damage and problems with neurological systems) (cadmium etc.)	Velmurugan (2016)	Workers working in the recycling sector encounter diseases such as cancer and brain damage due to the chemical release during the process.
Unawareness of recycling techniques and their importance	Godfrey et al. (2013); Welfens et al. (2016); Bai et al. (2018); Gunasekaraet al. (2019)	Consumers' ignorance about recycling techniques, their importance and habits such as accumulating electronic products at home prevent the sectoral development.
Lack of trained personnel	Yacob et al. (2012); Welfens et al. (2016); Meyer et al. (2017)	Uneducated and unconscious employees prevent the development of the sector.
ECONOMIC DIMENSIONS		

High costs of high-tech technologies	García-Sánchez et al. (2019)	The high cost of technologies to be used in the recycling process prevents firms from investing.
Lack of investment availability – long term investment	Gunasekara et al. (2019)	Long-term investment is required for recycling processes, which may result in a lack of profit in the long run.
Growing Informal Sector	Williams et al. (2008); Chi et al. (2011); Lines et al. (2016); Kumar and Dixit (2018)	The collection of electronic products in illegal ways (scrap dealers, street collectors) and their use with wrong recycling methods prevent the recycling sector from existing in emerging economies.
Fluctuations in market conditions	ILO (2014); Lucier and Gareau (2019)	Fluctuations in the market of electronic products prevent recycling activities both for producers and consumers.
High discrepancies between income and cost that firms will receive from recycling activities	Perkins et al. (2014); Thi et al. (2019)	Big differences between investment and earnings make companies reluctant to make recycling activities.
Uncertainty of the amount of return products	Shaharudin et al. (2017); Brkljač & Beker (2017)	The fact that the manufacturers do not know the number of products that can be returned for recycling causes the indecision over whether to implement the recycling process or not.
INFRASTRUCTURAL AND TECHNOLOGICAL DIMENSIONS		

Lack of Knowledge about Recycling Technologies	Yacob et al. (2012); Meyer et al. (2017)	Failure to give due importance to the recycling sector in emerging economies also leads to a lack of information about the technologies that should be used. Not knowing these technologies prevents recycling.
Lack of proper infrastructure to deal with the harmful substances arising during the recycling process - Inadequate treatment facilities	Osibanjo and Nnorom (2008); Kumar et al. (2016); Kumar and Dixit (2018); Ceballos and Dong (2016)	Especially in emerging economies, insufficient recycling facilities and the lack of suitable infrastructure to deal with harmful substances arising in the recycling process hinders the progress of the process.
LEGAL DIMENSIONS		
Lack of governmental policies	Rajesh (2011); Kumar and Dixit (2018)	The government needs to make regulations for companies and society to raise awareness about the recycling of electronic products.
Lack of financial and economic incentives	Ravi and Shakar (2005); Yacob et al. (2012); Meyer et al. (2017)	Insufficient economic support for the development of the recycling sector causes companies to be reluctant to recycle. The recycling processes should also be

		supported economically by the government.
Lack of communication between stakeholders in supply chain	Krykawskyy and Fihun, (2015); Mmereki et al. (2016); Ghadge et al. (2017)	Lack of communication between stakeholders in the supply chain affects the entire process negatively, including the collection and separation of electronic products.
MANAGERIAL AND BUSINESS DIMENSIONS		
Lack of awareness of the top management and company policies	Yacob et al. (2012); Brkljač & Beker (2017); Meyer et al. (2017)	The unconsciousness of companies and managers about the recycling of electronic products makes it difficult to learn this sector and follow the practices. Thus, companies do not striveto recycle electronic products.
Lack of green practices in product design for reuse	Gottberg et al. (2006); Ravi and Shakar (2014); Defra (2018)	The fact that the design of electronic products is not suitable for the “reuse” process to be applied, ignoring the circular activities and productivity, harms sustainability and the environment.
Lack of green practices in product design for repair	Krykawskyy and Fihun, (2015); Aneesh and Kumar (2019)	The fact that the design of electronic products is not suitable for the “repair” process to be applied, ignoring the circular activities and productivity, harms sustainability and the environment.

Lack of green practices in product design for reconditioning	Cheng et al. (2019)	The fact that the design of electronic products is not suitable for the “reconditioning” process to be applied, ignoring the circular activities and productivity, harms sustainability and the environment.
Lack of green practices in product design for refurbishing	Cheng et al. (2019)	The fact that the design of electronic products is not suitable for the “refurbishing” process to be applied, ignoring the circular activities and productivity, harms sustainability and the environment.
Lack of green practices in product design for remanufacturing	Gunasekara et al. (2019)	The fact that the design of electronic products is not suitable for the “remanufacturing” process to be applied, ignoring the circular activities and productivity, harms sustainability and the environment.
Lack of green practices in product design for recycle	Fleischmann (2000); Cheng et al. (2019)	The fact that the design of electronic products is not suitable for the “recycle” process to be applied, ignoring the circular activities and productivity, harms sustainability and the environment.
SUPPLY CHAIN MANAGEMENT DIMENSIONS		

Lack of operational integration	Ardente et al., 2014	Integration errors in the collection, separation and recycling processes affect the recycling of electronic products.
Mismanagement in collection and separation process	Elmas & Erdogmus (2011); Thi et al. (2019); Gadajisi et al. (2010); Cayumil et al. (2016); Salhofer (2017)	The collection of electronic products regardless of the content of them and the recycling process to be applied, and the failure to perform the separation process adversely affect the recycling process.

Ecological dimensions cover environmental hazards because of the toxins contained within electronic products (C1) and insufficient government regulations to prevent the release of toxic substances during the recycling process (C2). Social dimensions include health problems (cancer, liver damage and problems with neurological systems) (cadmium etc.) (C3), unawareness of recycling techniques and their importance (C4), and lack of trained personnel (C5).

Economic dimensions cover high costs of high-tech technologies (C6), lack of investment availability (C7), growing informal sector (C8), fluctuations in market conditions (C9), high discrepancies between income and cost that firms will receive from recycling activities (C10), and uncertainty of the amount of return products (C11). In addition, infrastructural and technological dimensions include lack of knowledge about recycling technologies (C12) and lack of proper infrastructure to deal with the harmful substances arising during the recycling process (C13). Legal dimensions involve lack of governmental policies (C14), lack of financial and economic incentives (C15), and lack of communication between stakeholders in supply chain (C16).

Managerial and business dimensions cover lack of awareness of the top management and company policies (C17), lack of green practices in product design for reuse (C18), lack of green practices in product design for repair (C19), lack of green practices in product design for reconditioning (C20), lack of green practices in product design for refurbishing (C21), lack of green practices in product design for remanufacturing (C22), and lack of green practices in product design for recycle (C23). Lastly, supply chain management dimensions include lack of operational integration (C24) and mismanagement in collection and separation process (C25).

4. CAUSE AND EFFECT ANALYSIS OF CHALLENGES OF E-WASTE RECYCLING ACTIVITIES: A CASE STUDY FOR MOBILE PHONES IN TURKEY

In the previous sections of the study, the challenges of e-waste recycling activities were specified with a detailed literature review. According to these challenges, importance and causal relationship between each factor can be determined with the help of a quantitative analysis.

As mentioned before, since mobile phones are one of the most important kinds of e-waste in Turkey, the quantitative analysis, which is Fuzzy DEMATEL, is implemented to determine the importance and causal relationship between each factor for mobile phone recycling processes.

In emerging economies, especially in Turkey, one of the product types that are wasted most is mobile phones. It can be said that mobile phones are the most common category of small electronic devices, especially at the household level (ITU, 2017). A person can have more than one mobile phone and consumers show the ability to change their mobile phones every year. As a result, the life of the usage of mobile phones is shortened. (Sarath et al., 2015). Mobile phones with an average life of 2 years are rapidly becoming e-waste and this is a fact that cannot be ignored since they contain valuable materials such as gold, silver and platinum (Thavalingam and Karunasena, 2016). However, since consumers do not see their mobile phones as waste and they need to have a spare one, the campaigns for cell phone recalls remain low (Sarath et al., 2015).

There were 2.9 billion mobile phone users in the world in 2018, and this number is estimated to reach 3.8 billion people in 2021. Especially China, India and the U.S.A have the highest number of mobile phone users. Moreover, 1.56 billion mobile phones were sold in the world in 2018. Like in the rest of the world, the problem of mobile phone waste is becoming a major problem in Turkey (Statista, 2018).

The number of mobile phone users in Turkey was estimated to be 41.9 million in 2018 and in 2021, this number is estimated to reach 52.8 million. Moreover, approximately 11 million new mobile phones are sold every year. In Turkey, the life of mobile phones is approximately 18 months and almost 1.5-2 million mobile phones become unusable every year (Statista, 2018).

Therefore, in this thesis, the mobile phones are selected as important types of e-waste and the challenges for mobile phone recycling are analysed with Fuzzy DEMATEL method.

In the following section, the methodology of this thesis is explained.

8.2. Expert Justification

The opinions of experienced employees on the subject are extremely important for such studies. For the implementation of the Fuzzy DEMATEL, 8 experts who are specialists in the electrical and electronic sector, IT sector, lighting sector and recycling operations have evaluated challenges for mobile phone recycling. The experts have been working on it for more than 5-years. It is seen that experts have reached a consensus and obtained meaningful results.

The specifications of the experts are given in Table 10.

Table 10 The Specifications of Experts

Expert	Area of Expertise	Sector	Position	Experience	Gender
1	Electrical and Electronic Engineer	Lighting Sector	Project Engineer	5	Male
2	Industrial Engineer	IT Sector	Service Delivery Engineer	5	Female

3	Electrical and Electronic Engineer	Consumer Electronics	R&D	6	Male
4	Industrial Engineer	IT Sector	Software Test Engineer	6	Female
5	Industrial Engineer	E-Waste Recycling Company	Project Engineer	7	Female
6	Industrial Engineer	Lighting Sector	R&D	8	Female
7	Environmental Engineer	E-Waste Recycling Company	Project Engineer	12	Male
8	Computer Engineer	IT Sector	R&D	5	Male

The implementation of the study is conducted via face-to-face meetings with the 8 specialists in the mobile phone recycling.

In the following part, the implementations and result of the study are given.

8.3. Implementation of Fuzzy DEMATEL

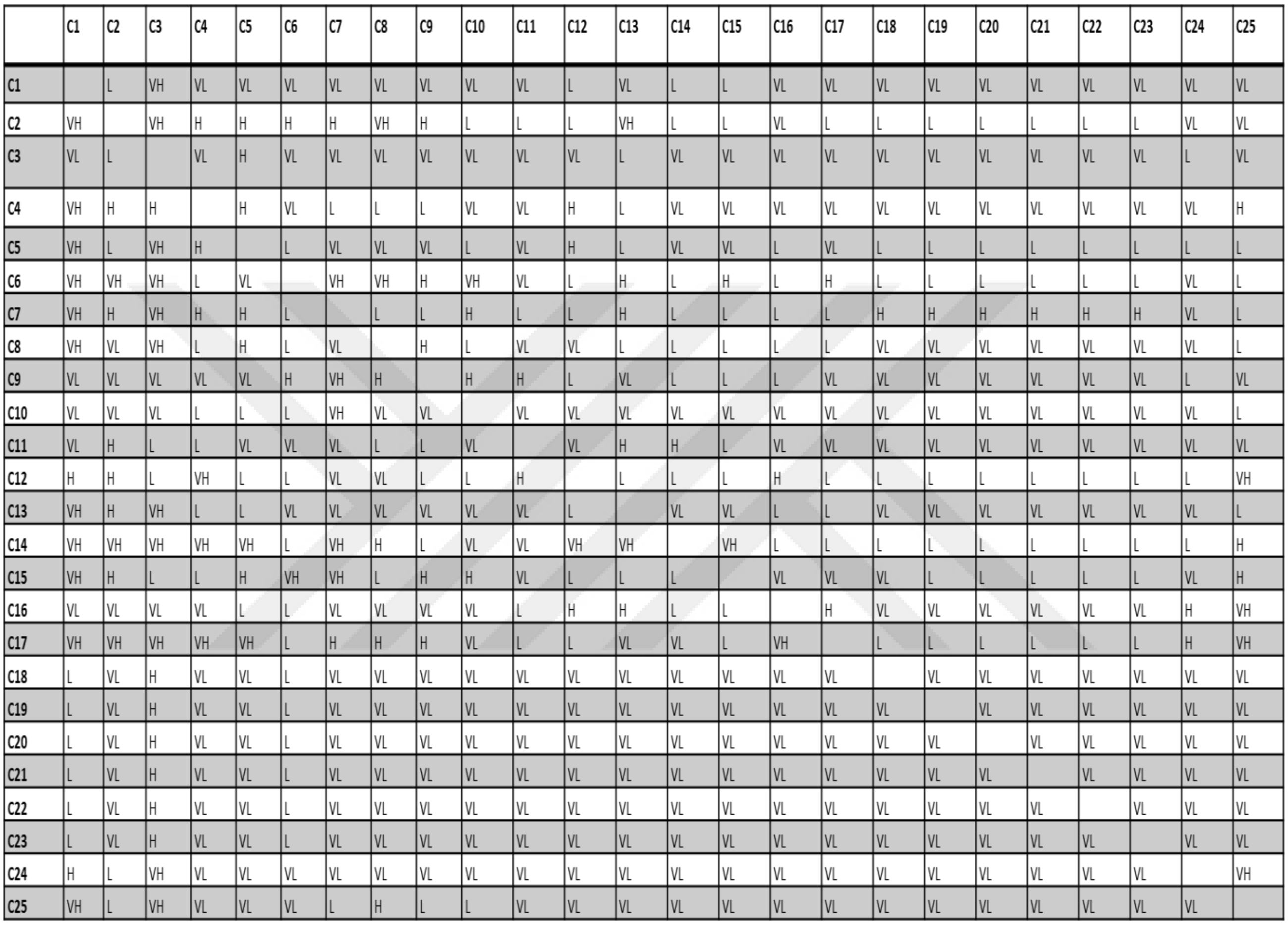
The DEMATEL method is a method used to create and analyse a structural model showing causality relationships between complex factors (Gabus and Fontela, 1972). Moreover, the method provides visual representation of the relationship between the criteria and an accurate evaluation with the help of the effect-relationship diagram (Chang, 2011).

As real-life problems involve complex structure, the degree of influence between factors is unknown (Abdullah and Goh, 2019). The DEMATEL method gets the needed information from experts by individually (Si et al., 2018). Moreover, as e-waste is one of the real-life problems, in this thesis, the judgments are linguistics terms and these terms are transformed into number with the help of fuzzy calculations (Gan and Luo, 2017). Fuzzy logic is based on fuzzy set theory and was introduced by Zadeh (Zadeh, 1965). There are linguistic expressions in daily life problems and these linguistic expressions can be numbered thanks to fuzzy logic. In addition, multi-criteria decision-making methods and fuzzy logic can be integrated each other and it provides clearer decision making in uncertain and complex decisions (Seleem et al., 2020). Therefore, Fuzzy DEMATEL is applied for this thesis.

According to the implementation, 8 experts are conducted pairwise comparisons of the challenges of mobile phone recycling activities.

The example of the linguistic assessments about the relationship between challenges of Expert 1 are shown in Table 11.

Table 11 A given example of the linguistic assessments about relationship between challenges



	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25
C1		L	VH	VL	VL	VL	VL	VL	VL	VL	VL	L	VL	L	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
C2	VH		VH	H	H	H	H	VH	H	L	L	L	VH	L	L	VL	L	L	L	L	L	L	L	VL	VL
C3	VL	L		VL	H	VL	VL	VL	VL	VL	VL	VL	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	L	VL
C4	VH	H	H		H	VL	L	L	L	VL	VL	H	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	H
C5	VH	L	VH	H		L	VL	VL	VL	L	VL	H	L	VL	VL	L	VL	L	L	L	L	L	L	L	L
C6	VH	VH	VH	L	VL		VH	VH	H	VH	VL	L	H	L	H	L	H	L	L	L	L	L	L	VL	L
C7	VH	H	VH	H	H	L		L	L	H	L	L	H	L	L	L	L	H	H	H	H	H	H	VL	L
C8	VH	VL	VH	L	H	L	VL		H	L	VL	VL	L	L	L	L	L	VL	VL	VL	VL	VL	VL	VL	L
C9	VL	VL	VL	VL	VL	H	VH	H		H	H	L	VL	L	L	L	VL	VL	VL	VL	VL	VL	VL	L	VL
C10	VL	VL	VL	L	L	L	VH	VL	VL		VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	L
C11	VL	H	L	L	VL	VL	VL	L	L	VL		VL	H	H	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL
C12	H	H	L	VH	L	L	VL	VL	L	L	H		L	L	L	H	L	L	L	L	L	L	L	L	VH
C13	VH	H	VH	L	L	VL	VL	VL	VL	VL	VL	L		VL	VL	L	L	VL	VL	VL	VL	VL	VL	VL	L
C14	VH	VH	VH	VH	VH	L	VH	H	L	VL	VL	VH	VH		VH	L	L	L	L	L	L	L	L	L	H
C15	VH	H	L	L	H	VH	VH	L	H	H	VL	L	L	L		VL	VL	VL	L	L	L	L	L	VL	H
C16	VL	VL	VL	VL	L	L	VL	VL	VL	VL	L	H	H	L	L		H	VL	VL	VL	VL	VL	VL	H	VH
C17	VH	VH	VH	VH	VH	L	H	H	H	VL	L	L	VL	VL	L	VH		L	L	L	L	L	L	H	VH
C18	L	VL	H	VL	VL	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL		VL	VL	VL	VL	VL	VL	VL
C19	L	VL	H	VL	VL	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL		VL	VL	VL	VL	VL	VL
C20	L	VL	H	VL	VL	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL		VL	VL	VL	VL	VL
C21	L	VL	H	VL	VL	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL		VL	VL	VL	VL
C22	L	VL	H	VL	VL	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL		VL	VL	VL
C23	L	VL	H	VL	VL	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL		VL	VL
C24	H	L	VH	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL		VH
C25	VH	L	VH	VL	VL	VL	L	H	L	L	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	VL	

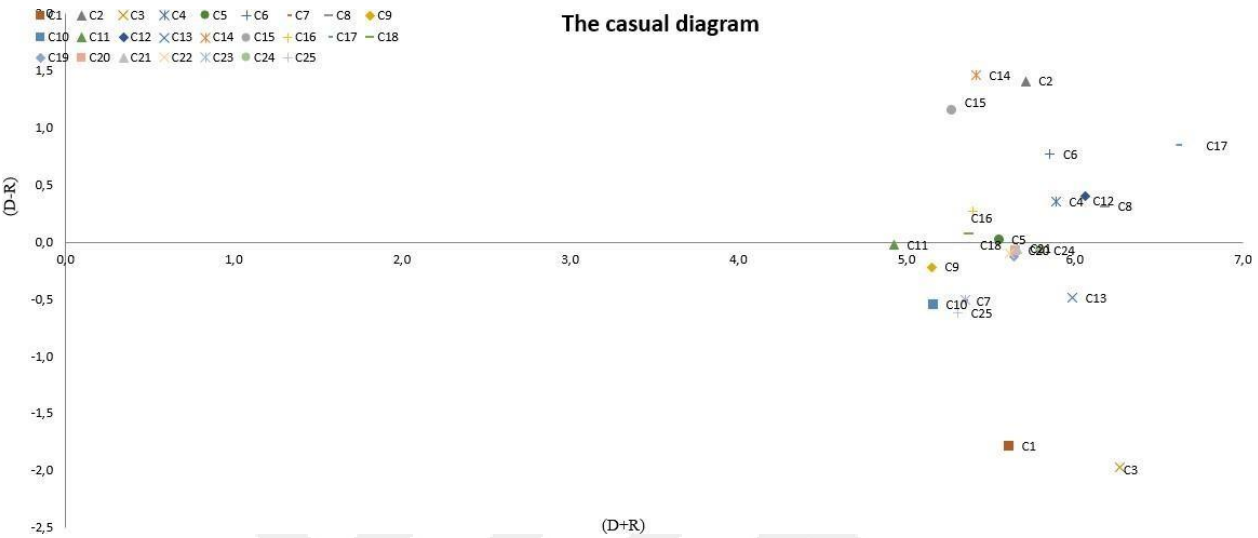
After implementing all steps of fuzzy DEMATEL, the results are given in Table 12.

Table 12 Values of D+R and D-R

Challenges	D+R	D-R	Challenges	D+R	D-R	Challenges	D+R	D-R
C1	5,6	-1,8	C10	5,2	-0,5	C19	5,6	-0,1
C2	5,7	1,4	C11	4,9	0	C20	5,6	-0,1
C3	6,3	-2	C12	6,1	0,4	C21	5,7	-0,1
C4	5,9	0,4	C13	6	-0,5	C22	5,6	-0,1
C5	5,5	0,0	C14	5,4	1,5	C23	5,3	-0,5
C6	5,9	0,8	C15	5,3	1,2	C24	5,8	-0,1
C7	5,3	-0,5	C16	5,4	0,3	C25	5,3	-0,6
C8	6,2	0,3	C17	6,6	0,8			
C9	5,2	-0,2	C18	5,4	0,1			

The relationship between the challenges are determined by displaying the D+R and D-R values. Based on these values, the causal relationship diagram is determined as shown in Figure 11.

Figure 11 The Casual Diagram



5. RESULTS

According to D-R (positive) values, factors that are in cause groups of the recycling of mobile phones are lack of governmental policies (C14), insufficient government regulations to prevent the release of toxic substances during the recycling process (C2), lack of financial and economic incentives (C15), lack of awareness of the top management and company policies (C17), high costs of high-tech technologies (C6), lack of knowledge about recycling technologies (C12), unawareness of recycling techniques and their importance (C4), growing informal sector (C8), lack of communication between stakeholders in supply chain (C16), lack of green practices in product design for reuse (C18), lack of trained personnel (C5), uncertainty of the amount of return products (C11), respectively.

According to D-R (negative) values, the most affected factors are health problems (cancer, liver damage and problems with neurological systems) (cadmium etc.) (C3), environmental hazards because of the toxins contained within electronic products (C1), mismanagement in collection and separation process (C25), lack of green practices in product design for recycle (C23), lack of proper infrastructure to deal with the harmful substances arising during the recycling process (C13), lack of investment availability (C7), high discrepancies between income and cost that firms will receive from recycling activities (C10), fluctuations in market conditions (C9), lack of green practices in product design for repair (C19), lack of green practices in product design for remanufacturing (C22), lack of green practices in product design for reconditioning (C20), lack of green practices in product design for refurbishing (C21), lack of operational integration (C24), respectively.

According to the order of importance based on D+R values, the challenges are listed as follows; lack of awareness of the top management and company policies (C17), health problems (cancer, liver damage and problems with neurological systems) (cadmium etc.) (C3), growing informal sector (C8), lack of knowledge about recycling technologies (C12), lack of proper infrastructure to deal with the harmful substances arising during the recycling process (C13), high costs of high-tech technologies (C6), unawareness of recycling techniques and their importance (C4), lack of operational integration (C24), insufficient government regulations for the prevention of toxic substances release during the recycling process (C2), lack of green practices in product design for refurbishing (C21), lack of green practices in product design for reconditioning (C20), lack of green practices in product design for remanufacturing (C22), lack of green practices in product design for repair (C19), environmental hazards because of the toxins contained within electronic products (C1), lack of trained personnel (C5), lack of governmental policies (C14), lack of communication between stakeholders in supply chain (C16), lack of green practices in product design for reuse (C18), lack of financial and economic incentives (C15), lack of green practices in product design for recycle (C23), lack of investment availability (C7), mismanagement in collection and separation process (C25), fluctuations in market conditions (C9), high discrepancies between income and cost that firms will receive from recycling activities (C10), uncertainty of the amount of return products (C11) respectively.

Moreover, considering the causal diagram shown in Figure 11, lack of governmental policies (C14), insufficient government regulations for the prevention of toxic substances release during the recycling process (C2), lack of financial and economic incentives (C15) affect the other challenge while environmental hazards because of the toxins contained within electronic products (C1) and health problems (cancer, liver damage and problems with neurological systems) (cadmium etc.) (C3) are the most affected.

In the following section, the determined results are discussed in detail.

6. DISCUSSIONS & IMPLICATIONS

E-waste has become very important worldwide and the number of e-wastes continues to increase day by day. The recycling of e-waste in the reverse logistics concept is less applicable in emerging economies. It is seen that in one of the emerging economies, Turkey, e-waste is increasing constantly. Turkey electronics sector, not only for the domestic market but also develop products for overseas. It also has significant market shares compared to most European countries in the television and white durable products category. As in the whole world, especially from emerging economies, which Turkey, reverse logistics processes are seeing the importance of adequate and e-waste occurs. In this thesis, the challenges of reverse logistics activities are determined under 7 main headings and 25 challenges, depending on the literature and expert opinions to create awareness about e-waste in the country. Like in the whole world, mobile phone usage has increased greatly and the life of mobile phones is getting shorter every day. Consumers buy a new mobile phone before it gets old. Therefore, the recycling process of mobile phones, which are the most important types of e-waste in Turkey like in the whole world are determined in this thesis. After receiving the opinion of 8 experts with Fuzzy DEMATEL, the following results are obtained.

According to the implementation, the first 5 challenges which affects theother challenge are lack of governmental policies (C14), insufficient government regulations for the prevention of toxic substances release during the recycling process (C2), lack of financial and economic incentives (C15), lack of awareness of the topmanagement and company policies (C17), high costs of high-tech technologies (C6), respectively. Moreover, the top 5 challenges which are affected by the other challenges are health problems (cancer, liver damage and problems with neurological systems) (cadmium etc.) (C3), environmental hazards because of the toxins contained within electronic products (C1), mismanagement in collection and separation process (C25), lack of green practices in product design for recycle (C23), lack of proper infrastructure to deal with the harmful substances arising during the recycling process (C13), respectively.

The most affected challenge which is lack of governmental policies (C14) is in the category of legal challenges. Governmental policies are the challenges with the highest cause score and the 16th importance score. The results show that effective governmental policies are needed to reduce waste in mobile phones and increase their recycle operations. Government policies can incentivise both the industry and consumers to reduce waste. These policies need to be built on sustainability and the circular economy. Thus, recycling activities in mobile phones and other e-wastes will be regulated within the legal framework and will minimize the impact of wastes on the environment and society from the sustainability point of view. It will contribute tothe increase of activities such as recycling, reuse and reproduction in these sectors. E-waste management contributes not only to the environment and social life, but also to emerging economies with employment advantages. Government policies will contribute to economic, environmental and social sustainability and circular economy in this framework. This situation is a winning approach in terms of both governments and sectors.

The insufficient government regulations to prevent the release of toxic substances during the recycling process (C2), which is in the category of ecological dimensions, has the second highest cause score and the 9th importance score. The criterion is also accepted in the category of legal dimensions since it involves government regulations. E-waste is a problem that is becoming more serious worldwide and it is causing damage in emerging economies faster than developed countries. One of the biggest problems experienced in this regard is the inadequate policy implementation by governments to prevent toxic gases occurring in the recycling of e-waste. Regulations made to control firms and prevent environmental damage are extremely important. Toxic gases that emerge not only from mobile phone recycling but also from the processing of all e-waste lead to deterioration of human health and environmental pollution. Inadequate regulations on this issue are highly important factors that complicate the recycling activities of mobile phones and other e-waste. To deal with the problem, it is needed to embark on sustainable and circular solutions such as increasing environmental and social consciousness and providing leakage minimisation with new policies.

The lack of financial and economic incentives (C15) is the third challenge with the highest cause score and the 20th importance score. The challenge is in the category of legal dimensions. As mentioned in the lack of governmental regulations, e-waste recycling activities needs financial and economic incentives. Since high-cost technology is needed for proper e-waste management, the sector should have financial and economic incentives. If e-waste is recycled with appropriate methods and technologies, it will be considered as a market that can create a significant business area, developing a situation that will be beneficial to the circular economy at the same time. With the recycling activities of mobile phones and other e-wastes, the reserve of precious metals in the country will be preserved and the metals that emerging economies will need and try to buy abroad can be found. According to statistics, economic value of recyclable e-waste which is buried in Turkey indicated nearly two billion TL. This means that there is huge waste in the economy due to the lack of financial and economic incentives. Moreover, a very important incentive for the industry component; especially large investment support can be given in cities. It is essential to adopt economic optimisation, which is one of the principles of circular economy, by developing innovation capabilities, skilled labour or increasing productivity. With the approach, it will be beneficial to economic sustainability in e-waste management.

The fourth highest cause criterion in the cause group is lack of awareness of the top management and company policies (C17), which is in the category of managerial and business dimensions. The criterion is the 1st in the importance order of the challenge. Managers in the industry are not sufficiently involved in mobile phone recycling operations due to insufficient regulations, incentives, and awareness studies. However, company policies with the awareness about the issue will reduce losses across countries and contribute to the circular economy and economic sustainability by utilizing waste. Company policies are the most important challenge affecting the challenges of recycling operations of mobile phones and other e-wastes. In this way, it is possible to shape the sector. Initially, they have the power to improve all processes from production to recycling, along with company policies and management decisions. As products are designed in accordance with recycling processes, recycling processes can also be designed in accordance with policies based on circular approaches. Furthermore, the development in the challenge provides innovations in social sustainability in waste management.

The fifth highest cause criterion in the cause group is high costs of high-tech technologies (C6), which is in the category of economic dimensions, and it comes the 7th in the importance order. The cost of technologies used for recycling e-waste is high in emerging countries. Therefore, without government incentives, corporations consider the disposal of e-waste cheaper. This causes the e-waste not to be used, to remain as waste and to harm the environment, economy and human life while being disposed of. With the circular economy approach, technologies suitable for the operation of the process should be adopted. The main purpose of this is to provide efficiency and effectiveness supporting the optimization of operations. Moreover, the contribution provides economic sustainability.

The challenge with the highest effect scores among the effect group is the health problems (cancer, liver damage and problems with neurological systems) (cadmium etc.) (C3), which is in the category of social dimensions. This criterion is the second most important among the other challenge. Procedures such as improper disposal and incineration of mobile phones and other e-wastes harm both workers' health and the health of the public with toxic gases emitted. Failure to recycle these products causes many fatal diseases such as cancer and brain damage. Therefore, governments or companies can prevent health and environmental problems by organizing trainings on these operations. These trainings and arrangements can increase environmental and social sustainability. This will enable companies to recycle with appropriate methods, to raise awareness of recycling activities in public and to contribute to the sector.

The second highest effective criterion is the environmental hazards because of the toxins contained within electronic products (C1), which is in the category of ecological dimensions. Due to insufficient government regulations, company policies and laws, chemical poisons emerge in the recycling of e-waste. Failure to prevent this release of poison causes environmental damage.

The challenge with the third highest effect score is mismanagement in collection and separation process (C25), which is in supply chain management group. Since deficiencies in e-waste recycling operations, low awareness of companies and inadequate government policies affect the development of this sector, the collection and separation of e-waste are also affected by this situation. Failure to give due importance to the sector leads to wrong collection and separation policies. However, it is necessary to raise awareness of the transportation and separation of e-waste, which is one of the most important issues, to raise public awareness, to improve company policies in this direction, and to provide incentives for high costs.

The challenge with the fourth highest effect score is lack of green practices in product design for recycle (C23), which is in managerial and business dimensions. Compliance of e-waste such as mobile phones with recycling methods is extremely important. Setting the design standards and designing the electronic products in an environmentally friendly manner will also reduce the harmful substances that arise during the recycling process. Companies, and especially governments, should also be guiding innovation.

The challenge with the fifth highest effect score is lack of proper infrastructure to deal with the harmful substances arising during the recycling process (C13), which is in the infrastructural and technological group. As with other affected challenges, environmental damage comes to the fore in this criterion. Considering the influencing challenge, as mentioned earlier, there are deficiencies in providing infrastructure for recycling due to inadequate policies and regulations.

In addition to these challenges discussed, there is another important criterion for challenges of recycling activities of mobile phones. The challenge with the 3rd importance score is growing informal sector (C8), which is the 8th in the cause group. Illegal sectors have started to grow due to the lack of legal regulations, awareness of companies and the inefficiency of the sector. Illegal collection of e-wastes which is done by scrap dealers and street pickers cause these wastes not to be used properly and it damages circular economy in waste management. E-waste given to scrap dealers is improperly broken down. Toxic substances occurring in this process are mixed with soil. They sell the spare parts of the waste and throw the rest away. That harms both the industry and the environment. In this context, it is extremely important to give enough incentives to the corporate companies in the sector, and to raise awareness of the municipalities about bringing the products held by the municipalities to the collection points rather than giving them to scrap dealers. All these suggestions can be applied with the help of circularity.

Moreover, lack of knowledge about recycling technologies (C12) has the 4th importance score and it is the 6th in the cause group. In addition to high cost of recycling technologies, being incapable of dealing with these technologies is a crucial problem for recycling activities of mobile phones and other types of e-waste. As mobile phone and other types of e-waste recycling activities will differ depending on the extent of damage, these operations and the technologies used require technical skills. In this case, governments need to provide practical knowledge transfer and trained staff. Employment programs to be created can provide employees with information about operations and increase employment with incentives such as training days.

As a result of the research, e-wastes threatening the environment and human health should be collected and separated appropriately. Accordingly,

1- Awareness should be raised for governments, companies and consumers about the recycling of e-waste.
2- In order to reduce household e-wastes, the most important example of which is mobile phone, it is necessary to reduce emotional commitment to wastes with high economic and moral value. In order to create this awareness, the values of the circular economy should be used.

3- It is necessary to ensure that the old appliances kept at home with the ideathat they will be used one day will enter the loop.
4- At the same time, in order to prevent the growth of the illegal sector, wastes should be recorded, and an appropriate infrastructure should be prepared.
5- Economic incentives need to be increased to ensure volunteering forrecycling operations.
6- The target of collecting the return rate from EEE to WEEE should be determined by the usage life of the device using the records kept.

From sustainability point of view, implementing effective recycling activities will provide economic, environmental and social benefits. While protecting the health of the public and employees socially, environmental damage will be minimized. Applying appropriate recycling activities of electronic wastes containing economically valuable metals will benefit both companies and the state.

To sum up, all analysed challenges clearly state that there is a huge problem about e-waste management in Turkey and only circular and sustainable solutions provide a solution to deal with this problem. Therefore, not only the government but also companies and consumers should consider the suggestions to tackle the problem.

CONCLUSION

Electrical and electronic products, which have become obsolete with reduced functionality, are referred to as e-waste, since their useful life expires or are replaced by new ones before they expire. Recently, with the rapid development of technology, consumption habits stimulated by capitalism, electronic dumpster has been growing rapidly. Even the mobile phones we have are becoming more and more wasteful with their new models that come out every year, before their battery life can be completed. Sometimes repairing a broken electronic device can be costlier than it actually is with the developments in production technologies.

Reverse logistics which involves recycling unwanted materials (waste, box, bottle, paper etc.), and re-producing and returning evaluation of products by reselling them in different sales channels is an effective logistics management. It contributes to the circular economy with its activities such as recycling, repairing and recycling of e-waste, which are reverse logistics activities.

Especially in emerging economies, reverse logistics activities based on circular economy cannot be carried out effectively due to the shortcomings experienced and the fact that wastes that can be utilized become garbage. For example, if Turkeystops a large part of these wastes and forms a uniform system of collection and recycling e-waste, this may also contribute to the circular economy. At the same time, the use of old products that have completed their life increases the energy consumption. As a result, improper recycling of e-waste causes the release of toxic materials such as lead, mercury, bromine and chromium and harms human health and nature.

With this aim, the thesis is structured around mobile phones which the most emerging e-waste in Turkey. It is aimed to create a road map for companies and governments based on sustainable and circular solutions by researching the reasons that affect the recycling of mobile phones. The challenges obtained are given under 7 main headings and the ones that cause the recycling of mobile phones and their results are determined. This way, it has been determined that legal deficiencies generally affect the recycling process of e-waste. Accordingly, problems such as environmental pollution, damage to human health, and valuable waste that could not be recycled to the economy have been identified.

To sum up, the necessary importance should be given to the recycling of e-waste in order to improve the sector and reduce e-waste, to regulate the government related laws, to encourage recycling facilities with appropriate technologies, toensure that waste producers fulfil their responsibilities to intervene in the informal economy, and the awareness of public and companies needs to be raised.

In this study, it is clearly stated that reverse logistics is a concept which is accepted under the circular economy approach and it is essential to adopt circular economy principles with reverse logistics activities in e-waste management to deal with e-waste problem in emerging economies. Therefore, this thesis focused on reverse logistics and e-waste management without going out of circular economy approach.

For further research, the implementation of the study can be applied to all types of electronic products. Moreover, since e-waste is a global problem, the implications should be taken into consideration not only for emerging economies, but also for developed countries.

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