MARMARA UNIVERSITY

INSTITUTE FOR GRADUATE STUDIES

IN PURE AND APPLIED SCIENCES

LCA COMPARISON OF MUNICIPAL SOLID WASTE MANAGEMENT STRATEGIES: A CASE STUDY

EREN YILDIZ-GEYHAN

Ph.D. THESIS

Department of Chemical Engineering

Thesis Supervisor

Assoc.Prof. Dr. Gökçen Alev ALTUN-ÇİFTÇİOĞLU

Thesis Co-Supervisor

Prof. Dr. M. A. Neşet KADIRGAN

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Jury Members

Assoc.Prof.Dr. Gökçen Alev ALTUN ÇIFTÇIOĞLU (Advisor)
Marmara University………………………………………(SIGN)………………...

Prof.Dr. Beyza ÜSTÜN (Jury Member)
Yıldız Technical University………………………………(SIGN)………………...

Prof.Dr. Emin ARCA (Jury Member)
Marmara University………………………………………(SIGN)………………...

Prof.Dr. Ayşegül ERSOY MERİÇBOYU (Jury Member)
İstanbul Technical University …………………………...…(SIGN)………………...

Assoc.Prof.Dr. Kozet YAPSAKLI (Jury Member)
Marmara University …………………………………….(SIGN)……………..…..

APPROVAL

Marmara University Institute for Graduate Studies in Pure and Applied Sciences Executive Committee approves that Eren YILDIZ GEYHAN be granted the degree of Doctor of Philosophy in Department of Chemical Engineering, Chemical Engineering Program on May 23, 2016. (Resolution no: …………..…..).

Director of the Institute
Prof. Dr. Adı SOYAD

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ÖZET

BELEDİYE KATI ATIK YÖNETİM STRATEJİLERİNİN YDD KARŞILAŞTIRMASI: BİR ÖRNEK ÇALIŞMA

Geri dönüştürülebilir ambalaj atıklarının kaynağında ayrı toplanması; sosyal, ekonomik, kültürel ve çevresel açıdan kozmopolit yapıya sahip olan İstanbul gibi büyük şehirlerde önemli bir problemdir. Çevresel ve sosyal açıdan etkin bir ayırma-toplama ve geri dönüşüm uygulamasının sağlanması için yönetim sistemleri; geri dönüştürülen materyal miktarı, kaynak tüketimi, emisyon oluşumu, çalışma koşulları, sosyal kabul edilebilirlik ve insan hakları gibi hususları da içeren bütünlükçü bir yaklaşımla analiz edilmelidir.

Bu tez kapsamında, mevcut ve alternatif belediye ambalaj atığı yönetim sistemleri çevresel ve sosyal etkiler dikkate alınarak analiz edilmiş ve kıyaslanmıştır. Araştırma, uzun dönemli saha gözlemi, veri toplama ve mevcut sistem analizi üzerine temellendirilmiştir. Mevcut sistem analizinden sonra, araştırma sahası için alternatif senaryolar belirlenmiştir. Alternatif senaryoların çevresel performansı mevcut sistem verilerine göre hesaplanırken; sosyal etkileri belirlemek için daha fazla saha gözlemi ve paydaşlarla ikili görüşmeler yapılmıştır. Senaryoların çevresel ve sosyal etkileri, Yaşam Döngü Değerlendirmesi metodu kullanılarak belirlenmiştir.

Araştırma sonuçları, yasal olmayan toplama sistemlerinin yasal toplama sistemlerine göre çevresel olarak daha etkili olduğunu göstermiştir. Kaynak tüketimi artsa dahi, daha fazla geri dönüştürülebilir materyalin toplandığı sistemler çevresel açıdan daha avantajlı olmuştur. Diğer taraftan; sosyal etki değerlendirme sonuçları, yasal olmayan toplama sistemlerinin yasal toplama sistemiyle karşılaştırıldığında dezavantajları olduğunu göstermiştir. Sonuç olarak, sistemlerin çevresel ve sosyal zayıflıklarının entegre edilmiş sistem uygulamalarıyla minimize edilebileceği bulunmuştur.

ABSTRACT

LCA COMPARISON OF MUNICIPAL SOLID WASTE MANAGEMENT STRATEGIES: A CASE STUDY

Source-separated collection of recyclable packaging wastes has been a huge issue for metropolitan cities such as Istanbul considering their socially, economically, culturally and environmentally cosmopolite structure. In order to provide an environmentally and socially effective separation-collection and recycling application; management system has to be analyzed with a holistic approach including the issues, such as recycled packaging material amounts, source consumptions, related emissions, working conditions, social acceptability and human rights.

In the scope of this thesis, existing and alternative municipal packaging waste management systems were analyzed and compared each other in terms of environmental and social impacts. The research was mainly based on a long term site observation, data collection and existing system analysis. After the existing system analysis, alternative scenarios were determined for the research area. Environmental performance of alternative scenarios were calculated in terms of existing system data, whereas more site observations and interviews with social groups were conducted for determination of the social impacts. Both environmental and social impacts of the scenarios were determined by using Life Cycle Assessment methodology.

Results of the study showed that informal collection was environmentally more effective than the formal collection systems. Even the resource consumptions were increased, more recycling material collected systems were still environmentally more beneficial. On the other hand, social impact assessment results indicated that informal collection system had social disadvantages compared to formal systems. And finally, it was found that environmental and social weaknesses of the system could be minimized with integrated system applications.

CLAIM FOR ORIGINALITY

In this thesis, newly developed environmental and social life cycle sustainability assessment methodology was applied on the packaging waste management collection systems, for the first time in Turkey.

To the best of our knowledge, many environmental life cycle assessment studies were performed on waste management system modeling. On the contrary, there are only a few social life cycle assessment studies on waste management systems. And, most of these studies mainly focused on the integrated waste management systems. However, each stage of an integrated waste management system involves a different management-operation strategy for itself. To achieve an optimum efficiency in a municipal solid waste management system, it is important to analyze each stage's requirements. In this management process, a well-organized separate collection stage increases the entire systems' efficiency. This thesis consist of a detail analysis of separate-collection of packaging waste in terms of energy and resource consumption. Thus, it is an important application analysis for service suppliers and decision-makers.

Applied methodology in this research is a holistic approach which integrates the environmental and social impacts together. Integrated environment and social analysis of the systems, is a significant aspect considering the importance of sustainable life concept. Thus; for the decision makers, the concept of sustainability was also covered and assessed in this study under the two perspective—environment and society, for the first time in Turkey.

In the literature, there is not a comprehensive life cycle assessment study on packaging waste management system. Therefore, this study is unique and will contribute to case studies especially on social life cycle assessment of waste management system, considering the insufficient number of the case studies in the literature.

SYMBOLS

E_i	: Emission of pollutant
$EF_{i,j,m}$	: Fuel consumption-specific emission factor
ESR_i	: Effective separation rate
$FC_{j,m}$	: Fuel consumption of veichle category
GR_i	: Specific waste generation rate
i	: Importance of criteria
n	: Number of criteria
Q_T	: Household solid waste
Q_M	: These data includes mixed solid waste collected by municipality
Q_F	: Formal collection by municipality
Q_I	: Informal collection by scavengers
PR_i	: Public participation rate
PWR_i	: Packaging waste rate
RE_i	: Recycling efficiency rate
SaR_i	: Substitution rate
SR_i	: Source separation rate
W_i	: Weight of the criteria
WR_i	: Wastage rate
x_k	: Indicator value for the scenario
x_{min}	: Minimum value of the indicator
x_{max}	: Maximum value of the indicator

ABBREVIATIONS

C	: Consumer
ELCA	: Environmental Life Cycle Assessment
E	: Egalitarian
FU	: Functional Unit
GO	: Governmental Organizations
H	: Hierarchic
I	: Individualistic
LC	: Local community
LCA	: Life Cycle Assessment
LCSA	: Life Cycle Sustainability Assessment
MoEU	: Ministry of Environment and Urbanization
MSWMS	: Municipal Solid Waste Management System
NGO	: Non-governmental Organizations
RCRA	: Resource Conservation and Recovery Act
S	: Society
SLCA	: Social Life Cycle Assessment
SWMS	: Solid Waste Management System
W	: Workers

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1 INTRODUCTION

Considering the world's human population through history, it is obvious that a rapid and inevitable growth stand out. This rapid population growth brings with so many problems such as increasing food production, energy demands, health issues, insufficient resource, and etc. As a result of responding these growing needs, an uncontrolled urbanization and industrialization occurred. These uncontrolled development cause a negative pressure and degradation on environment, intensification of agriculture, and the destruction of natural habitats. On the other hand, more resource usage by human communities causes more contaminant generation; such as air and water pollution, greenhouse gas emissions and also large quantities of solid waste. Moreover, increasing globalization may cause the outsourcing because of pushing the limits of earth's carrying and renewability capacity.

Solid waste management, especially in the urbanization areas is one of the most important aspects of these problems. Together with the population growth and industrialization in the worldwide; waste generation become a huge problem threatening the environment, humans and all living things. These raising environmental problems clearly bring out the importance of solid waste management phenomenon.

Solid Waste Management System (SWMS) is basically explained as a management system which controlling the waste from generation to storage, collection, processing and treatment and or disposal without endangering the environment and human health (Al-Maaded et al., 2012. This management system starts with the collection of waste from where they are produced and stored such as residential areas and commercial sectors. After the collection, solid waste are transported to sorting, recycling and final disposal facilities (Weitz et al., 1999). Each stage of an integrated waste management system involves a different management-operation strategy for itself. To achieve an optimum efficiency in a SWMS, it is important to analyze each stage's requirements. In this management process, a well-organized separate collection stage increases the entire systems' efficiency.

As a part of the solution, recycling process provides less waste materials to be sent to landfills and incinerators. Thus, greenhouse gas emissions and other pollutants will be reduced. Recycling of waste materials will also result in less usage of primary sources and conserve the natural resources.

From a resource management perspective, “anthropogenic resources” contained in solid waste become economically and environmentally interesting when realizing the decreasing availability and increasing prices for raw materials (GIZ, 2011). Specifically, material recycling is an important concept considering the increasing globalization and outsourcing all around the world. To achieve a sustainable resource management, it is necessary to recycle waste through the each part of the production-consumption processes. Because recycling is highly economical and causes less environmental impact than the extraction and processing of raw material, governmental organizations (GO) and non-governmental organizations (NGO) focus on improving collection rates of these materials. In this point of view, environmental and economic impacts of recyclable material collection systems seem to respond sustainability concept. However, economic and environmental sides are only two of the three columns of this concept. To accomplish a sustainable life concept, not only the economic and environmental impacts but also human’s well-being, working conditions should be considered under the name of social impacts. From an economic and environmental viewpoint, it may say that material recycling is mostly effective and had positive effect on environment. But, social impacts may be the negative side of these positive pictures. Because, recycling material collection system are mostly handled by informal collectors especially in developing countries. Therefore, considering the informal collection system’s disadvantageous such as inappropriate working conditions, child labour, health and safety issues, etc., effects of the social impacts has to be taken into account in all system analysis.

In Turkey, Environment and Urbanization Ministry (MoEU) published “Waste bring centers and a plan of double type collection of solid waste” in December 2014 to determine the responsibilities of social groups and the actions has to be taken to achieve a source separated recyclable material collection and as a consequence obtaining a sustainable integrated waste management system. Recently, MoEU also published a draft circular on “Regulation of Controlling Packaging Waste” in the 6th time from 2004 to 2016. However, although there are various changes in the law and regulations, there is not a waste management system which is fully-supported by the regulations yet and so, local authorities cannot apply an effective separate collection which is the most important part of the waste management system. Therefore, in order to achieve an effective separate collection system, regional differences, social awareness, economic conditions and environmental benefit should be analyzed in detail.

The present work focuses on the environmental and social life cycle assessment of different packaging waste collection systems. Existing formal collection systems and 13 different hypothetical collection scenarios; existing formal and informal collection systems (separately and in a combination), two formalized systems and one ideally formalized system suggestion, were analyzed and compared to determine the environmental and social weaknesses and strengths of the separate collection system of recyclable packaging materials as a part of integrated waste management system for the first time in Turkey. Aim of this study is mainly to give a different aspect to decision makers of packaging waste collection system to accomplish a sustainable life concept.

1.1 Background

In this part of the thesis, packaging waste were basically defined by emphasizing its importance. To give a general aspect on the packaging waste management systems, collection systems carried out in different countries and legal responsibilities were also summarized.

1.1.1 Definition of packaging waste

Packaging is a valuable product protective material. It protects the contaminants of the products, according to the structure and shape of its content, ensures it remains clean and simultaneously promotes the product.

In our daily life, usage of packaging fulfils an important role and become quite extensive. We buy many products from food to cosmetics, flowers to furniture in their packaging. It protects the products and keep them the stay clean and healthy on their journey from production to usage. After the usage of the products, packaging came to end of their prior duties and became packaging waste.

Table 1.1 represents the packaging waste types, raw materials used the productions of packaging and secondary materials which are produced by usage of packaging waste.

1.1.1 Importance of packaging waste recycling

Increasing populations and changing consumption habits decrease the natural resources day by day. Decreasing natural resources such as forests, water, petroleum etc., pose out the efficient resource management concept. The production processes and extraction of raw materials of glass, metal, plastic and paper-cardboard packaging consumes huge amount of resource. To eliminate these material and energy consumption, recycling should be considered as a solution strategy. After the usage of packaging launched into the market, they become waste. And to recycle these waste, they are separated according to their material types and delivered to the recycling industry. And these waste materials are recycled to the products which are used as secondary raw materials during the production process. Therefore, recycling process provides a huge saving on natural resources.

Advantageous of packaging waste usage of material resources is shown in Table 1.2.

Table 1.1. Packaging product and waste cycle.

Raw Material	Primary Packaging Products	Packaging Waste	Secondary material after recycling
Silica sand	glass packagings, glass bottles and jars	Glass	glass packagings
Forest constitute	used in many sectors such food, textile, cosmetics and electronics.	Paper-cardboard	Paper and cardboard
Petroleum or its derivatives	packaging of bottled water, beverages and oil; detergent and bleach containers, and shampoo bottles; packagings chemicals, healthcare, cosmetic products, lids of detergent containers, yoghurt and margarine packagings	Plastic	synthetic carpet, insulation materials, kitchen utensils, water pipes, floor coverings, various construction filling materials, detergent and bleach containers
Steel and aluminums	oil containers, preserve and beverage cans	Metal	Any kind of metal material
Paper and plastic	packing of beverages such as milk, fruit juice and liquid food products	Composite material	Packaging and furniture sector

Table 1.2. Advantageous of packaging waste usage as material resources.

Advantage	Definitions
Material savings	With the usage of secondary material, raw material extraction decreases. Less natural resources consumed
Energy savings	Usage of energy on secondary material processes is less than the production of primary material processes
Land savings	As a result of high volume of recyclable waste, need on landfilling areas decreases
Economic savings	Production of secondary material is cost less than the production of primary material

1.1.2 Legal responsibilities

In order to reduce the environmental impacts and increase the economic benefit result from recycling of packaging waste, some necessary legal and technical arrangements should be established. Figure 1.1 shows the implementation date of packaging waste management legislation, regulation and/or policies in some of the countries.

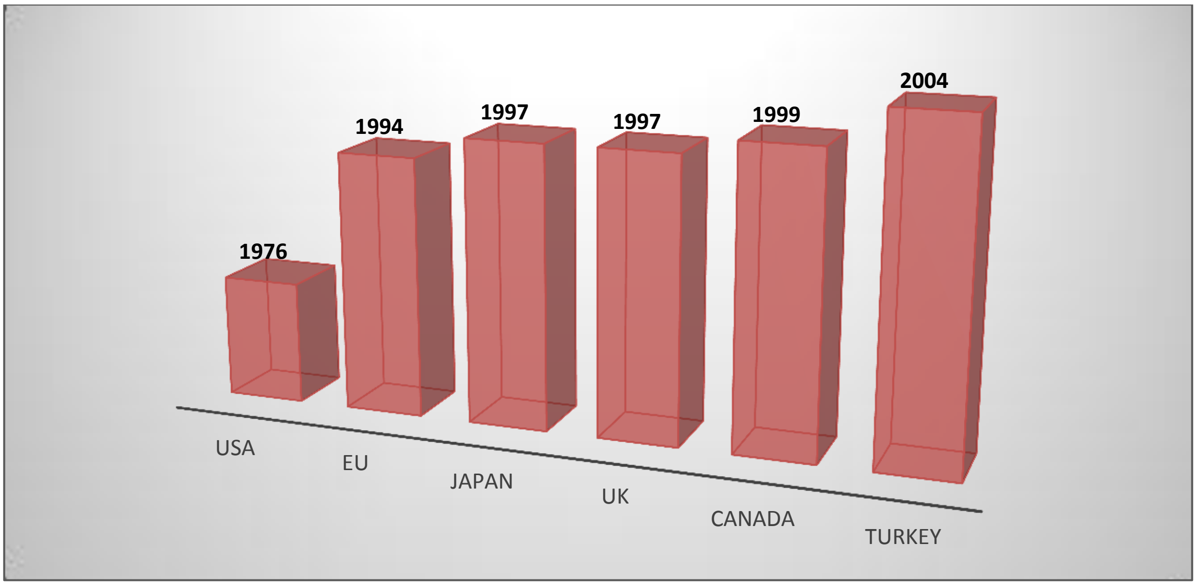

Figure 1.1. Implementation date of packaging waste management legislation, regulation and/or policies in some of the countries (RCRA, 1976).

In Japan, since 1977, reduction of the recyclable waste such as glass, plastic, paper and cardboards has been enforced by Laws; whereas in US, the Resource Conservation and Recovery Act (RCRA) set national goals for energy and resource conservation and reducing the waste generated rate by reduction and recycling (RCRA, 1976). The EU directive 85/339/EEC on packaging waste management were introduced in the early 1980s.The production, marketing, use and recycling are set on the Directive 94/62/EC by aiming an environmental protection (ED, 1994). Directive 94/62/EC targets is also summarized in Table 1.3.

Table 1.3. European Union recovery targets introduced in Directive 94/62/EC.

Deadline	Minimum target	Maximum target
30 June 2001	25 %	45 %
31 December 2008	55 %	80 %

Apart from EU directives, European countries have introduced national targets. An overview of national recovery and recycling targets is provided in Table 1.4.

Table 1.4. National recovery targets of European countries in terms of packaging waste.

	Global targets (%)		Recycling targets for packaging materials (%)					
Country	Total recycling	Material recycling	Glass	Paper-cardboard	Plastics	Steel	Aluminum	Beverage/ composites
Austria	25	15	93	90	-		95	40
Belgium	50	15	-	-	-	-	-	-
Denmark	-	-	65	55	15		15	-
Finland	42	15	48	53	45	25	25	-
France	25-45	15	-	-	-	-	-	-
Germany	45	15	75	70	60	70	60	60
Greece	-	-	-	-	-	-	-	-
Ireland	25-45	15	45	31	10	5	25	-
Italy	25-45	15	-	-	-	-	-	-
Luxembourg	45	15	-	-	-	-	-	-
Portugal	25	15	-	-	-	-	-	-
Spain	25-45	15	-	-	-	-	-	-
Sweden	-	-	70	40-65	30	70	-	-
Netherlands	45-65	15	90	85	35	80	-	-
UK	-	18	-	-	-	-	-	-

In Turkey, waste management has been a subject of legal arrangements since 1930s with the publication of “Public Hygiene Law” (UHK, 1930) and municipalities have been assigned as the main implementation authority with the publication of “Municipality Law” (BK, 1930). However, there were not any obligations on separation of recycling materials, until the publication of Regulation on Control of Solid Waste in 14.03.1991 on Official Gazette No: 20814 (KAKY, 1991). Moreover, with the publication of Regulation of Controlling Packaging Waste in 2004, Municipalities became responsible and the scopes of negotiation with EU, there have been considerable improvements in solid waste management regulations in order to meet the targets in the European Union’s Directive. Table 1.5 shows the evaluation of Legal arrangements for municipal and packaging waste management in Turkey.

Table 1.5. Legal arrangements for waste management and packaging waste management in Turkey.

Legislations	Publication date	Specifications / obligations
Municipality Law (BK, 1930)	1930	Municipalities are responsible for providing clean and healthy environment
Environmental Law (ÇK, 1983)	1983	Protection of environment for sustainable environment and development
Regulation of Controlling Solid Waste (KAKY,1991)	1991	Obligations on separation of recycling materials
Greater City Municipality Law (BBK,2004)	2004	Municipalities became responsible for solid waste collection
Regulation of Controlling Packaging Waste (AAKY, 2004)	2004	Municipalities became responsible for separate collection
Municipality Law (Law N 5393)	2005	Municipalities became responsible for solid waste collection
Regulation of Controlling Packaging Waste (AAKY, 2007)	2007	Municipalities specifically became responsible for separate collection
Regulation of Controlling Packaging Waste (AAKY, 2011)	2011	Municipalities specifically became responsible for separate collection
Communique of Waste Bring Center (AGMT, 2014)	2014	Municipalities are responsible for building up bring centers

According to the Control of Packaging Waste Regulation, packaging material producers are obliged to use the materials which is easy to recyclable and recover, and submit all produced packaging material amount to the Ministry annually. The regulation make citizens to separate the packaging waste from other solid waste and also municipalities to collect and transport the packaging waste separately. Source-separated packaging waste can be collected by service suppliers or municipalities. The regulation bans the unlicensed organizations on prosecuting the collection, transportation and recycling activities of the packaging waste. The regulation make the municipalities responsible for preparing a management plan by defining the collection system details of packaging waste and carry out the planned work in this scope. Manufacturers of the packaged product are also obliged to recover the packaging waste and submit these to the MoEU annually regarding with the AAKY, 2011 (Table 1.6).

Table 1.6. Annually recycling targets in terms of packaging material specified in AAKY, 2011 (%).

Year	Annually recycling target (%)			
	Glass	Plastic	Metal	Paper-cardboard
2005	32	32	30	20
2006	33	35	33	30
2007	35	35	35	35
2008	35	35	35	35
2009	36	36	36	36
2010	37	37	37	37
2011	38	38	38	38
2012	40	40	40	40
2013	42	42	42	42
2014	44	44	44	44
2015	48	48	48	48
2016	52	52	52	52
2017	54	54	54	54
2018	56	56	56	56
2019	58	58	58	58
2020	60	60	60	60

1.1.3 Collection system models

Considering the above explained legal directives and regulations, countries were developed different collection system. Some of the most used packaging waste collection system models are discussed in this section.

To separate and collect the recyclable packagings materials from the municipal solid waste, different systems have been applied. For separate collection at the source, equipment such as containers, disposal boxes, interior bins and recovery bags are used depending on the system applied. Collection systems are flowingly:

- Door-to-door collection
- Curbside collection
- Drop-off collection

- Bring centers
- Vacuum collection
- Collection by scavengers

1.1.3.1 Door-to-door collection system

The collection materials are placed at each door or other area accessible from the building. Bins, containers and plastic bags used for material collection. Citizens separate the waste and store them in home or building. In this system, travel distance to deposit the waste is minimal. Separated waste collected by municipalities once or twice a week. Towns with a low population density are more applicable areas (Kogler, 2007). Replacement of collection materials in a door-to-door collection system are shown in Figure 1.2. Red dots represent the collection materials location.

The advantages and disadvantages of a door-to-door collection system are listed below:

Advantages:

- Effortless for citizens
- No transportation distance for citizens
- High participation rate because of easy collection
- High collection rate comparing the curbside, drop-off and bring center systems
- More cleaner separated materials

Disadvantages:

- High plastic bag consumption
- More material requirement
- Complex collection route
- Fixed collection schedule
- High collection cost
- Storage requirement for participants

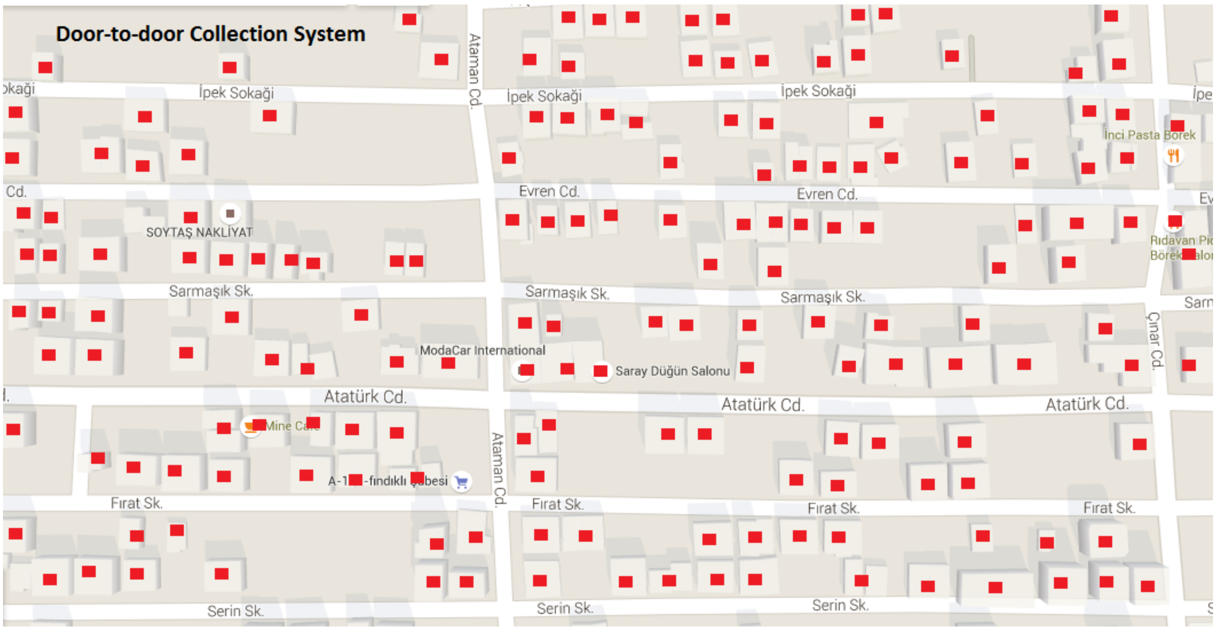

Figure 1.2. Replacement of collection materials in a door-to-door collection system.

1.1.3.2 Curbside collection system

In this system, waste producers stored the separated waste in special containers. Collection materials are placed every 50-100 m on the streets. Citizens do not have to travel very far and so public acceptance is good. The cities with a high population is more applicable for curbside collection (Kogler, 2007). An illustration of collection materials replacement on the streets in a curbside collection system is shown in Figure 1.3. The advantages and disadvantages of curbside collection can be noted flowingly:

Advantages:

- Easy access on the streets
- No storage problems in the buildings
- High user comfort
- High collection rate compared to drop-off and bring center
- Less transportation distance compared to drop-off and bring center

Disadvantages:

- High investments cost in vehicles and containers
- High operational costs resulting from usage of the smaller containers
- Low quality of recyclables
- Low material amount due to illegal collection

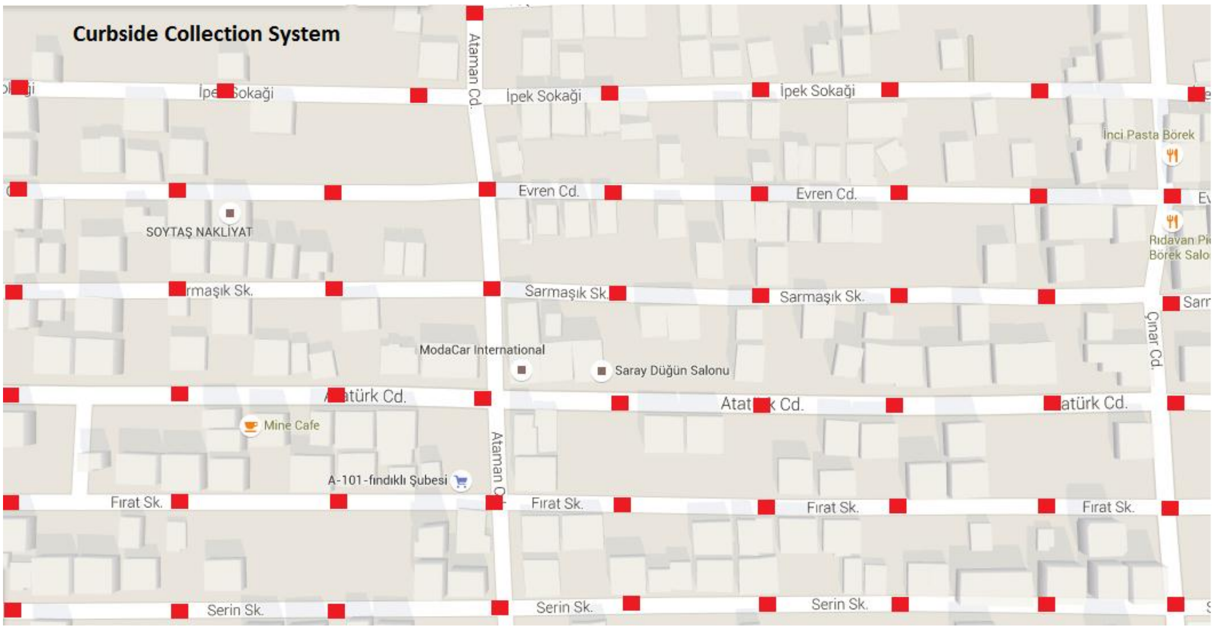

Figure 1.3. Replacement of collection materials in a curbside collection system.

1.1.3.3 Drop-off points collection system

In order to reduce management cost, containers are located at greater distances between 500 and 1000 m. The system mainly based on the voluntary collection. It requires long travel distance on foot (Kogler, 2007). Figure 1.4 indicates drop-off points replacement in a city.

The advantages and disadvantages of drop-off collection system are listed below:

Advantages:

- Less material consumption
- Easy access for collection municipality vehicles
- High participation rate because of easy collection
- No storage problem in the households
- Lower operational and investment cost compared to curbside collection
- Often higher quality of recyclables than curbside collection

Disadvantages:

- Long walking distance
- Low participation rate as a result of transportation distance
- More material requirement than door-to-door collection system
- More space requirement because of high volume of materials

- Finding suitable sites for the containers not easy
- Not suitable for narrow streets
- Special collection vehicles

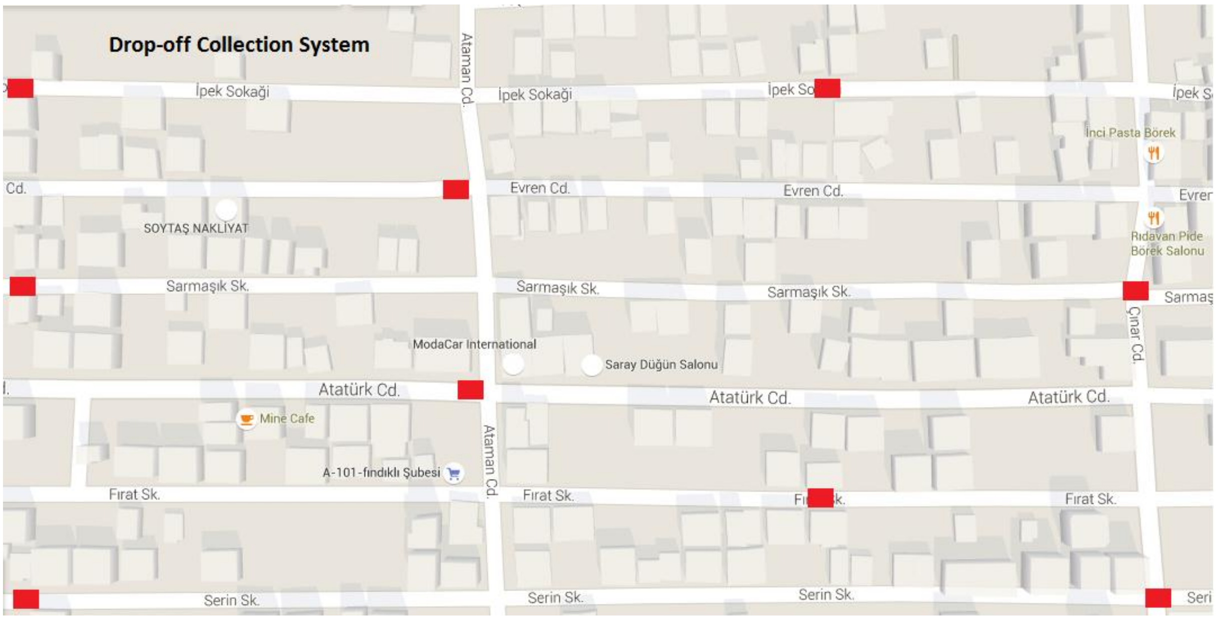

Figure 1.4. Replacement of collection materials in a drop-off collection system.

1.1.3.4 Bring centers

A bring center is a facility where the citizens can bring the packaging waste (Dahlén, 2008). Unlike drop-off points, in a bring center different kind of recyclable materials are accepted. Even bring centers are located away from the residential area, they has to be easy access for citizens. Kogler (2007) indicated that space and personnel requirements are the limitation for these centers. Figure 1.5 indicates bring center replacement in a city.

The advantages and disadvantages of drop-off collection system are listed below.

Advantages:

- Lower investments and operational cost
- Lower costs compared to curbside collection
- More separated waste

Disadvantages:

- Difficult access for citizens
- Low participation rate compared to other systems

- Low collection rate compared to other systems

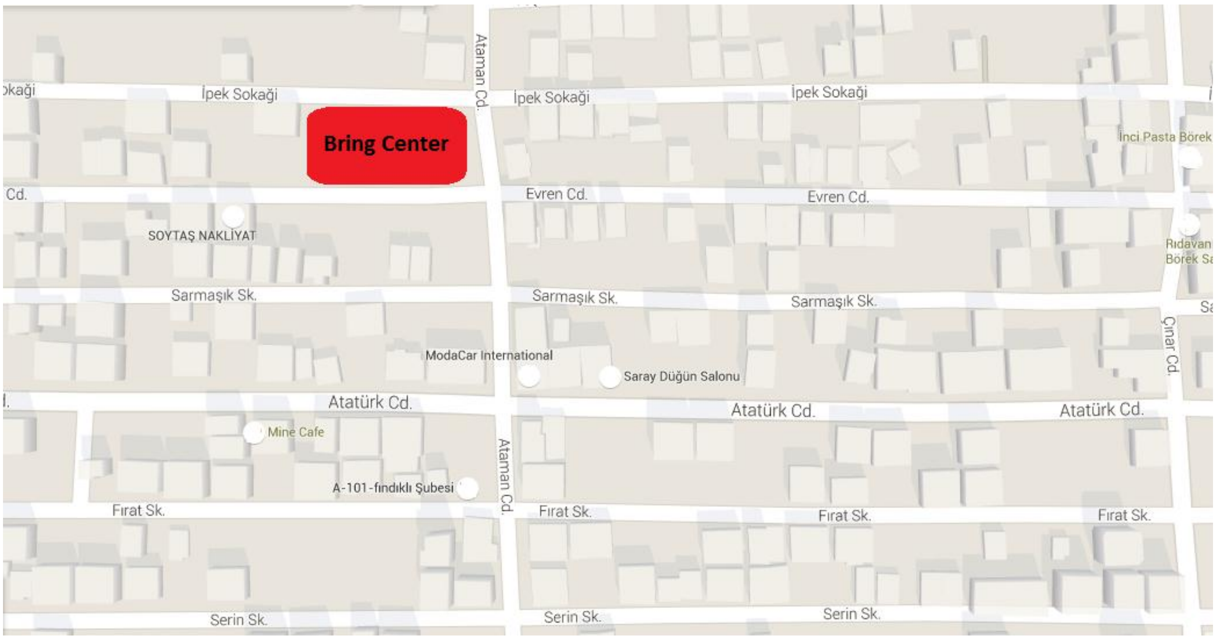

Figure 1.5. Replacement of collection materials in a bring center collection system.

1.1.3.5 Vacuum Collection

In a vacuum collection system, waste bins are located inside the building with a piping system reaches to each household as illustrated in Figure 1.6. Waste is stored in special waste inlets located in the buildings. System basically works with suction process. This system is the most preferable one for the citizens (Kogler, 2007).

Advantages:

- Easy application for citizens
- No need for collection material
- High collection rate

Disadvantages:

- Higher investment costs compared to other systems
- High operation cost of sucking stations
- Only applicable for new urbanized cities or sites

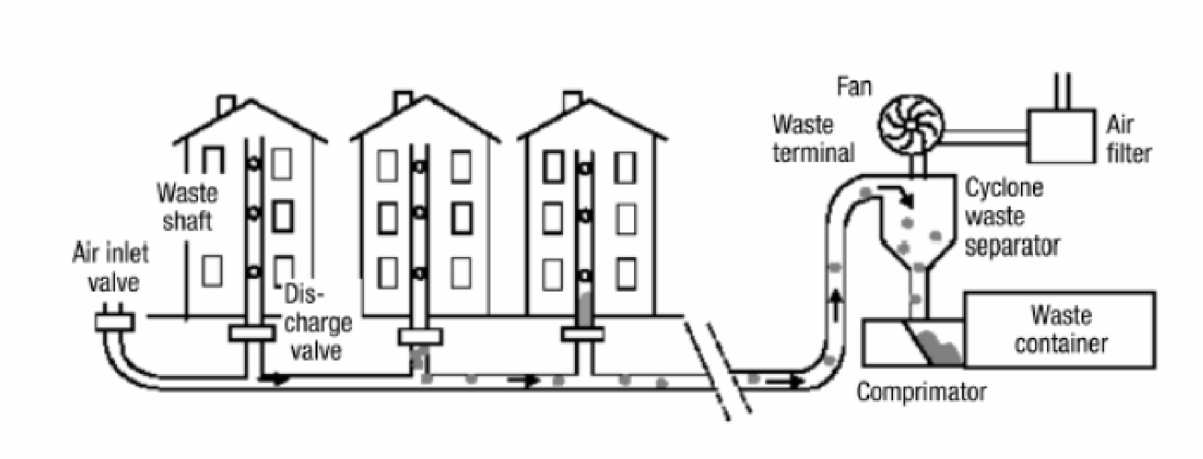

Figure 1.6. An illustration of vacuum collection system.

1.1.3.6 Collection by scavengers

The scavengers are the individual groups carrying out the collection activities in an informal way. They are also known as rag pickers or waste pickers depending. They separate and collect recyclable materials from curbside bins located on the streets, markets and other collection points and sell them in order to enhance their livelihoods. Their working conditions has too many health and safety risk. Informal recycling activities are mostly observed in low-income countries (Aparcana and Salhofer 2013a).

Advantages:

- High participation and collection rate
- Low investment and operational costs
- Easy for citizens

Disadvantages:

- Illegal working conditions
- Health and safety problems of workers

Table 1.7. Comparative analysis of the collection systems.

System	Definition	Advantages	Disadvantages
Door-to-door collection	Materials are located in each building and stored in the house or building. Then collected once a week	-Effortless for citizens -No transportation distance for citizens -High participation rate -High collection rate comparing the curbside, drop-off and bring center systems -More cleanly separated materials	-High plastic bag consumption -Fixed collection schedule -High collection cost -More material requirement -Complex collection route -Storage are requirement for participants
Curbside collection	Bins are located on the streets between the range of 50-100 m. Citizens may deposit the waste 7/24.	-High user comfort -High collection rate compared to drop-off and bring center system -Easy access on the streets -No storage problems in the buildings -Less transportation distance	-High investment costs -Higher operational costs resulting from usage of the smaller containers -Often lower quality of recyclables -Low material amount due to illegal collection
Drop-off collection	Bins are located on the streets between the range of 500-1000 m. Citizens may deposit the waste 7/24.	-Less material consumption -Easy access for collection vehicles -High participation rate -No storage problem in the households -Low operational and investment cost -High quality of recyclables	-Long walking distance -Low participation rate -More material and special vehicle requirement -More space requirement because -Difficulties to find suitable areas -Not suitable for narrow streets
Bring centers	Centers located in a place serving the 30,000-50,000 citizens	-Lower investments cost -Lower costs compared to curbside collection -More separated waste	-Difficult access for citizens -Low participation rate -Low collection rate compared
Vacuum collection	Separation and collection in the households	-Easy application for citizens -No need for collection material -High collection rate	-Higher investment costs -Higher costs for installation -Only applicable for new urbanized cities or sites
Scavengers	Collection on the street from mixed waste containers	-Highest collection rate -Lowest investment and operational costs	-Illegal working conditions -Health and safety problems

1.1.4 Packaging waste management in the World

In Europe, separate collection of packaging waste is carried out almost all countries, but in a very different way. Some countries have already had a long term experience of recycling of packaging materials. For instance, a well-functioning recycling system for glass, paper-cardboard packagings was already existed in Austria, Denmark, Finland, Germany, the Netherlands and Sweden, before the EU legislative directives. In order to comply with the legal arrangements given in Table 1.3, European union countries applied different collection systems. Table 1.8 below provides an overview of the collection systems applied in Europe. As seen on the Table 1.8, Austria and Germany has the most comprehensive collection system.

Table 1.8. European Packaging Waste collection systems (adapted from EC, 2001).

Country	Collection system
Austria	Curbside bring-centers for glass, paper and metals; most of the plastics are incinerated for energy recovery
Belgium	Curbside system except for glass; glass are collected separately in two colours
Denmark	Collection depends to local conditions. Glass separated in two colours; Paper collected with newspaper etc.
Finland	Bring system; cardboard is collected separately; glass are collected with curbside system
France	Colour separated glass collection; plastics and aluminums are collected separately
Germany	Mainly curbside bring-system for glass and paper ; Plastics, metals, composites: collected together
Ireland	Glass and aluminum are separately collected in bring centers
Italy	Depending on local condition, glass, paper, plastics and aluminum are separately collected
Luxembourg	Bring system except for plastics bottles, metals and cartons; Paper collected with newspapers; plastics are collected in blue bags or bins
Portugal	Mainly bring-system, in some areas curbside system; glass, paper and plastics are collected in separate bins
Spain	Mainly bring system, in some areas curbside system; glass, paper and plastics are collected in separate bins
Sweden	Bring-system
The Netherlands	Paper and cardboard collected mainly in bring; glass are collected separately; Plastics, metals are collected separately on a small scale
UK	Mainly bring system, some areas curbside system; glass collected separately; Aluminum collected in bring centers

In Europe, there are mainly three different types of recycling material collection systems in terms of sharing responsibilities (Table 1.9). In Austria, Germany, Sweden; industry covers the all financial expenses, municipalities are only be responsible for collection. In Belgium, Denmark, Finland, France, Ireland, Italy, Luxembourg, Portugal, Spain; industry is responsible for covering the sorting and recycling cost, whereas municipalities covers the separate collection costs. And in the United Kingdom and the Netherlands; industry and municipalities also share responsibilities of recycling system (EC, 2001).

Table 1.9. Share of responsibility according to recycling activity in Europe countries (derived from EC , 2001).

Country	Collection and sorting	Recovery
Austria	Private organizations	Private organizations
Belgium	Municipalities	Private organizations
Denmark	Municipalities	Industry
Finland	Municipalities	Private organizations
France	Municipalities	Private organizations
Germany	Private organizations	Industry
Ireland	Municipalities	Private organizations
Italy	Municipalities	Private organizations
Luxembourg	Municipalities	Private organizations
Portugal	Municipalities	Material manufacturers
Spain	Municipalities	Private organizations
Sweden	Material companies	Material companies
The Netherlands	Municipalities	Industry
UK	Municipalities	Industry

Regarding to the above given legalizations and recycling systems, most of the European countries complied with the targets as determined in the 94/62/EC. Considering 2008 targets given in Figure 1.7, 15 countries officially accomplished the minimum targets, whereas 14 of them have also exceed the maximum targets of the Directive. Figure 1.8 represent the recycling rate accomplished by whole European Union countries. On the other hand; in 2013 when overall packaging waste generation and recycled material rate were analyzed, 21 out of 31 European Union countries fulfilled the minimum target of 50 %.

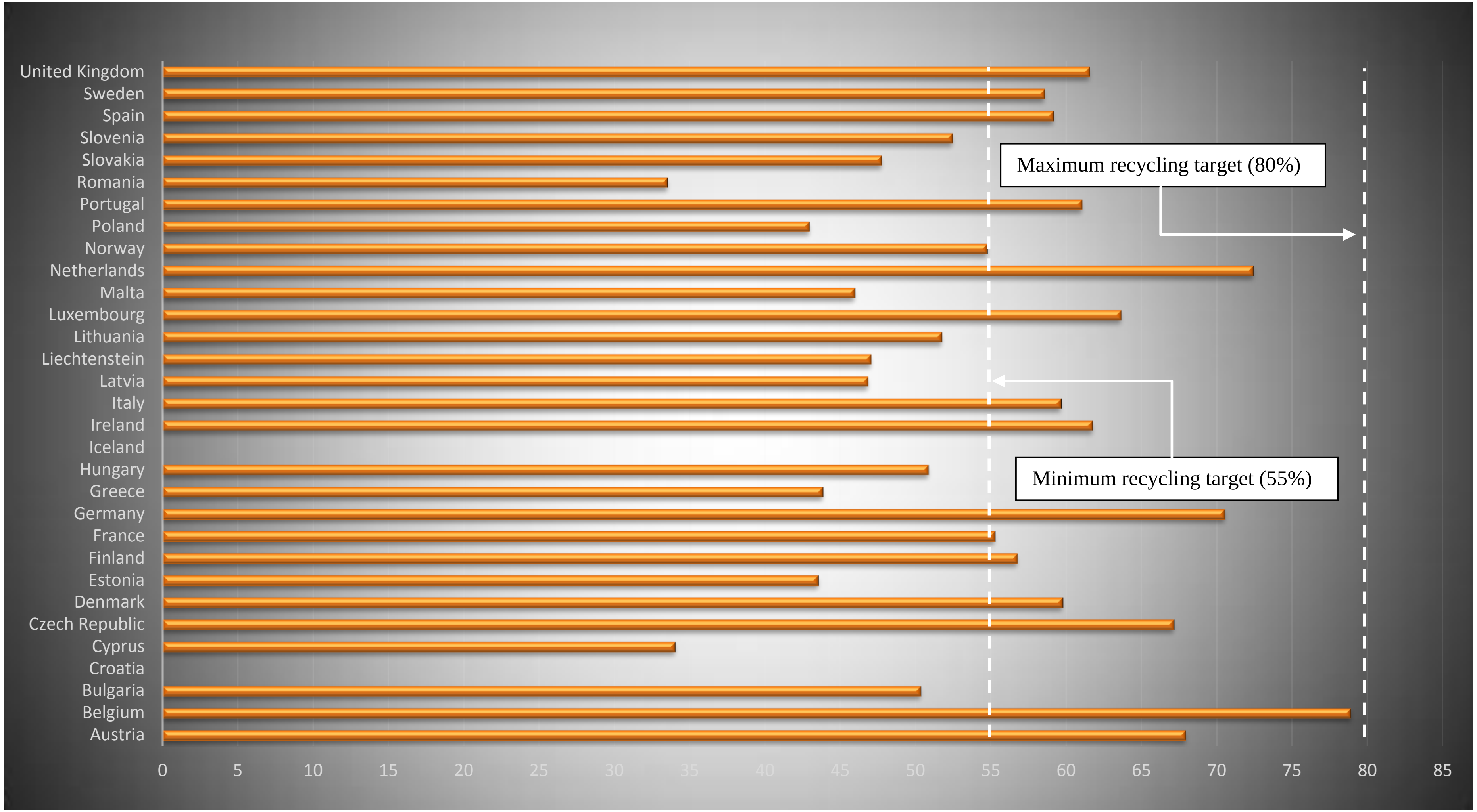

Figure 1.7. Packaging waste recycling rate in European Union countries in 2008 (% of packaging waste generated).
*Data for Iceland and Croatia are not available for 2008.

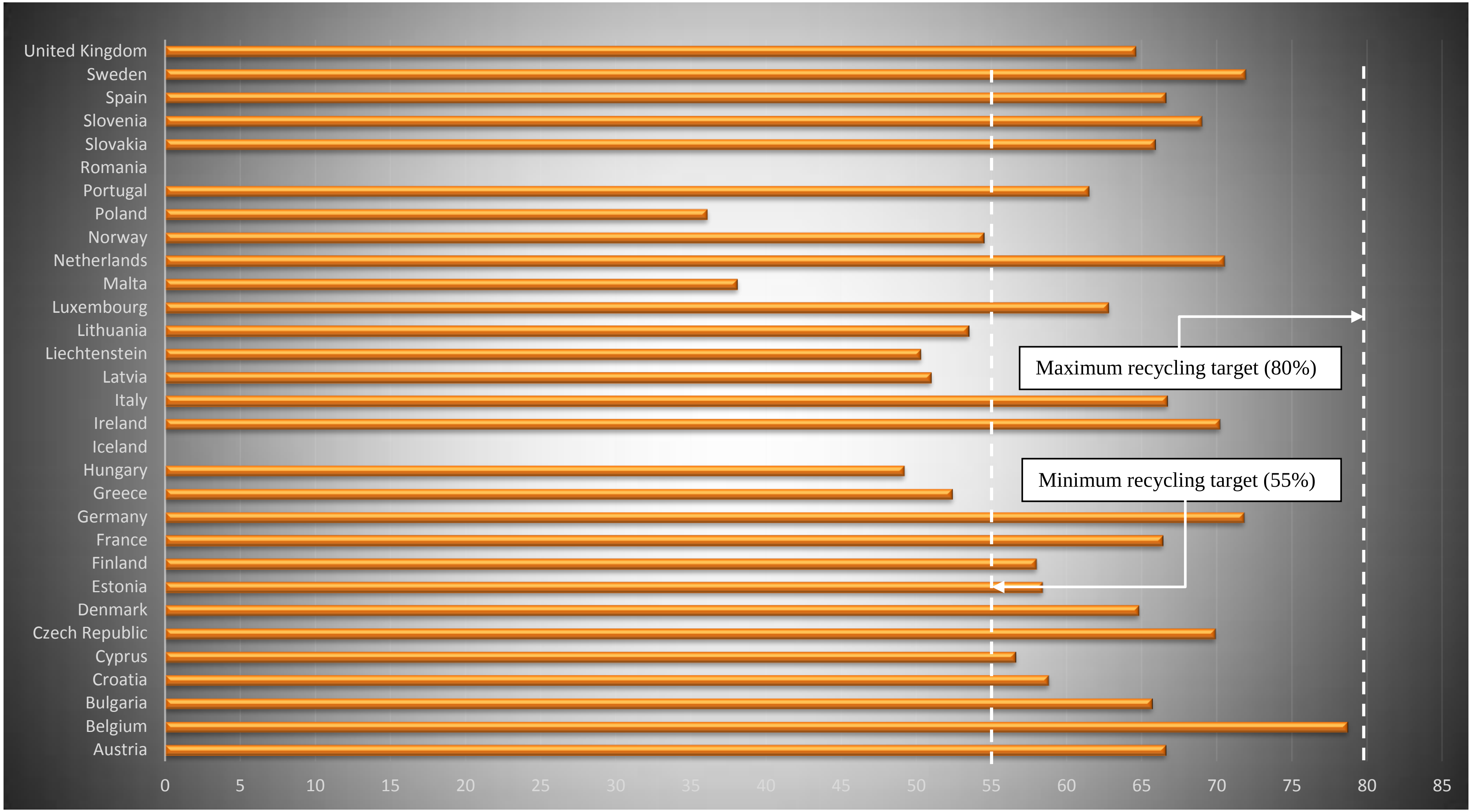

Figure 1.8. Packaging waste recycling rate in European Union countries in 2013 (% of packaging waste generated).
*Data for Romania and Iceland are not available for 2013

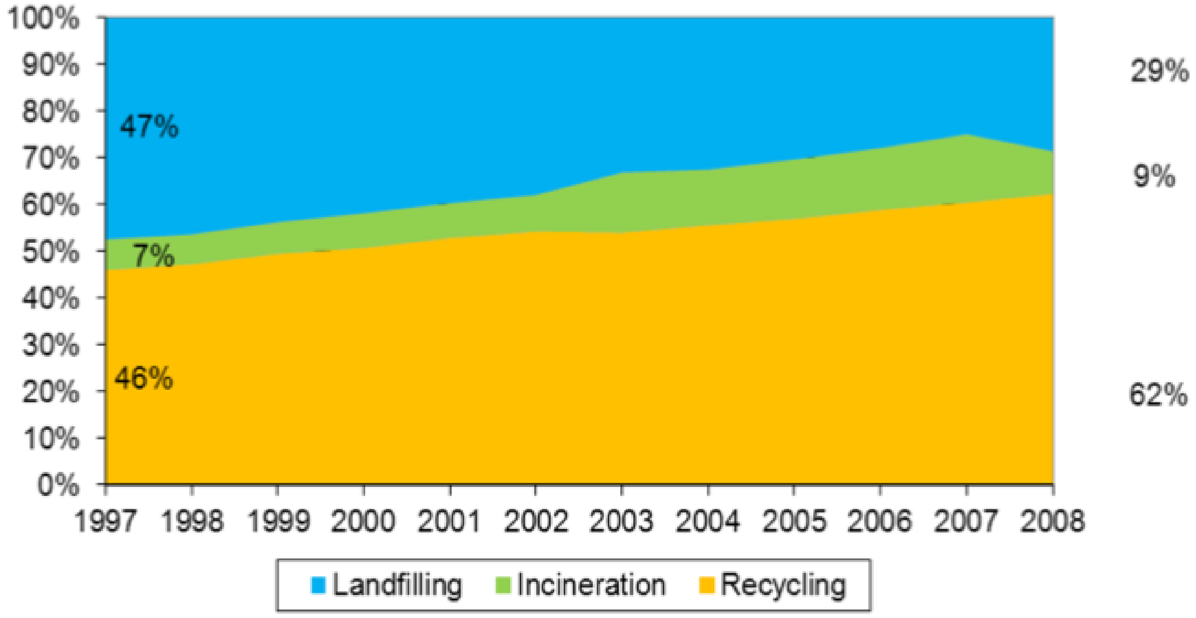

Figure 1.9. Packaging waste treatment methods applied in Europe (%)

In Figure 1.9, packaging waste treatment methods applied in Europe is shown. In 1997 landfilling and recycling of packaging wastes were almost same level, whereas in 2008 recycling rate increased to 62 % from 46 %.

1.1.5 Packaging waste management in Turkey

Similar to other developing countries, Turkey has also to deal with the problems caused by the increasing Municipal Solid Waste. In 1994, household solid waste amount was 17,757,000 ton/year whereas in 2014 it was approximately 28,011,000 ton/year. Figure 1.7 indicates the waste amount generated along with the population growth in between 1994 and 2014. Considering the collection of the packaging waste by informal collection, an estimated total municipal waste data is calculated in accordance with daily waste generation rate published in TUIK (2016). AYEP (2008) prepared by MoEU pointed out that daily waste generation amount rate should be calculated by considering the informal collection of packaging waste. So they considered an additional amount between 5 to 10 %.

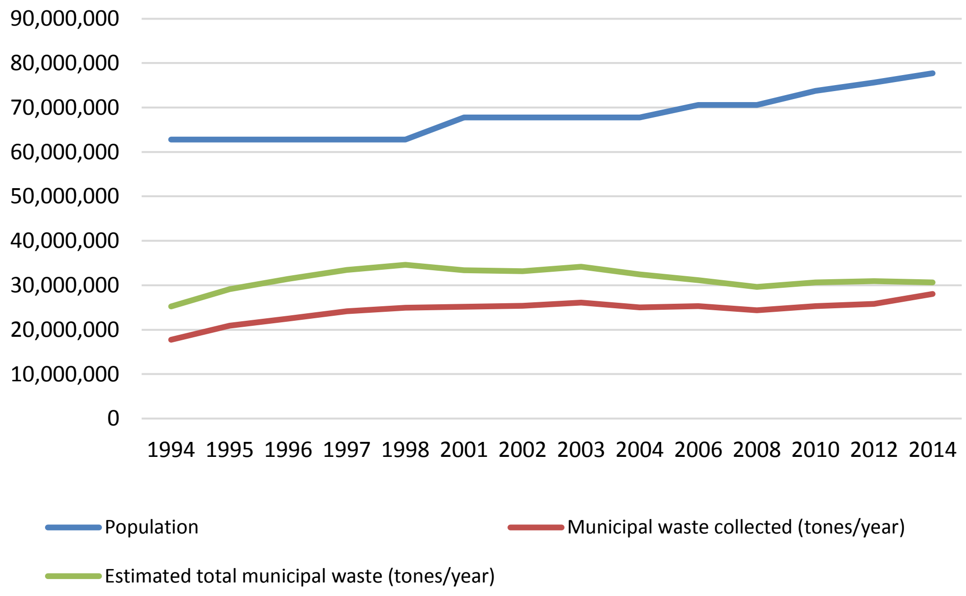

Figure 1.7. Annually amount of municipal solid waste in accordance with population in Turkey, between 1994 and 2014.

Municipal solid waste consist of 34 % food waste, 22 % incinerable waste (textile, wood, etc.), 19% non-incinerable waste (construction waste, inert waste), 11 % paper, 6 % glass, 5 % cardboard, 2 % plastic, 1 % metal waste (Figure 1.8). Packaging waste constitute the 25 % of the municipal waste generated in Turkey.

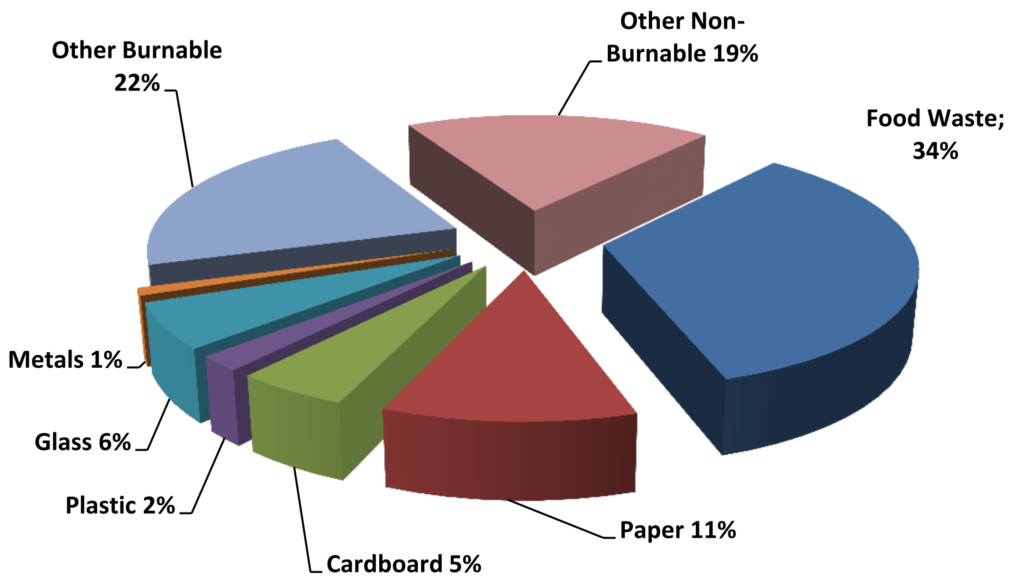

Figure 1.8. Household solid waste composition for Turkey (KAAP, 2012).

According to the Regulation, companies marketing packaged products to the domestic market with their own or imported brands are positioned as marketers. As we previously indicated, marketers are obliged to recycle or recover certain amount of packagings which they released to market.

The packagings put on the market between 1992 and 2013 is shown in Figure 1.9. As it is seen marketing of packaged products has been increased dramatically after the publication of the regulation of controlling packaging waste (AAKY, 2004). Between 1992 and 2003, the total amounts of packagings released to the market in the Turkey is about 3,174,967 ton. And 1,084,105 ton of packaging has been either recovered or recycled (Figure 1.9) and total recycling rate was 34.1 %. After the legislative arrangements in 2004, the marketing of packagings increased 18,254,773 ton. And 85 % of these packagings (15,522,812 ton) were either recovered or recycled (Figure 1.10 and Figure 1.11).

According to the reported data, the minimum recycling target indicated in the AAYP (2004) and AAYP (2007) was specifically exceeded from 2004 to 2007 (Figure 1.12). It is obvious that marketers also fulfilled the target in overall. This is mainly due to the recycling rates for paper/cardboard and glass packaging.

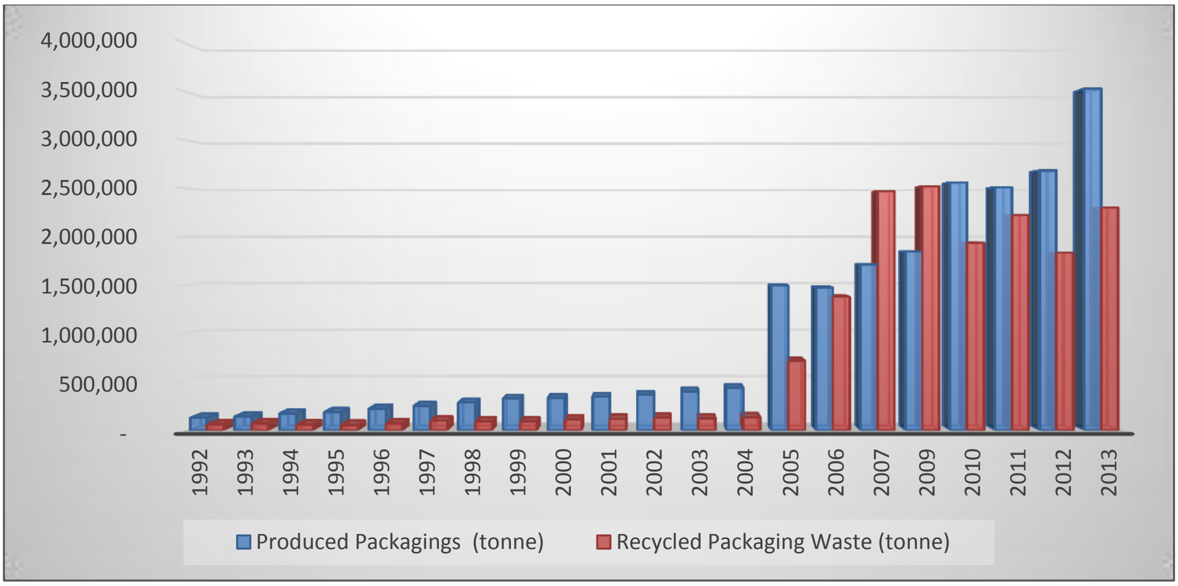

Figure 1.9. Annually produced and recycled packaging amounts in Turkey (AYEP, 2008; ÇSB,2016).

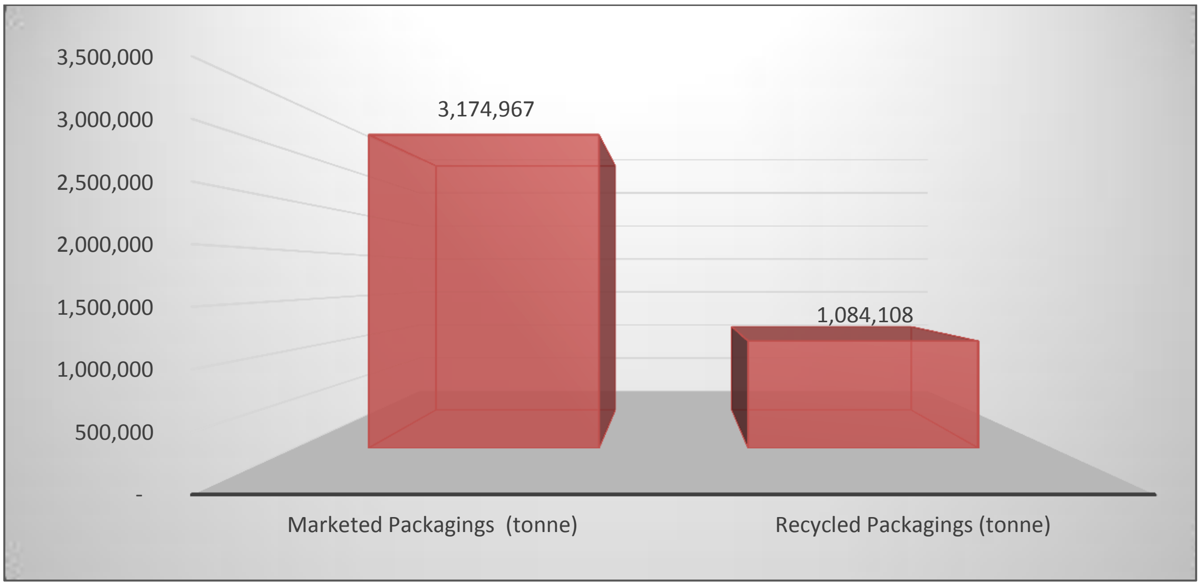

Figure 1.10. Total amounts of produced and recycled packagings by marketers in Turkey between 1992 and 2003 (AYEP, 2008; ÇSB,2016).

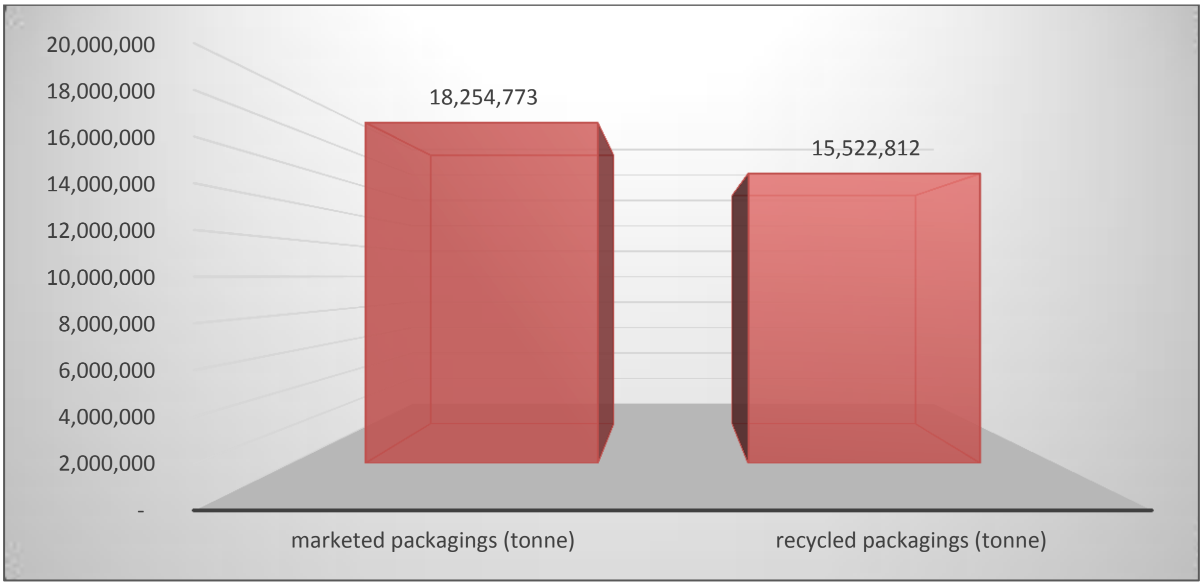

Figure 1.11. Total amounts of produced and recycled packagings by marketers in Turkey between 2004 and 2013 (CSB, 2012; 2013; 2014; 2015; 2016).

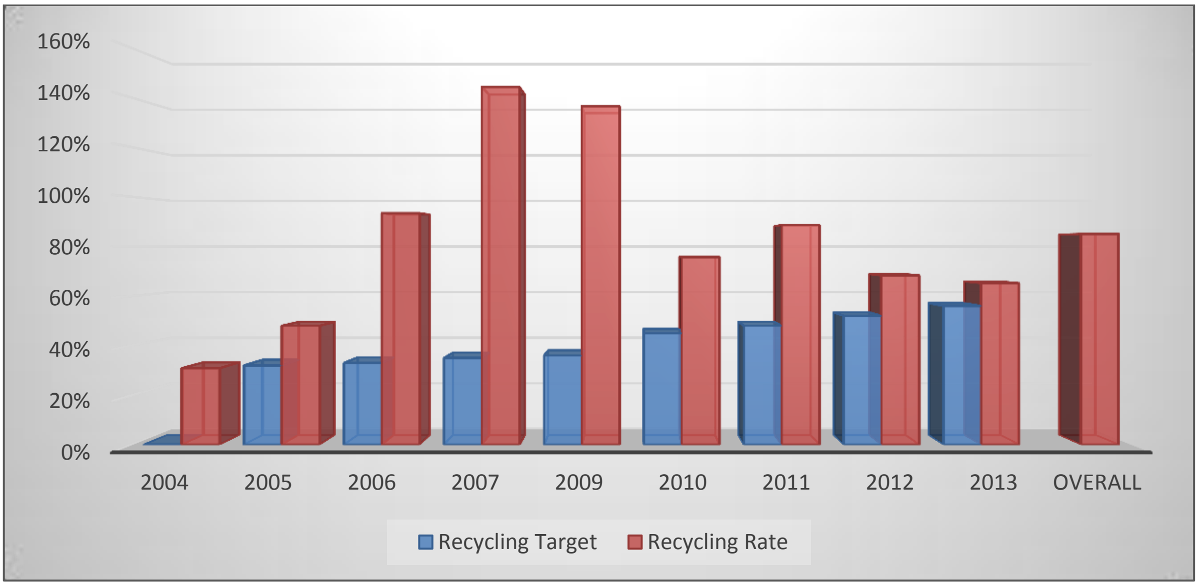

Figure 1.12. Overall recycling rates and legislative recycling targets of packaging waste accomplished by marketers in Turkey (CSB,2012; 2013; 2014; 2015; 2016).

For the successful and sustainable execution of practices regarding separate collection of packaging waste at source ; a "Packaging Waste Management Plan" which defining in detail what activity is to be done when, where and how need to be prepared by Municipalities according to the Regulation on the Control of Packaging Waste published in the Official Gazette dated 24.08.2011 and numbered 28035. Preparation and application of this plan is mainly done by the cooperation of municipal authorities, authorized institutions and licensed companies. Municipal authorities can either practice separate collection themselves or procure such service from licensed collection-separation plants.

In Turkey, there are only three authorized institutions namely; ÇEVKO, TUKÇEV and PAGÇEV. And in the existing situation, only 245 out of 1391 municipalities have legally cooperated with these authorized institutions (Figure 1.13).

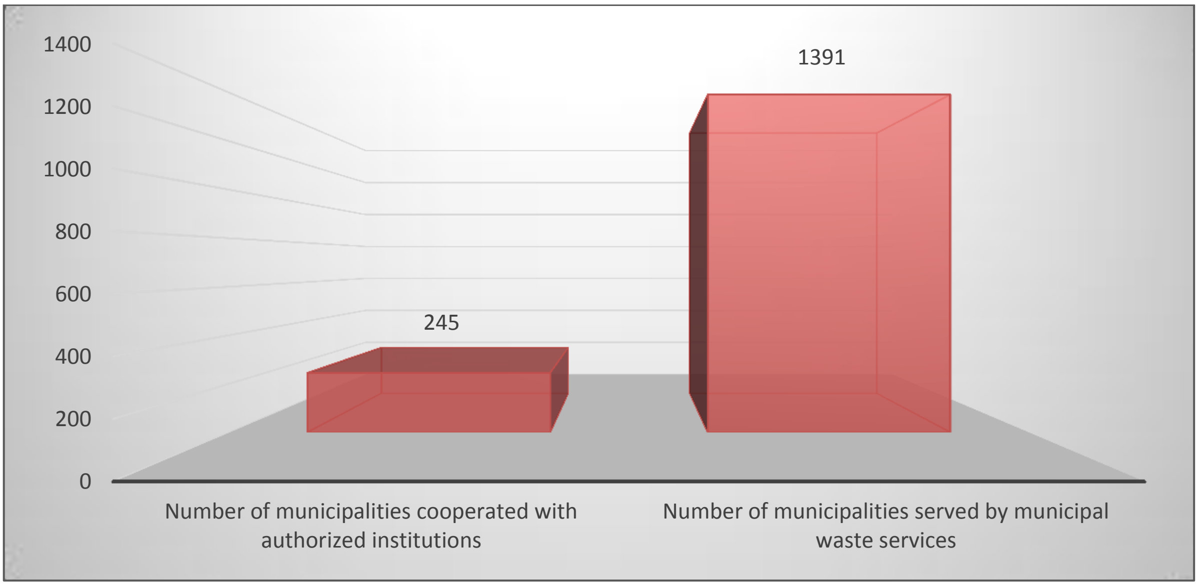

Figure 1.13. Analysis of cooperation with authorized institutions.

As we previously indicated, regulation make different social groups responsible for certain subjects. Even though above given sector-based targets are accomplished, a systematic collection is still required. Because most of the recycled materials collected unregistered and informally. Below collection system applied by different cities are discussed.

In Table 1.10, estimated packaging waste amounts and collection accomplished by municipalities are listed. It is clearly seen that municipalities has different efficiency on collection of packaging waste. For instance; in Istanbul, Zeytinburnu Municipality collected the 65 % of packaging waste whereas Gaziosmanpasa Municipality collected only 11 %. These difference depends on various factors such as; social awareness, authorities approach, insufficient legislative enforcement, inefficient collection system and mostly the existence of informal collection system (KBFR, 2015a; NBFR, 2015; ÇBFR, 2015; EBFR, 2015; TBFR, 2015; OBFR, 2015; KBFR, 2015b; MBFR, 2015; BBFR, 2015a; BBFR, 2015b; GBFR, 2015; ZBFR, 2015; ÜBFR, 2015; ÇBFR, 2015).

Table 1.10. Estimation of packaging waste amounts and formal collection rate accomplished by Municipalities in 2014.

City	District	Population (person)	*Daily waste generation (kg/person)	Municipal solid waste (ton/year)	**Potential packaging waste (ton/year)	***Formally collected packaging waste (ton/year)	Collection rate (%)
Ankara	Keçiören	889,876	1.28	415,750.07	62,362.51	13,491	22
Bursa	Nilüfer	358,265	1.24	162,150.74	24,322.61	8,991	37
Çanakkale	Çanakkale	511,790	1.16	216,691.89	32,503.78	8,575	26
Edirne	Edirne	400,280	1.16	169,478.55	25,421.78	2,240	9
Eskişehir	Tepebaşı	323,631	0.94	111,037.80	16,655.67	7,727	46
Eskişehir	Odunpazarı	376,650	0.94	129,228.62	19,384.29	7,970	41
İstanbul	Kadıköy	482,571	1.28	225,457.17	33,818.58	7,186	21
İstanbul	Bağcılar	754,623	1.28	352,559.87	52,883.98	11,262	21
İstanbul	Beşiktaş	188,793	1.28	88,204.09	13,230.61	5,503	42
İstanbul	Maltepe	476,806	1.28	222,763.76	33,414.56	4,630	14
İstanbul	Gaziosmanpaşa	498,120	1.28	232,721.66	34,908.25	3,841	11
İstanbul	Ümraniye	674,131	1.28	314,954.00	47,243.10	13,982	30
İstanbul	Zeytinburnu	287,223	1.28	134,190.59	20,128.59	13,081	65
Kocaeli	Çayırova	109,698	1.24	49,649.31	7,447.40	1,907	26

* Daily waste generation rate was indicated specifically for each city in AYEP, 2008.

**AYEP, 2008 determined the rate of the packagings as 15% in total municipal solid waste.

***Collection data found in Performance Reports of related Municipalities.

For an efficient collection system, the most outstanding factor is the collection system applied by municipalities. In Turkey, source-separated collection of packaging waste is provided by recycling bins and/or plastic bags. The collection method is determined by considering the characteristics of the region. Table 1.11 shows the main collection system applied in Turkey.

Table 1.11. Collection systems applied by Municipalities in Turkey.

Collection system	Main Definition
Door-to-door collection	Recycling bags used for collection. Municipality collect bags from doors.
Curbside collection	Preferable for the sites, schools and other secured areas. They are not placed on the streets because of the scavengers
Drop-off collection	Mainly placed on the streets. Bins are protected with a locked system

1.2 Problem Definition and Solution Approach

In the previous sections, importance of packaging waste management, legislative arrangement, most used collection systems and system applications around the world were discussed. The importance of packaging waste management significantly indicated. The main principle of waste management concept is to maximize the waste recovery rate through an effective collection, recycling and/or recovery considering the entire aspects of system.

The recyclable wastes in Turkey are mainly collected by door-to-door and drop-off point system, which is carried out by municipalities. However, a large proportion of recyclables are collected by scavengers, who are described by Sanneh et al. (2011) as the citizens collect the recyclable materials either from container located in the city or from dump sites and sell them to provide an income. Agunwamba (2003) stated that because of the social, cultural, financial and environmental conditions, the implementation of the source separation of recyclable materials in Nigeria may not be an effective system considering the investment cost, requirement of public education and expertise of the system. Therefore, integration of the scavengers into the system was suggested as a solution. However, this is an uncontrolled and informal collection system which has numerous social disadvantages such as health risk, low income, child labour, etc.

Even if increasing the amount of the recyclable materials have an important positive effect on ecosystem, it has also a negative effect arising from the collection system which consumes resources and release emissions. Therefore, it is important to analyze the system with a holistic approach.

In order to accomplish a social and environmental sustainable waste management system, life cycle assessment approach is suggested as a solution approach. A holistic life cycle assessment approach has to be applied for a sustainable waste management system. Life cycle sustainability assessment (LCSA) is an analysis assessing the environmental and social impacts related to all the stages of a service, organization or product's entire life from cradle to grave, gate to grave, grave to grave, gate to gate which is defined as from raw material extraction stage to materials processing, manufacturing, use, recycling and/or disposal (ISO 14040, 2006; UNEP/SETAC, 2012). The details of the life cycle approach is given in the following sections.

1.3 Literature Review

Considering the above given solution suggestion, in this section a literature review on LCA of waste management system is submitted. Different environmental life cycle assessment (ELCA) and social life cycle assessment (SLCA) studies are discussed particularly.

1.3.1 Literature Review on ELCA

ELCA is the most researched and applied analysis among the LCSA tools. When we search ELCA literature, there are over 200 ELCA studies which only focused on the waste management system as a special issue. For instance, Laurent et al. (2014) listed 222 ELCA studies of solid waste management systems published between 1995 and mid-2012, in their literature review. Between these studies, Manfredi et al. (2011), Larsen et al. (2010), Hunt (1995), Merrild et al. (2012), Rigamonti et al. (2009) and Rigamonti et al. (2010) were especially studied ELCA of recyclable materials such as organic, plastic, paper, glass and Al waste. For instance, Rigamonti et al. (2009) pointed out the influence of source-separated materials on integrated waste management systems. Bovea et al. (2010) were focused on the environmental impacts of pre-collection stage along with the integrated waste management system. Iriarte et al. (2009) compared the environmental impacts of the mobile pneumatic, multi-container and door-to-door collection systems. Larsen et al. (2010) also carried out environmental and economic assessment of five alternative collection systems with the different efficiency for collecting recyclables in Denmark. Guigliano et al. (2011) analyzed four collection systems to determine the environmentally best performing scenario.

Beside these system development studies, some researchers were focused on the efficiency increment. Gallardo et al. (2012) indicated that efficiency of a separate collection system was influenced by a number of elements which were mainly environmental, economic, social, political, legal and technological factors. Also to achieve an increment on the collection efficiency of recyclable materials, it is important to analyze citizens' behavior comparing the several collection systems: participation level, waste quality, economic reasons, etc. For the social aspects of the system, Martin et al. (2006) carried out a review of approaches taken in England to encourage citizens to participate in recycling and McDonald and Ball (1998), Read (1999), Perrin and Barton (2001), Dahlén et al. (2007), and Thomas (2001) were also studied on public participation in England. For instance, Kaciak and Kushner (2009) determined the factors that influence recycling behavior and examined the socio-demographic characteristics of participants in some regions of Canada. Also Omran et al. (2009) and Otitoju (2014) researched the individual attitude of participants in Malaysia and Nigeria, respectively. Gellynck et al. (2011) identified the 12 variables to increase recycling and reducing the residual household waste in Belgium. Heravi et al. (2013) compared different recycling collection scenarios, in Tehran, considering the source consumption, cost benefit, public acceptability, and risk assessment of the scenarios.

Above given literature researches, mainly examined the efficiency of source separation system related with multiple variations. Generally, main purpose on these researches was to make an increment on the amount of recyclable materials or to determine reason of the current situation. However, even if increasing the amount of the recyclable materials have an important positive effect on ecosystem, it has also a negative effect arising from the collection system which consumes resources and release emissions. Therefore, it is important to analyze the system with a holistic approach.

The environmental, economic and social analysis of the municipal solid waste management systems was generally conducted using the LCA methodology. Many researches applied in this subject were focused on the use of LCA as a decision support tool in the determination of the optimum system and it is commonly used through the world on any stages or whole stages of MSWMS (Weitz et al., 1999; Soderman, 2003; Skordilis, 2004; Rebitzer et al., 2004; Özeler et al., 2006; Guereca et al., 2006;Boer et al., 2007; Gomes et al., 2008;Rigamonti et al., 2009;Banar et al., 2009; Rives et al., 2010; Hong et al., 2010;Bovea and Powell, 2010; Menikpura et al., 2012a; Menikpura et al., 2012b).

For example, Slagstag and Brattemo (2012) used the LCA methodology in the planning of new urbanized area, to analyze different SWMS scenarios comparing current system to other solutions. To analyze the environmental impact assessment, five management scenarios are model combining incineration, recycling and anaerobic digestion. Increasing the sorting efficiency of recyclable materials in somewhat was more beneficial.

Teerioja et al. (2012) compared social life cycle costs of a stationary pneumatic waste collection system to a vehicle-operated door-to-door collection system in Finland and found that traditional door-to-door system economically had more advantages than pneumatic system.

Bovea et al. (2010) studied on the environmental life cycle of 24 waste management scenarios which were consisted of pre-collection, collection, transport, pre-treatment and treatment/disposal stages.

Iriarte et al. (2009) quantified and compared the potential environmental impacts of mobile pneumatic, multi-container and door-to-door collection systems and found that, the collection system with the least impact was multi-container collection system whereas door-to-door and mobile pneumatic systems had the greatest impact at the urban subsystem level.

Rigamonti et al. (2009) evaluated how different assumptions about recycling system influenced the LCA results of integrated waste management system and indicated that source-separated collected materials had a great influence of the whole management system as 15% decrease on the selection efficiencies resulted in 26% increase on global warming effect of the system.

Larsen et al. (2010) carried out environmental and economic assessment of five alternative collection systems with the different efficiency for collecting recyclables in Denmark and found that curbside collection would be environmentally more beneficial than drop-off and bring centers.

Guigliano et al. (2011) analyzed four scenarios of separate collection system including drop-off collection systems with 35 and 50 % overall separation and curbside collection systems with overall separate collection value of 50 and 65 %, and found that 50% separate collection system was the best performing scenario.

Until this year, as Laurent et al. (2014) indicated, only Banar et al. (2006) and Özeler et al. (2006) were used the LCA methodology to determine the optimum municipal solid waste management system in Ankara, Turkey. Similar study was conducted by Erses Yay A.S (2015) for Sakarya, Turkey.

1.3.2 Literature Review on SLCA

Comparing with ELCA, SLCA is a very young and still developing research area. Literature review showed that there had been only a few theoretical studies on the integration of social impact into LCA and methodological approaches developed for SLCA concept. In order to integrate the social impacts into LCA studies there are a few studies carried out by (O'Brian M, et. al., 1996; Kloepffer W., 2003; Dreyer et. al., 2005; Schmidt et al., 2005; Weidema, 2005; Weidema, 2006; Hunkeler, 2006; Brent et al., 2006; Brent and Labuschagne, 2006;), Griesshammer et. al., 2006; Dreyer et. al., 2006; Jorgensen et. al., 2008; Hutchins and Sutherland, 2008; Kloepffer, 2006).

O'Brien et al. (1996) suggested a technique for integrating environmental and social assessments of different systems considering the human needs in both operational and strategic terms in an energy system as a specific case study/example.

Schmidt et al.(2005) aimed to propose a life cycle assessment tool to achieve eco-efficiency and socio-efficiency of the alternative products or processes.

Dreyer et al. (2005) searched the social impact as a decision-making tool and incorporated the impacts of products and services respecting to fulfillment of the basic health and dignity needs of humans.

Hunkeler (2006) considered the working hours as a variable to assess the social impacts. A case study based on the comparative production was analyzed. In the case study, four impact categories, namely housing, health care, education, and necessities were developed. This study showed that concerned method could be implemented by adapting the impact categories.

Weidema (2006) focused on the elements of Cost Benefit Analysis and identified six damage categories in the other terms Areas of Protection or 'Impact Categories' and converted to all impacts into the Quality Adjusted Life Years as a main measure of human health and well-being.

Norris (2006) proposed a methodology to examine the health benefits and damages of economic development impacts in a products' life cycle.

Griesshammer et al. (2006) studied the integration of social aspects into LCA as a feasibility study in order to identify if the social impact can be integrated into LCA or not.

A review of SLCA methodology approaches is studied by Jorgensen et al. (2008). In this review, these approaches were compared, and methodological difference and general limitations were determined by following the methodological steps of the ISO 14044 standard.

Hauschild et al. (2008) presented the SLCA implementation in four years worked industry and lessons learned on development of a methodology to this industry.

Simultaneously with these studies, between the 2004 and 2009, United Nations Environment Program/Society of Environmental Toxicology and Chemistry (UNEP/SETAC) working group conducted a research and in 2009 the publication of the "Guidelines for Social Life Cycle Assessment of Products" was launched. Guideline consist of a methodological sheets for providing a more practical support to the practitioners. Social issues are expressed as subcategories and classified with regard to social group categories and impact categories. Social groups are categorized as workers, value chain actors, consumers, society and local communities where as impact categories are classified as human rights, working conditions, health and safety, cultural heritage, governance, and socioeconomic repercussions. UNEP/SETAC, (2009) defines the social issues by relating them with international instruments such as conventions, agreements, targets, and describes the possible social indicators in the light of the policy relevance. After the publication of UNEP/SETAC guideline, more case studies have been conducted. However, case study applications are still very limited. Below same case studies and reviews published after the guideline are summarized.

Franze and Ciroth, (2011) aimed to try out a method based on the "Guidelines for Social Life Cycle Assessment of Products" which was developed by the UNEP/SETAC life cycle initiative. Rose production case studies in Ecuador and Netherlands were analyzed and compared in the scope of environmental and social life cycle assessment. In the Ecuador case study 16 indicator for production part and 18 indicator for cutting and packaging parts of roses were identified whereas in the Netherlands case study it was 13 and 15 indicators for the same production stages. Scoring of the indicators were done considering their existence (exist or not exist). Impacts to health and safety, socio-economic repercussion, development of the country, human rights and indigenous rights were considered as impact categories. Each subcategory under these selected impact categories was evaluated with a color. The case study results showed that environmental and social impact were completely different and need to perform together.

Lehmann et al. (2013) focused on identifying suitable subcategories and indicators and discuss the applicability of SLCA approach proposed in the UNEP/SETAC (2009)guideline for a comparative technology analysis on a product level.

Dreyer et al. (2010a) was mainly focused on the examining of labour rights in SLCA. Previously developed indicators were discussed considering their ability to reflect impacts within the four impact categories (forced labour, discrimination, restrictions of freedom of association and collective bargaining, and child labour) representing the labour rights. Inventory data were also analyzed in terms of their feasibility and the availability. It is concluded that required indicators were feasible and represent the labour right impact categories.

Dreyer et al. (2010b) examined the application of the characterization method implementing the SLCA into six case studies. Forced labour, discrimination, freedom of association and collective bargaining and child labour were researched. In this study, some case studies were conducted respecting to the inventory and characterization steps of the method developed in Dreyer et al. (2010a). It was pointed out that applied methodology were a good alternative for SLCA researches.

Besides all these different SLCA studies; there are only a few SLCA case studies mainly based on waste management systems. To the best of our knowledge, apart from the current thesis, Vinyes et al. (2013), Umair et al. (2013), Ferrao et al. (2013), Foolmaun and Ramjeeawon (2013), Teerioja et al. (2012), Aparcana and Salhofer (2013a,b) had carried out researches on the social issues in waste and waste management systems. Between these studies, Teerioja et al. (2012), Ferrao et al. (2013), Umair et al. (2013), Aparcana and Salhofer (2013a,b) were specifically focused on recyclable material collection systems.

Vinyes et al. (2013) compared the environmental, economic and social sustainability of three domestic used cooking oil collection systems, namely door to door, schools collecting centers and urban collecting centers, in order to design socially and economically efficient system.

Umair et al. (2013) studied the informal electronic waste recycling in Pakistan to improve decision making related to information and communication technology, electronic equipment, and electronic waste, by providing better data on the social impacts. 15 subcategory had been analyzed and assessed in midpoint impact category level. It showed that although informal recycling played a vital role in economic development, it had mostly negative impacts on its workers and community.

For example, Ferrao et al. (2013) were conducted social life cycle cost assessment of a packaging waste management system regarding with number of jobs created as a social issue. Also, Teeriojaet al. (2012) compared social life cycle costs of a stationary pneumatic waste collection system to a vehicle-operated door-to-door collection system in Finland but they only included the maintenance and operation cost of the systems.

Aparcana and Salhofer (2013a) focused on the development of the social life cycle assessment approach by analyzing the proposed indicators and characterization models for informal and formal recycling collection system in low-income countries. Within these framework, 3 social impact categories, 9 social subcategories and 26 semi-quantitative indicators were identified. Research showed that identified categories represent the social problem of informal recyclers. Therefore, it was concluded that application of SLCA methodology to recycling system in low-income countries were feasible.

Aparcana and Salhofer (2013b) applied a methodological approach, developed by Aparcana and Salhofer (2013a), for the social impacts assessment of Peruvian recycling systems with formalization approaches. Three formalized recycling system were analyzed to determine the feasibility of applying proposed methodology. In order to formalize recycling systems two different approaches were used. In the first approach, a cooperation had been done with recyclers ’associations and in the second approach, recyclers were employed by the municipality. To analyze social impacts 26 indicator previously identified by Aparcana and Salhofer (2013a) were used. Because used data form were semi-quantitative, they were transformed into numerical values by using a scoring system. Result of the study showed that freedom of association and collective bargaining, psychological working conditions and social acceptance reveals a positive impact on cooperation with recyclers' associations' approach, while working hours and minimum and fair wages achieved better performance in the method operated by the municipality. Considering the child labour both approaches displayed similar results. However, social impacts for discrimination, employments relationships, physical working conditions and education had the negative social impacts for both formalized system. The study pointed out that SLCA is feasibly adapted to recycling system analysis although it was originally developed for product and process assessments.

These literature reviews showed us, how numbers of social life cycle assessment case studies are insufficient comparing with ELCA studies, especially in packaging waste collection system which is our area of interest.

1.4 Aim of the Study

The overall aim of the thesis is to analyze alternative packaging waste management collection systems and to obtain socially and environmentally optimum collection system alternatives for local authorities and decision makers. The specific aims are to answer the following questions:

From an environmental perspective:

- Is the existing collection system environmentally acceptable ?
- Are the impacts of the formal and informal systems comparable ?
- Which environmental factors affect the collection results?

From a social perspective:

- Has the system social impacts?
- Is the system socially acceptable ?
- Which social factors affect the collection results ?

From an environmental and social perspective:

- Is the collection system idealized ?
- Are the modelled collection systems sustainable in terms of environmental and social perspective ?

2 METHODOLOGY

In this thesis Life Cycle Assessment approach used as a methodology. Life cycle assessment approach is mainly considers environmental effect of an industrial product. However, in this study we used this methodology to determine the environmental and social impacts of existing and alternative recycling material collection systems.

2.1 Life Cycle Approach

The life cycle approach is a perspective considers all life cycle stages of a products or services in a comprehensive production-consumption chains; from the extraction of resources, through production, use, and recycling, up to the final disposal of remaining waste (Perrin and Barton, 2001). It is an integrated concept addressing the environmental, economic, technological, and social aspects of products, services, and organizations. These integration parameters are also pillars of life cycle sustainability methodology which mainly refers to the evaluation of all negative impacts and benefits in decision-making processes towards more sustainable product and/or services throughout their life cycle (ISO, 2006a; ISO, 2006b). LCA research the essentially industrial systems from “cradle-to-grave”. For a production system “Cradle-to-grave” begins with the extraction of raw materials from the earth and ends with disposal as returning back to the earth (EPA, 2006). Figure 2.1 illustrates of a product’s life cycle diagram.

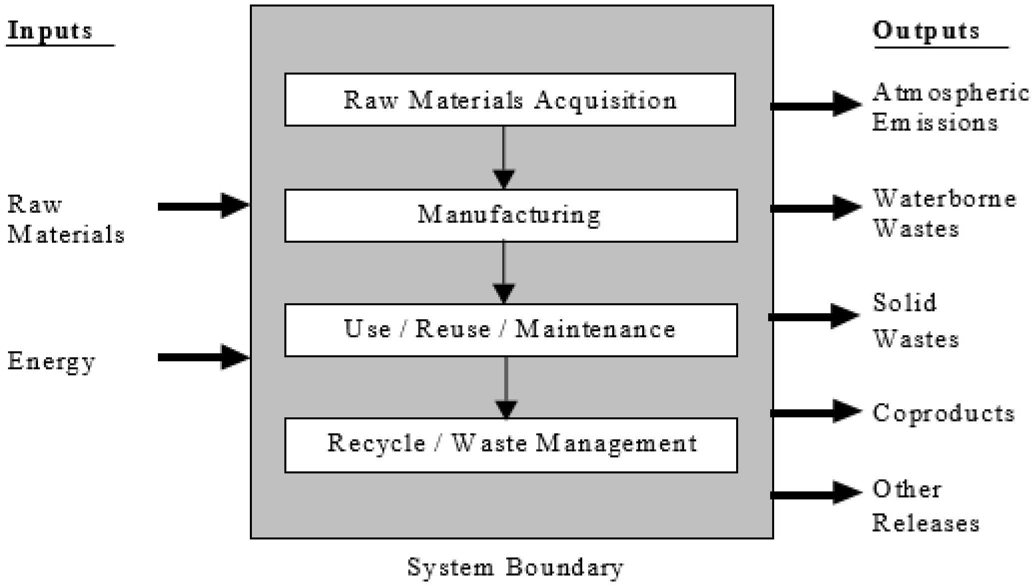

Figure 2.1. Illustration of a product’s life cycle approach (derived from EPA, 2006).

Before the LCSA concept is evaluated, LCA was only considered in an environmental perspective. An ELCA, determines the environmental impacts of production processes or services by measuring the resource consumptions such as energy and material and all relevant emissions associated with these services and products (JRC/IES, 2010). ISO (2006a) defines the" compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system throughout its life cycle".

A SLCA is defined by UNEP/SETAC (2009) as "a social impact assessment technique that aims to assess the social and socio-economic aspects of products and their potential positive and negative impacts along their life cycle". In SLCA, all social aspects are directly related to social groups positively or negatively. Environmental and social life cycle sustainability assessment basically provides similar perspective with ISO (2006a) which is the international standard established for the (environmental) LCA. The UNEP/SETAC (2012) propose that LCSA conforms to the ISO 14040 framework; however, with some adaptation. The methodological framework provided in the guidelines closely follows the LCA methodology, as described in ISO (2006a) and ISO (2006b). Same as LCA, an LCSA consists of four components: goal definition and scoping, inventory analysis, impact assessment, and interpretation. Stages of an LCSA and its key factors are given in Table 2.1 explained in the following sections in detail.

Table 2.1. Stages of an LCSA (adapted from ISO, 2006a).

LCA Phase	Key factors
Goal and Scope	• Goal definition • Scope definition • Functional unit • System boundaries
Life cycle inventory (LCI)	• Developing a flow diagram of the processes • Planning data collection and collecting data • Calculating LCI results
Life cycle impact assessment (LCIA)	• Selection and definition of impact categories • Classification • Characterization • Normalization • Weighting
Interpretations	• Identification of significant issues • Evaluation • Conclusions, limitations and recommendations

2.1.1 Goal and scope definition

ISO, 2006a defines the goal and scope phase of an LCA as the stage where the purpose of the study and methodologies are defined. The scope which is the part compatibly and sufficiently addressing the stated goal by giving the depth and breadth of the study. Scope presents the limitation of the life cycle researches.

The Goal and scope phase of an LCA states the below given items:

- Goal
- Scope
- Functional Unit (FU)
- System Boundaries

The first thing in an LCA application is the an exact definition of the study's purpose which consist of the goal of the study. The second step is the expression of the scope. In this goal and scope definition part, functional unit and system boundaries are also need to be determined (UNEP/SETAC, 2009). Table 2.2 which prepared from ISO, 2006a and ISO, 2006b reports , give the main properties of goal and scope stage of LCA studies.

Table 2.2. Detail description of goal and scope stage of an LCA study (derived from ISO, 2006a).

Goal	Scope	Functional Unit	System Boundaries
–the intended application, –the reasons for carrying out the study, –the intended audience, i.e. to whom the results of the study are intended to be communicated, and –whether the results are intended to be used in comparative assertions intended to be disclosed to the public.	–the product system to be studied; –the functions of the product system or, in the case of comparative studies, the systems; –the functional unit; –the system boundary; –allocation procedures; –impact categories selected and methodology of impact assessment, and subsequent interpretation to be used; –data requirements; –assumptions; –limitations; –initial data quality requirements; –type of critical review, if any; –type and format of the report required for the study.	-a system may have a number of possible functions and the one(s) selected for a study depend(s) on the goal and scope of the LCA. -defines the quantification of the identified functions of the product. - provide a reference to which the inputs and outputs are related. -comparability of LCA results is particularly critical when different systems are being assessed, to ensure that such comparisons are made on a common basis. -it is important to determine the reference flow in each product system, in order to fulfil the intended function, i.e. the amount of products needed to fulfil the function	-should defines the which unit processes to be included in the system -the system should be modelled in such a manner that inputs and outputs at its boundary are elementary flows. -elements of the physical system to be modelled depends on the goal and scope definition -the models used should be described and the assumptions underlying those choices should be identified. -the cut-off criteria used within a study should be clearly understood and described.

2.1.2 Life cycle inventory

According to ISO (2006a), inventory analysis focuses on the data collection and calculation procedures to quantify relevant inputs and outputs of a product or service. Inventory data collection part must be consistent with the goal and scope definition phase of the LCA. Because the inventory stage consist of data collection, acquisition, and modeling phases, it is generally the most consuming part and requires great effort. Life cycle inventory analyses can be used in various ways. It can be useful for an organization or company comparing the material selection considering the environmental and social factors. In addition; regarding resource use and environmental emissions, inventory analyses can be used in developing policies.

Life cycle inventory phase consist of below listed operational steps (JRC/IES, 2011; EPA, 2006):

- Develop a flow diagram of the processes being evaluated.

A flow diagram which shows the input and output of the process should be developed. Depending on the decision context of the study, it is appropriate to view the main systems and sub-systems on the flow diagram.

- Planning data collection and collecting data

Planning collection of input data and information. This part consist of data type and source identification, identifying data quality indicators, developing a data collection worksheet and checklist.

- Calculating LCI results

This part includes the summing up all inputs and outputs of the processes within the determined system boundaries.

2.1.3 Life cycle impact assessment

To evaluate the significance of potential environmental and social impacts of LCI results, impact assessment phase of LCA is conducted. In this process inventory data are associated with the specific environmental and social impact categories. An LCIA part of the LCA study has a mandatory steps as classification and characterization that correlate the inventories to impact categories, and optional steps as normalization and weighting which is used for aggregation of the results (Figure 2.2).

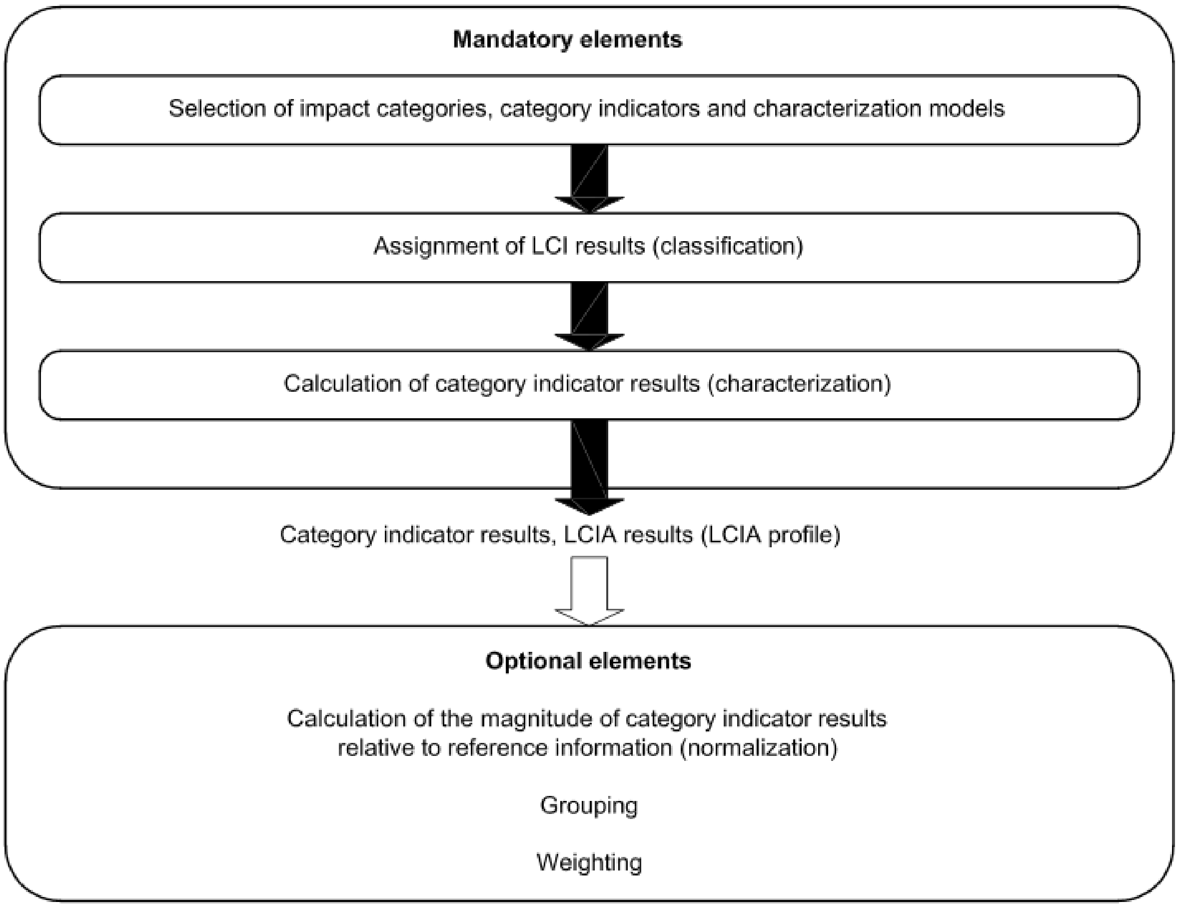

Figure 2.2. Elements of life cycle impact assessment (ISO, 2006a).

The following key steps comprise a life cycle impact assessment (ISO, 2006a; JRC/IES, 2011; EPA, 2006):

- Selection and Definition of Impact Categories

Identifying relevant environmental and social impact categories (e.g.; global warming, acidification, terrestrial toxicity for environmental impacts and secure living (labor and citizens) conditions, working hours for social impacts).

- Classification

Assigning LCI results to the one or more relevant impact categories (e.g., classifying carbon dioxide emissions to global warming impact category or regular payment to wage impact category).

- Characterization

Modeling LCI impacts within impact categories using science-based impact factors (e.g., modeling the potential impact of carbon dioxide and methane on global warming). The "characterization factors" express the individual contributions to the impact factor of each inputs.

- Normalization

To identify the most relevant factor between the impact categories, all units need to be in the same scale. Also, expressing potential impacts in a single score requires normalization (e.g. comparing the global warming impact of carbon dioxide and methane for the two options).

- Weighting

Weighting is an optional step as normalization. Analyzed impacts are subjectively assigned with related weighting factors. To emphasize the most important potential impacts weighting should be applied.

Even normalization and weighting are an optional steps for ELCA and SLCA, in a single score results such as LCSA they must conducted.

2.1.4 Interpretation

According to ISO (2006a), interpretation was the integration of the LCI and LCIA results. Life cycle interpretation provides an understandable, complete and consistent presentation of the LCIA results and also explains the limitations and provides recommendations.

The interpretation phase consist of below listed operational steps(ISO, 2006a; ISO 2006b; JRC/IES, 2011):

- Identification of significant issues

In this first part of the interpretation, the findings of the earlier stages of the LCA is structured and analyzed. These can be among the following: inventory items, impact categories, modeling choices, methods assumptions, commissioner and interested parties, etc.

- Evaluation

The evaluation step involves completeness, sensitivity, consistency checks for reaching functional conclusions and developing recommendations.

- Conclusions, limitations and recommendations

This step involves the limitations of the study and recommendations for the audience.

2.2 Environmental Life Cycle Assessment

2.2.1 Goal and scope of the study

The main objective of this part was to determine the environmental behavior of the existing source separated collection-transportation and recycling system of packaging waste, and compared the system with proposed alternative scenarios. The result of the study may assist decision makers to apply the environmentally optimum collection-transportation scenario.

In this stage of the ELCA study, system boundaries and functional unit were also determined. Figure 2.3 presents existing household waste management system. Household solid waste was collected in two fractions as mixed waste and recyclable packaging waste. In the scope of this study only the packaging waste collection systems were researched. It was assumed that the system boundary for the study starts when household solid waste delivered to any collection material by residents and it ends with the transportation of separated waste to the treatment facilities. The disposal system of the collected waste was out of the scope of this study.

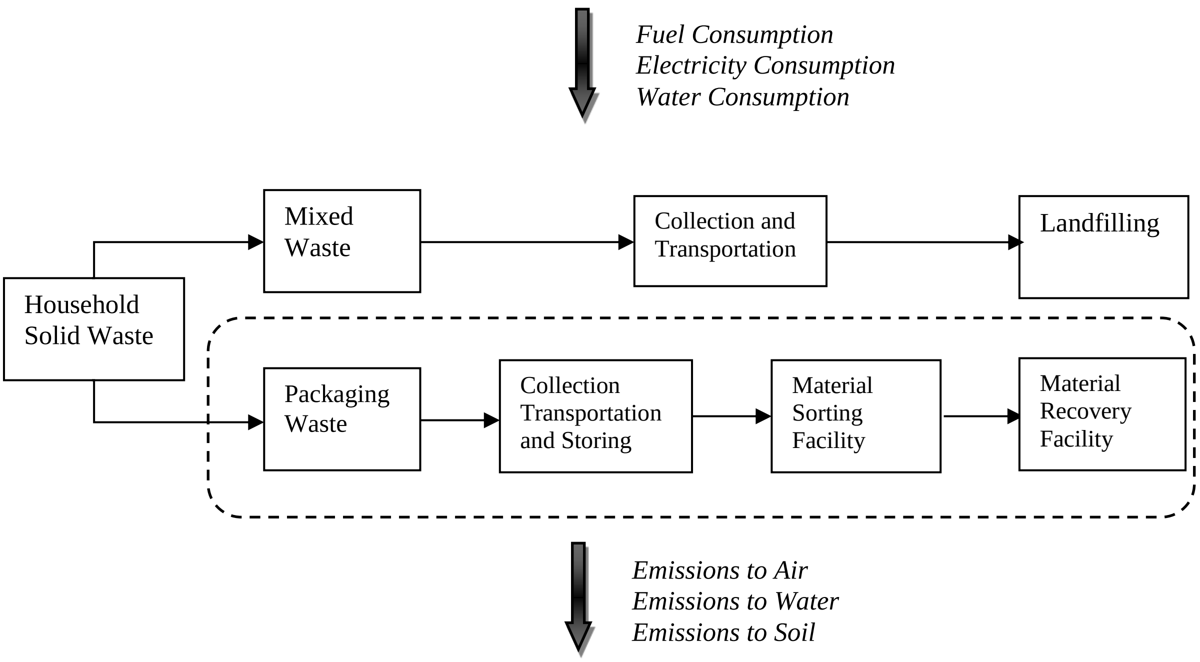

Figure 2.3. Existing household collection system and system boundaries for the study

2.2.1.1 Functional unit

As it was previously indicated, FU was a reference unit defining the quantified performance of analyzed system. And determination of FU is particularly important for comparing different systems. In this study, the functional unit was selected as total mixed packaging waste collected by municipality and/or scavengers in 2012.

2.2.1.2 System boundaries

In this section, existing system and alternative scenarios were defined. The scenarios were evaluated considering two parameters as separation and collection system modeling. The scenario modeling system used in this study is schematized in Figure 2.4. There were mainly four separation methods planned to be employed in this study which were the separation and storage in door-to-door, curbside and drop-off points, and storage in mixed waste bins without source-separation. In the mixed waste collection method, wastes were not separated at the source by citizens. Instead, they were all stored in a mixed waste bin and scavengers separated the recyclable wastes inside these bins and transported them to the transfer centers. The details of door-to-door, curbside, drop-off collection systems were already explained in section 1.1.3.

On the other hand; considering the collection system, scenarios were classified in three various methods namely, formal, informal and formalized collection. In the formal collection, it is suggested that packaging waste separated by citizens were collected by municipality or any related formal service. In the informal collection systems, packagings were separated from mixed waste bins by scavenger without any formalization. In the third option, formal and informal collections were integrated and a formalized collection system conducted. Formalization were primarily suggested respecting a social amelioration in the employee’s working conditions.

All scenarios were mainly based on the separation and collection methods mentioned above. Additionally these scenarios were differentiated according to fractionated separation and collection of the materials which requires different collection material for different waste fractions. Instead of picking solely one of the collection systems, researchers are generally focused on the double or triple combinations of these collection systems according to the specifications of the waste. For instance, Gallardo et al. (2012) determined the best separate collection system between the eight collections systems used in Spanish towns. In these eight types of collection systems implemented in Spain wastes were separated into four or five fractions and collected from drop-off points and/or picked up door-to-door systems and/or collected at curbside. Similarly, Guigliano et al. (2011) used the combination of curbside and drop-off collection and proposed the collection of waste fractions on a mono or multi-material basis. Furthermore, Larsen et al. (2010) proposed five collections scenarios which included different combinations of collection of packaging waste at curbside, drop-off containers and recycling centers.

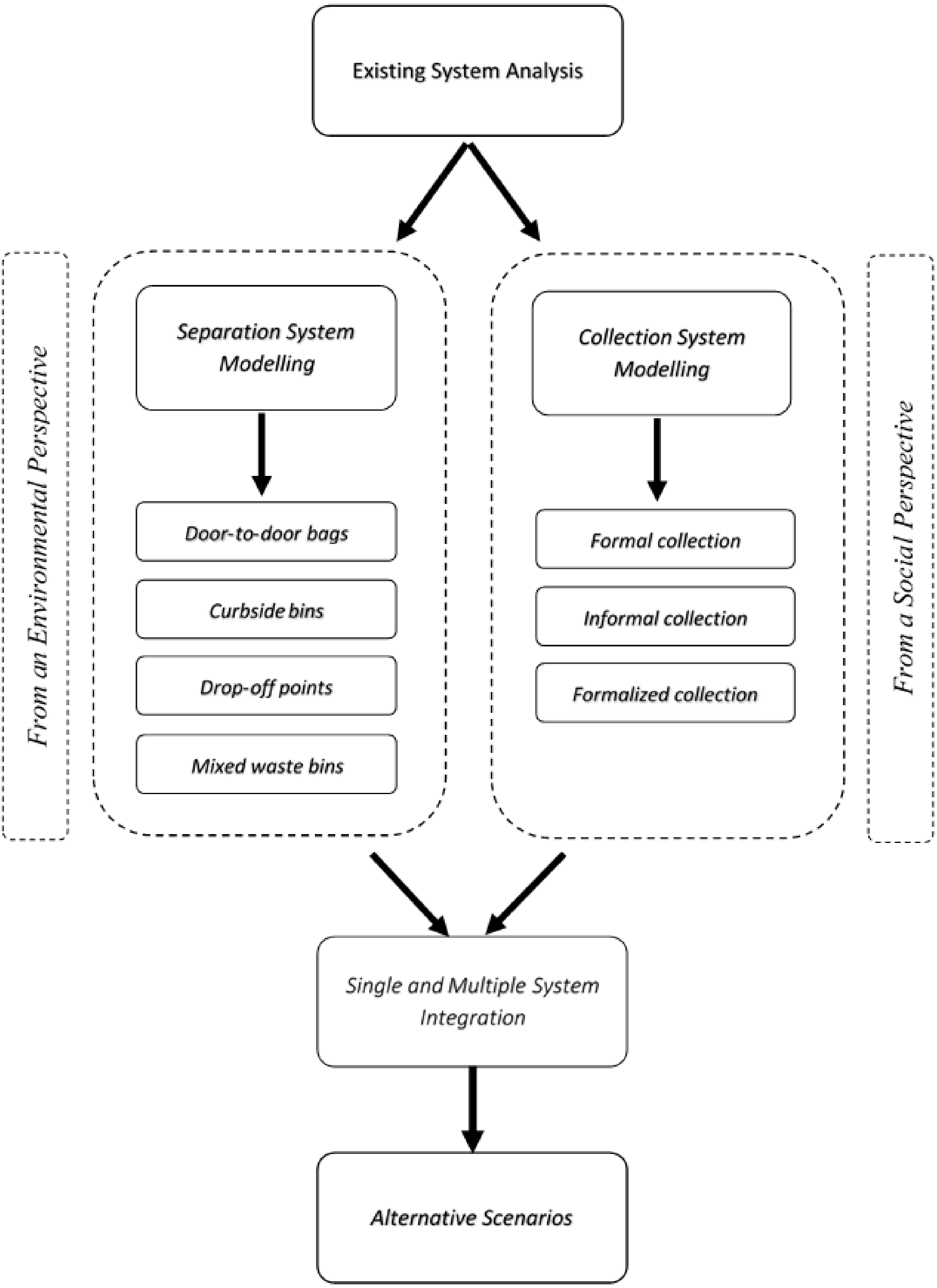

Figure 2.4. Scenario modelling system evaluated for this study.

Regarding the determined system boundary, the existing system and thirteen alternative collection scenarios were analyzed. Alternative scenarios were evaluated considering the formal and informal collection systems. Detailed description of existing system and alternative scenarios are as follows:

Existing System (ES): Recyclable packaging wastes were separated into 2 fractions. Mixed packaging wastes (paper-cardboard, glass, metal, plastic) were collected by door-to-door system and glass wastes were collected in drop-off points whereas unsorted waste were collected in curbside bins. Plastic bags were used to store mixed packaging wastes. In this system, packaging wastes which were disposed in mixed waste container by residents were picked from curbside containers by scavengers. So, in the existing system waste collected both by formal and informal collectors.

Scenario 1 (S1): Wastes were separated into 2 fractions and the collection system was almost same as the existing system. On the contrary of the existing system, in addition to the plastic bags, containers were also used. Mixed wastes were collected in plastic bags and then stored in a plastic container which was located at the door of the building. Only difference from the existing system was the used material. Separated wastes were collected formally by municipality. This was the scenario suggested by the regulation.

Scenario 2 (S2): Packaging wastes were not separated into fractions. Paper-cardboard, heavy-lightweight packaging waste (metal and plastic) and glass waste were stored in a plastic bag and collected by door-to-door collection system in weekly periods. Separated wastes were collected formally by municipality.

Scenario 3 (S3): Wastes were separated into 3 fractions. Paper-cardboard, heavy-lightweight (metal and plastic waste) packaging waste and glass waste were separately stored in plastic bags and collected by door-to-door collection system in weekly periods. Separated wastes were collected formally by municipality.

Scenario 4 (S4): Wastes were separated into 4 fractions. Paper-cardboard, heavyweight (metal waste), lightweight (plastic waste) packaging waste and glass waste were separately stored in plastic bags and collected by door-to-door collection system in weekly periods.

Scenario 5 (S5): Similar to the existing system and scenario 1, wastes were separated into 2 fractions as mixed packaging waste and glass waste. However in scenario 5, instead of door-to-door collection and drop-off points, wastes were collected in 2 different plastic curbside bins. Curbside bins were placed on the streets in the range of between 100 and 400m and collected formally by municipality.

Scenario 6 (S6): Wastes were separated into 3 fractions as paper-cardboard, heavy-lightweight packaging waste and glass waste. All these 3 fractionated waste were collected in plastic curbside bins by municipality. Drop-off points were located on the streets in the range of between 500 and 1000 m. Separated wastes were collected formally by municipality.

Scenario 7 (S7): Scenario 7 was similar to Scenario 5. Wastes were separated in 2 fractions. The only difference was mixed packaging waste and glass wastes were collected at drop-off points in galvanized steel containers.

Scenario 8 (S8): In this scenario wastes were separated into 3 fractions. Paper-cardboard waste, heavy-lightweight packaging and glass waste were collected at drop-off points in galvanized steel containers. Drop-off points were located on the streets in the range of between 500 and 1000 m. Separated wastes were collected formally by municipality.

Scenario 9 (S9): Packaging wastes were separated into 2 fractions as mixed packaging waste and glass waste. Mixed packaging wastes were collected by door-to-door system and glass wastes were also collected in drop-off points separately. This scenario was almost similar to existing system. The difference was the separated wastes were only collected formally by municipality.

Scenario 10 (S10): In this scenario packaging wastes were not source-separated by participants. Wastes were separated by waste picker from mixed waste containers. So, only the informal collection was applied in this scenario. Scenario was similar to existing system. Only difference was formal collectors were excluded from the collection system. As a result of this exclusion glass waste was not collected.

Scenario 11 (S11): This scenario suggested as the integration of formal and informal collection systems. Packaging wastes were separated and collected by scavengers from mixed waste curbside containers, whereas glass waste was collected separately from drop-off points. In the formalized system, a social amelioration on the waste picker’s working conditions were suggested.

*Scenario 12 (S12):*Collection and formalization system in this scenario was similar to scenario 11. Formal collection of mixed packaging wastes were not excluded from the scenario to meet the demands resulted from the participants collection habits. Scavengers were still separated the packaging waste from curbside containers. However, they were integrated to system in a limited number. And, glass waste was collected from drop-off points.

Scenario 13 (S13): Curbside bins were placed near to each mixed waste bins on the streets. Glass waste was collected from drop-off points. It is assumed that packaging wastes were separated from mixed waste by citizens. And the collection rate were same as scenario 11. On the contrary of the other scenarios, this scenario was evaluated as a socially idealized model.

Classification of the analyzed scenarios in terms of separation and collection techniques summarized in Table 2.3. And also a schematic overview of existing and alternative collection system is provided in Figure 2.5.

Table 2.3. Classification of the analyzed scenarios in terms of separation and collection system modelling.

Scenario	Separation System Modelling	Collection System Modelling
ES	Door-to-door collection Drop-off collection Mixed waste collection	Formal collection İnformal collection
S1	Door-to-door collection Curbside collection	Formal collection
S2	Door-to-door collection	Formal collection
S3	Door-to-door collection	Formal collection
S4	Door-to-door collection	Formal collection
S5	Curbside collection	Formal collection
S6	Curbside collection	Formal collection
S7	Drop-off collection	Formal collection
S8	Drop-off collection	Formal collection
S9	Door-to-door collection Drop-off collection	Formal collection
S10	Mixed waste collection	Informal collection
S11	Mixed waste collection Drop-off collection	Formalized collection
S12	Door-to-door collection Drop-off collection Mixed waste collection	Formalized collection
S13	Curbside collection Drop-off collection	Formalized collection

Figure 2.5. Separation scheme of the existing collection system and alternative scenarios.

2.2.2 Inventory analysis methodology

2.2.2.1 Data for collection, sorting and recycling activities

In the existing situation, packaging waste were transported in two stages. Firstly, wastes were collected from sources and transported to the sorting facility, and then sorted materials were transported to the recycling centers. For the existing system, all transportation data such as fuel consumption, distance travelled, and vehicle types were taken from municipality's inventory. Alternative scenarios were calculated respecting the these data.

Respecting the separation system modelling, one of the most significant difference between the existing system and alternative scenarios was the material use. Characteristics of basic collection materials are given in Table 3.5. All consumption data for the alternative scenarios were calculated based on the existing system. Further details about the calculations are explained in the following section.

Measuring the efficiency of source separation system

In order to analyze the efficiency of the source separated collection system, there are some indicators determined and used to observe the systems' alteration (Gallardo, 2010; Tchobanoglous and Kreith, 2001; Thomas, 2001; Panaretoul et al., 2012; Tai et al., 2011; A_002). The most used efficiency indicators are listed below:

- Quantity of collected recyclables
- Quality of recyclables
- Recycling rate
- Participation rate
- Willingness to participate
- Satisfaction degree
- Capture rate
- Diversion rate

In this dissertation, mainly, following indicators and equations were applied to determine the efficiency of the existing system and estimate the scenarios potential efficiency.

Specific Waste Generation Rate, $[GR]_i$: The ratio between the weight of potential packaging waste and weight of total household municipal solid waste.

$$[GR]_i = \frac{weight of potential\ packaging\ waste}{weight of total household\ solidwaste}\ (\%) \quad (2.1)$$

*Public Participation Rate, $[PR]_i$:*This indicator presents the percentage of the people who participates the source separated collection system.Participation rate is also defined by Tchobanoglous and Kreith, 2001 as “the percent of households or businesses that regularly set out recyclables”.

$$[PR]_i = \frac{population\ that\ participates\ the\ separation\ system}{total\ population\ of\ application\ area}\ (\%) \quad (2.2)$$

Source Separation Rate, $[SR]_i$: The ratio between the weight of source separated recycling waste and the weight of total household solid waste.

$$[SR]_i = \frac{weight of sourceseparately\ collectedwaste}{weight of total household\ solidwaste}\ (\%) \quad (2.3)$$

Effective Separation Rate, $[ESR]_i$: This indicator presents the effectivines of citizens, who participate the system. In the participation rate, it is assumed that citizens separated their waste in 100% efficiency. Source separation rate shows how much waste are separated. So the ratio between them gives the efficiency separation rate.

$$[ESR]_i = \frac{Public\ Participation\ Rate}{Source\ Separation\ Rate}\ (\%) \quad (2.4)$$

Wastage Rate, $[WR]_i$: Wastage rate is defined as the ratio between the weight of residual material remain from sorting of collected packagings and weight of total source separately collected recycling waste.

$$[WR]_i = \frac{weight\ of\ wastage\ materials\ in\ collected\ recyclables}{weight of sourceseparately\ collectedwaste}\ (\%) \quad (2.5)$$

Packaging Waste Rate, $[PWR]_i$: Packaging waste rate is defined as the percentage of packaging material sent to reprocessing facilities.

$$[PWR]_i = \frac{weight of sorted\ packaging\ waste}{weight of total household\ solidwaste}\ (\%) \quad (2.6)$$

Substitution rate, $[SaR]_i$: In which proportion recycling material eliminate to extract/product/use virgin material.

Recycling efficiency rate[RE]$_i$:: This is the efficiency of recycling facility' depending on recycling technology.

On a voluntary collection system, PR is directly and indirectly related to several factors such as collection frequency, materials collected, collection day, size of housing, compulsory separate collection, socio-economic level, education and promotion, economic factors, socio-demographic characteristics, publicity and information provided to residents, history and context of scheme, collection vehicle, provision of collection container (Gallardo et al., 2012; Dahlén and Lagerkvist, 2008; Thomas, 2001; Woodard et al., 2005; Lober, 1996). For instance, White at al. (1995) indicated that citizens' motivations were easily influenced by collection frequency so it affected the system directly. Also, Noehammer et al. (1997) found that increment on the number of separated fraction decreased the participation rate. Another important factor is the property-close collection system. Gallardo et al. (1999) showed that in Spain participation rate of the citizens decreased when distance to the deposit point increased. In the same way Dahlen et al. (2008) made an observation on different household waste collection system design in Swedish and found that when separated packaging collected from the points close to the property, higher amounts of sorted metal plastic and paper packaging collected than drop-off points.

In this study, on calculation of the scenarios' participation rate, it was assumed that there were no changes on the socio-economic and education level of the citizens and socio-demographic characteristic of the analyzed area. As an another assumption, collection day and collection frequency were also not taken into account. It was assumed that only distance to collection point and number of fractions affected the participation rate of the citizens. However, as a result of fractionated collection of the packaging materials, different wastage rates were estimated. Due to the mixed collection of packaging materials such as paper-cardboard, plastic, metal and glass waste, wastage rate should be included to calculations made.

At first, selected indicators were calculated for the existing scenario. Specific Waste Generation Rate and Source Separation Rate were calculated by using releated equation. The challenging part was the calculation of PR. PR was assumed to be related to only two variables such as number of the participated buildings and apartments. Because of the voluntary-based collection system, not every building on the streets and not every apartment in buildings were considered as a part of the system. However, as a result of address-based collection system, it was known how many buildings and apartments participated to the system. So participation ratio were determined by using these data.

On the estimation of the scenario indicators, first participation rate and then separation rate were determined. PR values of the scenarios were estimated by considering the socio-demographic characteristics of the area, education level and willingness of the citizens. In accordance with these results, collection rate was calculated by using Equation 2.7.

$$\frac{[PR_a]_i}{[PR_a]_0} \times \frac{[PR_b]_i}{[PR_b]_0} \times \frac{[ESR]_i}{[ESR]_0} = \frac{[SR]_i}{[SR]_0} \qquad (2.7)$$

2.2.2.2 Determination of environmental inventory indicators

In the determination of environmental performance of packaging waste collection, transportation and sorting activities, inventory indicators listed in the Table 2.4. Environmental inventory indicators used in this study are used. Fossil fuel consumption is the most important inventory in the environmental analysis, because suggested systems are differentiate in collection and as a result in transportation. In the calculation of the fuel consumption, distance, time between every stop to pick up the waste, fuel type were taken into consideration. Vehicle type is important to analyze the fuel consumption and emission released. Water and electricity only used in sorting facilities. Collection materials are also varied from one scenario to another. Therefore it is important to determine the material type and amount.

Table 2.4. Environmental inventory indicators used in this study.

Inventory Indicator	Performance Source	Researched data
Fossil fuel	Collection and transportation	Type and amount
Water	Sorting facility	Type and amount
Electricity	Sorting facility	Type and amount
Collection material	Source separation and storage	Type and amount
Vehicles	Collection and transportation	Type and amount

2.2.2.3 Calculation of Emissions

The emission estimation methodology, IPCC Trier 1 developed by IPCC, covers exhaust emissions of CO, NOx, NMVOC, CH_4, CO_2, N_2O, NH_3, SOx, exhaust PM, PAHs and POPs, dioxins and furans, PCBs, HCB, and heavy metals contained in the fuel (lead, arsenic, cadmium, copper, chromium, mercury, nickel, selenium and zinc).

All mobile emissions were calculated using IPCC Trier 1 methodology (IPCC, 2006). Emission factor were taken from EEA (2013). Airborne emissions were calculated using Equation 2.8.

$$E_i=\sum_j\left(\sum_m (FC_{j,m} \times EF_{i,j,m})\right) \quad (2.8)$$

Where;

E_i : emission of pollutant i, (g)

$FC_{j,m}$: fuel consumption of veichle category j using fuel m, (kg)

$EF_{i,j,m}$: fuel consumption-specific emission factor of pollutant i for vehicle category j and fuel m, (g/kg)

2.2.2.4 Software used for modelling

For LCA studies different software tools were used by researchers. Over the years, a large variety of LCA software has been developed, typically designed to be applied in the countries where they were developed. Laurent et al., 2014b analyzed the usage of different software tools such as SimaPro, GaBi, EASEWASTE, ORWARE, WRATE or WAMPS in waste management researches. The study showed the SimaPro was the most preferred software tool. In this thesis, we also used SimaPro 8.0.1 to develop system modeling.

2.2.3 Impact assessment methodology

After inventory analysis, impact assessment step follows. CML- IA method was used to determine the environmental impacts of the systems. Following impact categories were selected to indicate the environmental effects of the compared systems: Abiotic resource depletion (minerals and fossil fuels), Acidification, global warming potential (20a and 100a), ozone layer depletion, photochemical oxidation creation potential, eutrophication. Definition of impact assessment indicators are illustrated in Table 2.5.

Moreover, single score analysis were performed via EDIP, IMPACT 2002+, EPS, RECIPE (endpoint) methods which are the most widely used Life Cycle Impact Assessment (LCIA) methodologies on solid waste management systems (Laurent et al., 2014b).

Environmental impact indicators are summarized below.

2.2.3.1 Abiotic depletion potential (ADP):

Minerals were exist when the earth was formed, and when cooling down, geologic processes created areas in which minerals were concentrated (Goedkoop et al. 2013).Depletion of fossil fuels is one of the critical global environmental challengers. Fossil energy for operational activities are used in each stage of waste management system requires.

2.2.3.2 Acidification potential (AP):

AP is mainly expressed relative to the acidifying effect of SO_2, NOx, NH_3, H_2S and SOx. Major acidifying substances that can be emitted from open dumping conditions are NH_3 and H_2S. AP for each acidifying emission is expressed as kg SO_2 equivalents (Pre Sustainability, 2014b; Goedkoop et al. 2013).

2.2.3.3 Global warming potential (GWP):

GWP is a greenhouse effect quantifying indicator. This value is normally quantified for time horizons of 20, 100 or 500 years for greenhouse gasses such as CO_2, CH_4,N_2O, CFC's, HCFC's, HFC's (Pre Sustainability, 2014b).Global warming caused by the greenhouse gas emissions from landfilling sites is a crucial problem that should be considered seriously. carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) are the major greenhouse gases emitted from existing MSW disposal sites. The GWP is expressed in units of CO_2 equivalent (Goedkoop et al. 2013).

2.2.3.4 Ozone depletion potential (ODP):

Anthropogenic emissions are mainly resulted in the ozone layer depletion. The ODP has been defined as a relative measure of the ozone depletion capacity of an ozone depleting substance. ODP values have been related to mainly hydrocarbons containing combined bromine, fluorine and chlorine, or CFCs (Goedkoop et al. 2013; Pre Sustainability, 2014b).

2.2.3.5 Photochemical Oxidation Creation Potential (POCP)

Tropospheric or ground level ozone is one of the important parameter threaten the environment in local based-scale. It is known that high concentrations is dangers to human health, also the lower concentrations damage to vegetation (EPA, 2005).

2.2.3.6 Eutrophication potential (EP):

Nutrient enrichment in the aquatic environment can be defined as aquatic eutrophication. These nutrients may affect the aquatic and terrestrial ecosystems quality, negatively. Increased biomass production may lead to decreased oxygen concentration in the aquatic environment because of the additional consumption of oxygen during biomass decomposition (Pre Sustainability, 2014b; Goedkoop et al. 2013).

Table 2.5. Definition of impact assessment

Impact Assessment Indicators	Definition	Unit	Method
Abiotic depletion potential	Related to extraction of minerals and fossil fuels due to inputs in the system	kg Sb eq and MJ	CML-IA
Acidification potential	Related to Nitric acid, Sulfuric acid, Sulfur trioxide, Hydrogen chloride, Hydrogen fluoride, Phosphoric acid and Hydrogen sulfide	kg SO_2 eq	CML-IA
Global warming potential (20a) (100a)	Related to emissions of greenhouse gases such as Carbon dioxide (CO_2), Nitrogen dioxide (NO_2), Methane (CH_4) Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Methyl bromide (CH_3Br)	kg CO_2 eq	IPCC 2007 CML-IA
Ozone depletion potential	Related to emissions of Chlorofluorocarbons (CFCs) Hydrochlorofluorocarbons (HCFCs) Halons methyl bromide (CH_3Br)	kg CFC-11 eq	CML-IA
Photochemical Oxidation Creation Potential	Related to formation of reactive substances (mainly ozone) such as Non-methane hydrocarbon (NMHC)	kg C_2H_4 eq	CML-IA
Eutrophication potential	Related to mainly with Phosphate (PO_4) Nitrogen oxide (NO) Nitrogen dioxide (NO_2) Nitrates ammonia (NH_4)	kg PO_4^{-3} eq	CML-IA

Apart from above given impacts; human toxicity, terrestrial toxicity, fresh water and marine aquatic eco-toxicity should be considered to determine the clear impacts on natural system.

2.2.4 Interpretation

In order to check the consistency of CML-IA method results, six diverse impact assessment methods namely EDIP, IMPACT 2002+, EPS, RECIPE/Egalitarian (E), RECIPE/Individualistic (I) and RECIPE/Hierarchic (H) were also conducted in SimaPro 8.0.1 software program. And results were compared to each other.

2.3 Social Life Cycle Assessment

2.3.1 Goal and scope of the study

When initiating an SLCA study, a clear definition of purpose is required. The UNEP/SETAC, (2009) guideline state that the most important objective for performing an SLCA methodology is to provide an improvement on the social performance of a product throughout its life cycle along with the all related social groups. Also, earlier studies classified goals into two part as comparison of product, process or company (Methot, 2005; Schmidt et al., 2005) and identification of improvement potential of products or processes (Flysjö, 2006; Dreyer et al., 2006; Manhart and Grießhammer, 2006; Gauthier, 2005; Jorgensen et al., 2008). In the frame of these classifications, the goal of the study is defined in two parts.

The main goal of the SLCA in this study is to analyze the existing formal and informal collecting systems and compare them with the alternative scenarios proposed. Waste management systems especially in developing countries are socially weak services because of the informal collection. Therefore, the second goal is designed within finding these social weaknesses and strengths of the currently applied collection systems.

ISO (2006a) defines the scope which is the part compatibly and sufficiently addressing the stated goal by giving the depth and breadth of the study. Scope presents the limitation of the life cycle researches and should include the functional units, the system boundaries, related impact categories and subcategories, performance indicators, the data type and source selected for the study (ISO, 2006; UNEP/SETAC, 2009).

2.3.1.1 Functional unit

According to the first guidelines of LCSA (UNEP/SETAC, 2012), the same functional unit should be used for all sustainability assessments to implement a complementary approach. However, Dreyer et al. (2006) pointed out that there was not a direct correlation between social impacts and processes. Then, it is quite difficult to link the functional unit with the results for SLCA (Hauschild et al., 2008; Kloepffer, 2008). In another way, processes' outputs cannot be presented by attributes or characteristics inputs which express the SLCA inventory.

Thus, inventory data type selection plays a critical role. For instance, Hosseinijou et al. (2014) indicated the social impacts would hardly be related to FU of the product if the inventory data is based on semi-qualitative and qualitative data. On the other hand, Kruse et al. (2009) pointed out even if the inventory data were quantitative, indicators still cannot be directly related to FU. They might be separated in two types as “descriptive indicators” and “additive indicators” and only additive indicators may be reduced to FU. Despite of these different views, it is still compulsory to identify a functional unit. And according to first guidelines of life cycle sustainability assessment (UNEP/SETAC, 2012), the same functional unit should be used for environmental and social assessments to implement a complementary approach.

In the behalf of these researches, for the current study the same functional unit previously determined for ELCA was used. Existing and proposed system were analyzed considering the collection of total packaging waste in 2012.

2.3.1.2 System boundaries

Same as the functional unit, system boundaries for the environmental and social life cycle assessment should be same. The SLCA scope of packaging waste management study involves the collection, transportation and separation processes. Existing collection system and system boundary is given in Figure 2.6.

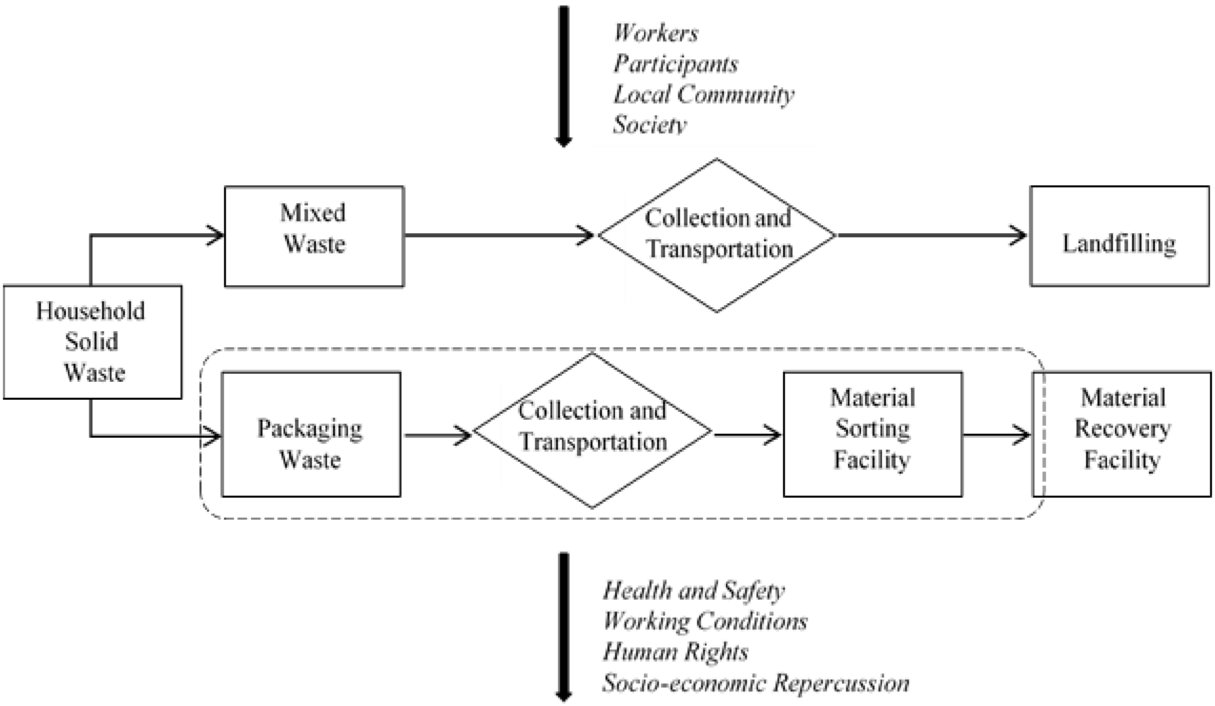

Figure 2.6. Existing household waste collection system and system boundary for the study.

Regarding this system boundary, previously described existing system and thirteen alternative collection scenarios were discussed in this section with respect to the social conditions.

In the existing system (ES), packaging waste was collected by formal and informal collectors. Mixed packaging wastes were collected in door-to-door system and glass wastes were also collected in drop-off points separately by municipality. Packaging wastes which were disposed in mixed waste container by residents were picked from curbside containers by scavengers. 95 % of employees worked at illegal conditions.

In the scenarios from S1 to S9, waste collection by scavengers was excluded in order to comply with country's legal standards. Thus, separated waste were only collected by municipality. And it is assumed that collection rate is 2.09 % as existing formal collection.

In scenario 10 (S10) packaging waste was not source-separated by participants. Waste was separated by waste picker from mixed waste containers. So, only the informal collection was applied in this scenario.100 % of scavengers worked at illegal conditions.

Apart from these scenarios, in S11, S12 and S13,the integration of formal and informal collection systems was suggested. In S11 and S12, scavengers still separated the packaging waste from containers. However, their working conditions such as social security, health, and safety, etc. were considered to be recovered and legalized. On the contrary of S11, in scenario 12 only limited number of scavengers were employed formally respecting to transition period of the system.

Scenario 13 considered as socially idealized scenario. In this scenario, it was assumed that not only the working and health conditions but also the socio-economic repercussions were recovered. Ideally, packaging wastes were separated by only citizens and stored at curbside bins. Collection rate was considered same as the informal collection rate. Because collection rate was high, most of the scavenger were integrated to system.

2.3.1.3 Determination of impact categories and subcategories

For SLCA, the most used guideline UNEP/SETAC (2009) identifies 6 impact categories and 31 subcategories related with group categories. The main impact categories are health and safety, human rights, working conditions, socio-economic repercussions, cultural heritage and governance. Pre-Sustainability (2014) prepared as a handbook based on extensively UNEP/SETAC(2009) guideline. In this handbook 19 subcategories; however they named it as ‘social topic’, were identified considering 3 groups as workers (W), local community (Lc), and society (S). In this study, to determine the subcategories which will identify the waste management system, we integrated indicators given in both guideline and handbook. At first, 5 groups and 35 subcategories were taken into consideration.

Because SLCA studies and guidelines are mainly based on a product analysis, it is important to analyze if the social groups and subcategories represent a packaging waste collection system or not. Considering these issues, all related groups were also identified, after the determination of system boundaries. However it should be noted that not all information on social groups involve in each process needed to be reported in a system boundary. Therefore, unrelated social groups and subcategories have to be eliminated.

Workers are main and probably weakest social groups in a social analysis of a waste collection system as a result of working conditions. In the scope of this study, 2 type of workers were identified. First one was the employees representing the formal collection and second one was the scavengers who were the employees in the informal collection system. Another social group was the consumer who used the products or services. In this study, consumers were identified as the participants who separated the packaging waste and used the collection service. Secondly, ‘value chain actors’ was not included in the scope of the study in order to apply a comprehensive study. Social groups and their definitions for the research are analyzed in this study is represented in Table 2.6. After elimination of social group, unrelated subcategories were excluded and then remaining were prioritized considering the social problems experienced in the sector, data availability, reliability and importance. These subcategory prioritization systems were also used by Martinez-Blanco et al. (2014) and Aparcana and Salhofer (2013a). Prioritization studies showed that informal collection system required additional subcategories such as social acceptance and service satisfaction. Table 2.7 shows the related social groups and subcategories determined for this study.

Table 2.6. Definitions of social groups considered in this case study.

Social groups	Definition
Workers	Formal and informal collectors
Participants	Collection system participants (citizens)
Local community	People lives in Istanbul
Society	People lives in Turkey

After the selection of appropriate subcategories, all of them were correlated with impact categories. Although there is not a particular correlation between the impact categories and subcategories, it was associated the selected subcategories to impact categories as Aparcana and Salhofer (2013a) studied. Correlated impact categories and subcategories are presented in Table 2.8.

Table 2.7. Social groups and subcategories determined for this study.

Social group categories	Subcategories
Workers	Health and safe working conditions (W)
	Job satisfaction and engagement(W)
	Working hours (W)
	Wage (W)
	Social benefits/security (W)
	Forced labour (W)
	Training and education (W)
	Child labour (W)
	Freedom of association and collective bargaining (W)
	Discrimination (W)
Participants	Service satisfaction (C)
Local community	Health and safe living conditions (Lc)
	Secure living conditions (Lc)
	Employment (Lc)
	Social acceptability (Lc)
	Delocalization and migration (Lc)
Society	Contribution to economic development (S)

Table 2.8. Impact categories and subcategories correlation.

Impact Category	Subcategory
Health and safety / security	Health and safe working conditions (W)
	Health and safe living conditions (Lc)
	Secure living conditions (Lc)
Working conditions	Job satisfaction and engagement(W)
	Working hours (W)
	Wage (W)
	Social benefits/security (W)
	Forced labour (W)
	Training and education (W)
Human rights	Child labour (W)
	Freedom of association and collective bargaining (W)
	Discrimination (W)
Socio-economic repercussion	Employment (Lc)
	Social acceptability (Lc)
	Service satisfaction (C)
	Delocalization and migration (Lc)
	Contribution to economic development (S)

2.3.1.4 Definition of Impact Categories and Subcategories

Health and Safety / Security:

All humans have the right to live and work in a healthy and safe conditions. In this impact category, workers and employee's working and living conditions are analyzed.

Healthy and safe working conditions cover all physical and mental diseases affecting the health of the employees and all serious hazards occur in the workplace. This subcategory should assess the both incidents and the measures of prevention systems(Pre Sustainability, 2014;UNEP/SETAC, 2009).

Healthy and safe living conditions are directly related to local communities living conditions. This subcategory assesses how organizations or services impact community's general health and safety conditions of operations(Pre Sustainability, 2014; UNEP/SETAC, 2009).

Secure living conditions is also connected to local communities. This subcategory interest if the organization or services endanger the local communities security conditions or not (Pre Sustainability, 2014; UNEP/SETAC, 2009).

Working Conditions:

Working Conditions are only correlated with workers. Job satisfaction, working hours, wages are measured to determine the sufficient working conditions.

Job satisfaction is mainly refers to workers feelings about their job, employer, working conditions, etc. It is the workers' view that they are treated respectfully and appropriately by management (Pre Sustainability, 2014;UNEP/SETAC, 2009).

The working hours is limited by laws and/or regulations. According to laws weekly working hour should not exceed the 48 hours. At least one day of should be provided to workers after the every six sequential days of working. There is also limitations on overtime work respecting to weekly working hours (Pre Sustainability, 2014; UNEP/SETAC, 2009).

Living wage provides to meet the minimum living standards such as food, water, shelter, healthcare, education, etc. This subcategory aims to assess whether analyzed system's wage limits comply with the at least the minimum wage, established either by law, collective bargaining agreement, or industry standard (Pre Sustainability, 2014; UNEP/SETAC, 2009).

In addition to wages, the provision of social benefits should comply with laws. Basically indicators such as retirement, disability, survivor benefits are quantified (Pre Sustainability, 2014; UNEP/SETAC, 2009).

Forced labour is another working condition assessment tool. It measures if the person work under the threat of any penalty and/or not working voluntarily. The subcategory aims to verify that there is no use of forced or compulsory labour by organization or company(Pre Sustainability, 2014;UNEP/SETAC, 2009).

To improve and expand the workers aptitudes and skills, companies or organizations prefer to educate and train the workers. Capability increasing educations is contributes the growth of human capital within the organization (Pre Sustainability, 2014; UNEP/SETAC, 2009).

Human Rights:

Human rights is measured by existence of child labour, freedom of association and collective bargaining and discrimination in the workplace. Thus, it is only related with workers.

Child labour is an important subcategory for measuring the social impacts of the organizations. Illegal working conditions is harmful to children's physical and mental development. Extreme child labour conditions involves children's forced labour, separated from their families, exposed to health and safety problems(Pre Sustainability, 2014; UNEP/SETAC, 2009).

Workers should have the right the freedom of association and collective bargaining. This right includes the right of workers to strike, organize without restriction, select their representatives freely, etc. (Pre Sustainability, 2014; UNEP/SETAC, 2009).

Discrimination defined in UNEP/SETAC (2009) as a social subcategory which refers to any kind of distinction, exclusion or preference eliminating the equal working conditions between the employees. The company should prevent discrimination in hiring, salary, retirement etc., which is based on race, national or social origin, religion, disability, gender, marital status, union membership, political opinions, state of health, age, or any other circumstance (Pre Sustainability, 2014).

Socio-economic repercussions:

In this study, selected subcategories for socio-economic repercussions were mainly correlated to local community and society. Employment, social acceptability, service satisfaction and contribution to economic development were the main subcategories.

Employment subcategory is directly affected by job creation potential, income generation and training opportunities to community members. Organizations or companies can have a strong effect on the development of local community when they hire local workers(Pre Sustainability, 2014; UNEP/SETAC, 2009).

Social acceptability states the consumers or participants' opinion related to analyzed product or service. Social acceptance is not expressed as a quantitative way. Measurement is mostly qualitative obtained according to the results of the survey carried out in the researched area. Social acceptability is useful to analyze the products or services' social efficiency (Wang et al. 2009).

Service satisfaction is directly related to citizens approval or pleasure degree of the service or the product which is provided by organizations or companies. It is particularly important to measure the socio-economic repercussion.

Contribution of the product/sector/company to economic development is one of the other social subcategory. Contribution indicator is extremely related to economic growth. It measures if the service organization limit the economic development of the country/region or not. Because organizations can contribute to economic development in many ways, there are several ways to assess this indicator. The choice of the indicator to use is a very important step as they may not represent the organization's true contribution to the economic development. A high revenue does not automatically lead to a high contribution (UNEP/SETAC, 2013).

2.3.1.5 Determination of Inventory Indicator

Inventory indicators are specific definitions of the required data and they provide the direct evidence of the condition they are measuring (UNEP/SETAC, 2009). Pre Sustainability (2014) defines inventory indicators as quantitative and qualitative markers of performance for each of the subcategory. Researchers also explained an impact measurement tool acts as a bridge between the behavior of the system and researched impacts (Afgan and Carvalho, 2004; Ibanez-Fores et al. 2014).

There are almost two hundred suggested social inventory indicators in the literature related to previously explained social group and impact categories (Hunkeler, 2006; UNEP/SETAC, 2013). An effective social analysis strictly depends on the indicator selection. According to Klöpffer (2008) this is one of the five main challenges in SLCA.

In the literature researches, some studies used multiple indicators whereas the others used only a single indicator. It should be noted that for a reliable data and social analysis result, qualification of the indicator is more important than the number of it. Ekener-Petersen and Finnveden (2013), examined 54 indicators proposed in the methodological sheets; however 24 of them were invalid or not relevant. If different systems are compared, same data set should be collected for each process. In some cases a single indicator is enough to measure the social performance of the system. For instance, Hunkeler (2006) used only working hours as a one single indicator. Employment hours of each unit processes were obtained to determine a certain life cycle stage. Apart from the existing indicators, system-specific indicators may also be used. Weidema (2006) proposed a comprehensive set of indicators to identify the damages in human life and well-being and measured all indicators in QALYs (quality of adjusted life years) and provide an alternative single-score.

Based on these researches all indicators especially provided by Pre Sustainability (2014), UNEP/SETAC (2009), UNEP/SETAC (2013) guidelines were investigated. The best representative inventory indicators for each subcategory were identified regarding to the data availability and reliability in the formal and informal collection systems. Related impact categories, subcategories and inventory indicators are given Table 2.9.

Table 2.9. Inventory indicators, subcategories and related impact categories used in this case study.

Impact Category	Subcategory	Performance Indicator
Health and Safety / Security	Health and safe working conditions (W)	Incident risk
		Occupational health risk
		Health and safety awareness
		Safety risk of the system
		Health and safety training
		Working with appropriate equipment
	Health and safe living conditions (Lc)	Local community's health and safe living conditions
	Secure living conditions (Lc)	Local community's secure living conditions
Working conditions	Job satisfaction and engagement(W)	Work satisfaction
	Working hours (W)	Legal working hours limit
		Night work
	Wage (W)	Payment in the living wage standards
		Regular payment
	Social benefits/security (W)	Legal working contracts
		Retirement rights
		Social security
	Training and education (W)	Training programs
	Forced labour (W)	Forced labour
Human Rights	Child labour (W)	Child labour
	Freedom of association and collective bargaining (W)	Right of associations or bargain collectively
	Discrimination (W)	Political, regional and religious discrimination
Socio-economic repercussion	Employment (Lc)	Job creation potential
		Job lose potential
	Social acceptability (Lc)	Supporting the system
	Service satisfaction (C)	Identification of complaints
	Contribution to economic development (S)	Contribution of the system to economic development

2.3.2 Inventory analysis methodology

The objective of the inventory analysis is to collect and analyze relevant data identified during the scope definition (Jorgensen et al., 2008). Inventory analysis is the most time required and challenging phase of SLCA in particular data collection.

2.3.2.1 Data sources and type

There are two kinds of data sources as specific data and generic data. According to UNEP/SETAC (2009) guideline, specific data refers to data collected for a specific process in a specific location, whereas generic data means that data is not specific to selected area, data is collected from other companies. For a reliable SLCA study, both specific and generic data are needed in some manner.

Ciroth and Franze (2011) highlighted that even site-specific data was essential for the investigation of specific companies, country and the sector-specific generic data were also important to identify the reference value for the inventory indicator. And they exemplified that company based wage analysis will not be enough to determine the positive or negative impacts of the wage unless country based living cost take into consideration. However, there is some disagreement among researchers on the type data sources (Paragahawewa et al., 2009). For instance, Jorgensen et al. (2008) emphasized that two different companies producing exactly the same product in the same industrial process may possibly had the same environmental impact, but they can have completely different social impacts. These social variations are not directly related to process flows, they mostly arise from behavioral differences of companies such as interaction between social groups (Dreyer and Hauschild, 2006; Hauschild et al., 2008). Therefore, it should be noted that social impacts are highly site-specific, and there are clear challenges obtaining site-specific social data for a complete chain (Benoit and Vickery-Niederman, 2010; Jorgensen et al., 2008; Martinez-Blanco, 2014). On the other hand, researches may still be evaluated using only generic data. For instance, Ekener-Petersen and Finnveden (2013), Ekener-Petersen and Moberg (2013) conducted a generic hotspot analysis by focusing on the country-specific data for the indicators. Sector-specific data were only used for one indicator, namely working hours, out of 54 indicators in total. Also Weidema (2006), Schmidt et al. (2005), Barthel et al. (2005) pointed out that the use of generic data in country and sector level could give a rough estimation.

According to Jorgensen et al. (2008), in the data characterization two important distinctions become apparent. The first one concerns the measurement unit of the indicators as quantitative, qualitative, and semi-quantitative. The second one relates to whether the indicator measures the impact directly or indirectly.

The type of social inventory data may form qualitative, quantitative and semi-quantitative as proposed in methodological sheets of UNEP/SETAC (2009). Quantitative indicators can be directly measured by numerically whereas qualitative indicators evaluate the information in descriptive way. On the other hand, semi-quantitative indicators are defined as numerical descriptions of qualitative data (UNEP/SETAC, 2009). In the environmental LCA applications, quantitative and comparable indicators are used to provide environmental impacts of the researched systems or products. Because of the complexity of the social impact, most of the social indicators are difficult to measure in quantitatively, and so selection of data type poses a challenge to the SLCA framework (Dreyer et al., 2010). Papong et al. (2015) pointed out that almost all social impacts addressed in the SLCA case studies measured were in terms of a qualitative and semi-quantitative approach.

The second data characterization method is the determination of either the social impact information will be provided by direct or indirect indicators. Jorgensen et al. 2008 and Dreyer et al. 2006 were described the direct indicators as a one-dimensional and traditional quantitative representation of a social impact. Indirect indicators are used when direct indicators are not express the social impacts accurately or indicators cannot measure a reliable data. Dreyer et al. (2006) explained this issue with an example related to safe working conditions. The authors pointed out that safety at the working place cannot be always measured with the number of accidents, especially if the accidents were not registered. In this case, indirect indicators such as health and safety awareness or trainings implemented by company, should be used.

Considering the above explained inventory data characterization steps, we classified all inventory indicators chosen for this research. In this study, the data that has been collected was mainly based site specific data. However, because it was difficult to collect social data especially for informal collection, some generic data was also used. Similarly, quantitative data collection posed a problem in informal collection system, because there are no legal reports, records. However, in the formal collection almost all information related to social groups was systematically reported. Therefore, different data types were used in previously determined parts of the SLCA study. In the comparison of formal collection and informal collection systems, quantitative and semi-quantitative data were used. Detailed list of data characterization of inventory indicators is given in Table 2.10, 2.11, 2.12 and 2.13.

2.3.2.2 Data Collection

Inventory data were gathered from different sources including technical reports, publications, statistical sources as generic data and company records, interviews with social groups involved in the processes, through observations during field visits as specific data. Data collection part classified in line with previously selected social groups categories. Four social groups were selected for this study namely workers, consumers (named as participants) and local community.

Data collection for workers was carried out for formal and informal system separately and different questionnaires were prepared. For the formal system data collection, company's reports related with health and safety, social security, wage records were conducted. Information of the existing system and determination of the predicted data for the proposed models, interviews were held on.

In the existing situation, there were 50 legal workers in total. We conducted face to face interviews with all formal system workers one by one. The survey includes "yes" or "no" type descriptive questions which measures the social group's opinions and attitudes. For the informal collection system, there are no formal records even though interviewed with Waste Picker Association. Inventory data are gathered by using interviews and country based statistical reports. Interviewing with scavengers poses some challenges. For example, they were not willing to give any kind of information especially related with their work because of its illegality. Therefore it was the most difficult part to find reluctant respondents. This problem was handled by using snowball sampling technique which guides us to the next respondent when we find one.

All information collected by interviews was crosschecked to compile reliable and consistent inventory data. For instance, to determine child labour in informal collection sector, a field trip was conducted around the research area to observe this kind of working conditions of scavengers, apart from using the survey result and country statistics. Data collection for participants and local community were held on with a check list of 10 questions. 50

questionnaires were administered to with social groups consist of different socio-economic groups.

A summary of data collection methodology for inventory indicators, in accordance with social impact and subcategories, presented in Table 2.10, 2.11, 2.12 and 2.13.

Table 2.10. Inventory data collection and analysis methodology of “health, safety and security” subcategory-level impact.

Subcategory	Inventory Indicator	Data Source	Data Measurement	Data Type	Data Methodology
Health and safe working conditions (W)	Incident risk	Specific and generic	Direct	Semi-quantitative	Interviews - literature - company records
	Occupational health risk	Specific and generic	Direct	Semi-quantitative	Interviews - literature - company records
	Health and safety awareness	Specific	Direct	Semi-quantitative	Interviews - literature - company records
	Safety risk of the system	Specific	Direct	Semi-quantitative	Interviews - literature - company records
	Presence of protective equipment	Specific	Direct	Semi-quantitative	Interviews - site observations
Health and safe living conditions (Lc)	Local community's health and safe living conditions	Specific	Direct	Semi-quantitative	Interviews - records of GOs
Secure living conditions (Lc)	Local community's secure living conditions	Specific and generic	Direct	Semi-quantitative	Interviews - literature - country statistics

Table 2.11. Inventory data collection and analysis methodology of "working conditions" subcategory-level impact.

Subcategory	Inventory Indicator	Data Source	Data Measurement	Data Type	Data Methodology
Job satisfaction and engagement (W)	Work satisfaction	Specific	Direct	Semi-quantitative	Interviews
Working hours (W)	Legal working hours limit	Specific and generic	Direct	Semi-quantitative	interviews - literature - country statistics
	Night work	Specific and generic	Direct	Semi-quantitative	interviews - literature - country statistics
Wage (W)	Payment in a living wage	Specific	Direct	Semi-quantitative	interviews
	Regular payment	Specific	Direct	Semi-quantitative	Interviews
Social benefits/security (W)	Legal working contracts	Specific	Direct	Semi-quantitative	Interviews - company records
	Retirement rights	Specific	Direct	Semi-quantitative	Interviews - company records
	Social security	Specific	Direct	Semi-quantitative	Interviews - company records
Training and education (W)	Training programs	Specific	Direct	Semi-quantitative	Interviews - company records
Forced labour (W)	Forced labour	Specific	Direct	Semi-quantitative	Interviews

Table 2.12. Inventory data collection and analysis methodology of "human rights" subcategory-level impact.

Subcategory	Inventory Indicator	Data Source	Data Measurement	Data Type	Data Methodology
Child labour (W)	Child labour	Specific	Direct	Semi-quantitative	Interviews - site observations
Freedom of association and collective bargaining (W)	Rights of the associations or bargain collectively	Specific	Direct	Semi-quantitative	interviews - company record
Discrimination (W)	Political, regional and religious discrimination	Specific and generic	Direct	Semi-quantitative	interviews - literature

Table 2.13. Inventory data collection and analysis methodology of "socio-economic repercussion" subcategory-level impact.

Subcategory	Inventory Indicator	Data Source	Data Measurement	Data Type	Data Methodology
Employment (Lc)	Job creation potential	Specific and generic	Direct	Quantitative	Interviews - country statistics
	Job lose potential	Specific and generic	Direct	Quantitative	Interviews - literature - country statistics
Social acceptability (Lc)	Supporting the system	Specific	Direct	Quantitative	Interviews
Service satisfaction (Lc)	Identification of complaints	Specific	Direct	Quantitative	Interviews – municipality records
Contribution to economic development (S)	Contribution of the service to economic development	Specific and generic	Direct	Quantitative	Interviews - literature - country statistics

2.3.3 Impact assessment methodology

2.3.3.1 Characterization (Scoring)

The UNEP/SETAC (2009) emphasizes that inventory data can be evaluated and interpreted with the use of a scoring system. In the literature, there is still not a specific and certain characterization method for the social impacts. Researchers evaluated different scoring systems for characterization of impacts. For instance, Spillemaeckers et al. (2001) used a method based on the fulfillment (1) or non-fulfillment (0) of the social indicators. Similarly, Bork et al. (2015) applied and Foolmaun and Ramjeeawon (2013) applied “yes” or “no” corresponding on the measurement of semi-quantitative indicators.

Foolmaun and Ramjeeawon (2013) developed a new characterization approach to aggregate the inventory results, where the data was collected through questionnaires consist of “yes” or “no” type questions. With these scoring systems, qualitative inventory data were converted into quantitative results. Proposed methodologies consist of three steps. In the first step, all indicator results were converted into percentages. Secondly, percentage data were allocated to each subcategories ranging from 0 to 4. In the final step, previously ranged scores were basically summed up without multiplying any weighting factor. Umair et al. (2013) and Brouwer and Van Ek (2004) proposed a different scoring system which only indicates the data as negative (-) or positive (+). Apart from the other researchers, they didn’t use any numerical values to score the impacts. Blom and Solmar (2009) used (1), (0) and (-1) scores to characterize the inventory indicators. Score (1) indicates one or more issues with negative effect under one indicator whereas (-1) one or more issues with positive effect under one indicator and (0) points to no issue or no data found. Although Wan (2012) applied a characterization methodology consisting of (1), (0), (-1), their effects assigned totally different from Blom and Solmar (2009), where (1) indicates positive social impacts and (-1) negative social impacts.

Besides these characterization methods, 1-to-n scoring system, where the numbers indicates the importance of impact as low to very high, was also used by Martinez-Blanco et al. (2014), Klang et al. (2003), Kijak and Moy (2004). The ranking in this scoring system can be varied one research to another. For instance, Manik et al. (2013) measured the indicators with the questionnaire using the seven-point Likert scale. In this survey, participants were asked to rank the indicators from 1 to 7, where 1 means unimportant and 7 means very important. Later on, these scores were multiplied with the weight of each indicator and then aggregated to the impact categories. Hsu et al. (2013) proposed a new framework which analyzes the quantitative and qualitative indicators differently. They measured the quantitative indicators in percentages and ranked them with 9 scores from 1 to 5 (1, 1.5, 2…, and 5). On the other hand, qualitative indicators degreed as (0), (0.5) and (1). Franze and Ciroth (2011) evaluated a color-based system ranging from very good performance to very poor performance and applied these systems also scoring the impacts ranging from very negative impacts to positive impacts. For each color, a specific factor is assigned to quantify the performance and impacts.

Apart from these studies, some researchers were integrated above given characterization methods. For example, Aparcana and Salhofer (2013b) applied a methodological approach for the social impacts assessment of recycling systems with formalization approaches was developed by Aparcana and Salhofer (2013a). In this characterization procedure, some indicators were measured regarding to the fulfilment or non-fulfilment of the social criteria, whereas for the others 1 to 5 scaling system was performed. Finally, all indicators were converted into (1) and (0) values. And the average score for each indicator was calculated. Busset et al. (2013) applied a scoring system using the methods of Foolmaun and Ramjeeawon (2013) and Hsu et al. (2013). They scored the indicators using four different ranking systems. Some indicators were measured as percentages and ranked from 0 to 4, whereas some of them scored considering the fulfillment (1) or non-fulfillment (0) of the performance. Besides these, (-1), (0), (1) and (0), (0.5), (1) scoring systems were also used for appropriate indicators.

These literature researches apparently showed that there is no agreed social impact assessment method available in SLCA.

In this study, we used only one scoring system for the analysis of the inventory indicators. The survey questionnaires were prepared to comply with quantitative and semi-quantitative data. Therefore, all indicators were measured in either quantitatively or semi-quantitatively. Later on, these indicators were converted into comparable scores low (0), medium (0.5) and high (1) where lowest shore means the negative social impacts, highest score means the positive social impact. These scores assigned to each indicator by classifying the percentages as 0- 33 %, 33-66 % and 66-100 % and marked as (0), (0.5) and (1), respectively. According to this scoring system; if percentage of incidents is 70 %, the score will be 0. However, it should be noted that some indicators had reverse effect. For instance, presence of health and safety awareness has positive social impact. Then, if 70 % of workers aware of this issue; the score will be 1.

Measurement of selected indicators and related reference values are listed in Table 2.14. Each social impact indicator, apart from indicators of socio-economic repercussion impact, were measured by absence or presence of the indicator. Reference values were also determined to assess the score of related indicator. For instance, risk of the having incident in the workplace were measured by the existence of accidents. And the reference of the indicator "No" means there shouldn't be any accidents. On the other hand, because the indicators of socio-economic impact were quantitative (given in Table 2.13), they were measured by numbers or amounts. For example, contribution of the system to economic development were quantified by amounts of recycled material. Amounts were normalized by using min-max linear normalization and scored between 0 and 1. Ranking was performed by using previously explained percentage range.

Table 2.14. Measurement of selected social indicators and related reference values

Inventory indicator	Measurement	Reference Point
Incident risk	Existence of risk	No
Occupational health risk	Existence of risk	No
Health and safety awareness	Existence of awareness	Yes
Safety risk of the system	Existence of risk	No
Health and safety training	Existence of training	Yes
Working with appropriate equipment	Existence	Yes
Local community's health and safe living conditions	Existence of danger	No
Local community's secure living conditions	Existence of danger	No
Work satisfaction	Existence of satisfaction	Yes
Legal working hours limit	Existence of limit	Yes
Night work	Existence	No
Payment in the living wage standards	Existence of standards	Yes
Regular payment	Existence	Yes
Legal working contracts	Existence	Yes
Retirement rights	Existence	Yes
Social security rights	Existence	Yes
Training programs	Existence	Yes
Forced labour	Existence	No
Child labour	Existence	No
Rights of the associations or bargain collectively	Existence	Yes
Political, regional and religious discrimination	Existence	No
Job creation potential	Number of person	Ranking
Job lose potential	Number of person	Ranking
Supporting the system	Number of person	Ranking
Identification of complaints	Number of complaints	Ranking
Contribution of the system to economic development	Amount of recycled waste	Ranking

2.3.3.2 Weighting

Based on the importance of the impacts, each one of them assign with a relative weighting value. Weighting is important because the impact categories should also reflect study goals and social group values (EPA,2006).

Generally there are two weighting methods: the equal weighting and the rank-order weightings (Wang et al. 2009).

- The equal weights method is formulized as:

$$W_i = \frac{1}{n},\ i = 1,2,\ldots, n \qquad (2.9)$$

Where;

W_i : is the weight of the criteria i,

i : importance of criteria, from1 to n,

n : the number of criteria.

Equal weighting is used if all criteria are equally important. Therefore, It doesn't requires classification. Each criterion/impact receives the same weight.

- The rank-order weighting method is formulized as:

$$W_1 \geq W_2 \geq \cdots W_3 \geq 0 \ , \qquad (2.10)$$

Where $\sum_{i=1}^{n} W_i = 1$.

Rank-order weighting is more complicated method comparing to equal weighting. Details of this methods is discussed in Section 2.4.2.

To allocate the inventory results into a single score, equal weighting were used in all three weighting steps: respectively allocation from inventory indicators to subcategory level (1st degree weighting), allocation from subcategory level to impact category level (2nd degree weighting) and allocation from impact category level to total impacts (3rd degree weighting).

2.4 Environmental and Social Life Cycle Sustainability Assessment

After determination of the each environmental and social life cycle impact, sustainability assessment may be conducted. In the aggregation of the ELCA and SLCA results to a single score, there are some important issues should be considered as normalization and weighting.

2.4.1 Normalization

To reach a comparable single score for and sum up the results of environmental and social impacts, impact scores need to be normalized. Normalization is based on the calculation of the magnitude of certain indicators in relation to reference information in order to express them into a common scale. Then, scores are easily comparable and agreeable even though they are in different units (Guinee et al., 2001, Ibanez-Fores et al. 2014).

LCSA of the packaging waste system researched in this study, values were normalized respecting to “min-max linear normalization method”. This method standardizes the results on a scale of 0 to 1, where the 0 is assigned as the lowest value, 1 is the best value. Because of the scoring system of the SLCA represent an utility results were directly correlated by using direct correlation equation (Equation 2.11). On the contrary, inverse correlation was used for normalization of ELCA results (Equation 2.12) (Maxim, 2014).

For direct correlation:

$$u(x_k) = \frac{(x_k - x_{min})}{(x_{max} - x_{min})} \qquad (2.11)$$

For inverse correlation:

$$u(x_k) = \frac{(x_{max} - x_k)}{(x_{max} - x_{min})} \qquad (2.12)$$

where;

x_k : is the indicator value for the scenario k,

x_{min} : the minimum value of the indicator,

x_{max} :the maximum value of the indicator.

2.4.2 Weighting

In order to compare results numerically, normalized LCIA results are multiplied by the weighting factors. To get a single score impact value, all weighted results summed up. This aggregation provided a total score, then existing system and alternative scenarios were compared in terms of environmental and social LCSA.

In this study, to aggregate the ELCA and SLCA results, the rank-order weighting method was used. This method is classified into three categories: subjective, objective and combination weighting methods. In this study; Simple multi-attribute ranking technique (SMART) which is one of the subjective weighting methods originally described by Edwards in 1977 (Wang et al. 2009) was used. In this technique, importance of criteria is asked to a reference group. In the weighting 1 represents the most important criterion 1. The weight of the ith criterion is determined by the following formula:

$$W_i = \frac{1}{n}\sum_{J=i}^{n}\frac{1}{j}, \quad i = 1,\ldots,n \qquad (2.13)$$

where;

W_i : is the weight of the criteria i,

i : importance of criteria, from1 to n,

n : the number of criteria.

Considering the ranking methodology, there were only three possible rank for two criteria as; Environmental:1- Social:2, Environmental:2- Social:1 and Environmental:1- Social:1. Since, this was the first study it was necessary to have an objective perspective. So, all three ranking possibilities were conducted without using a reference group.

2.4.3 Interpretation

In this step, after the normalization and weighting steps of the LCSA, single score results were environmental and social were analyzed and integrated to a total single score. Figure 2.7 illustrates the whole methodological stages of the environmental and social life cycle sustainability assessment carried out in this thesis, briefly.

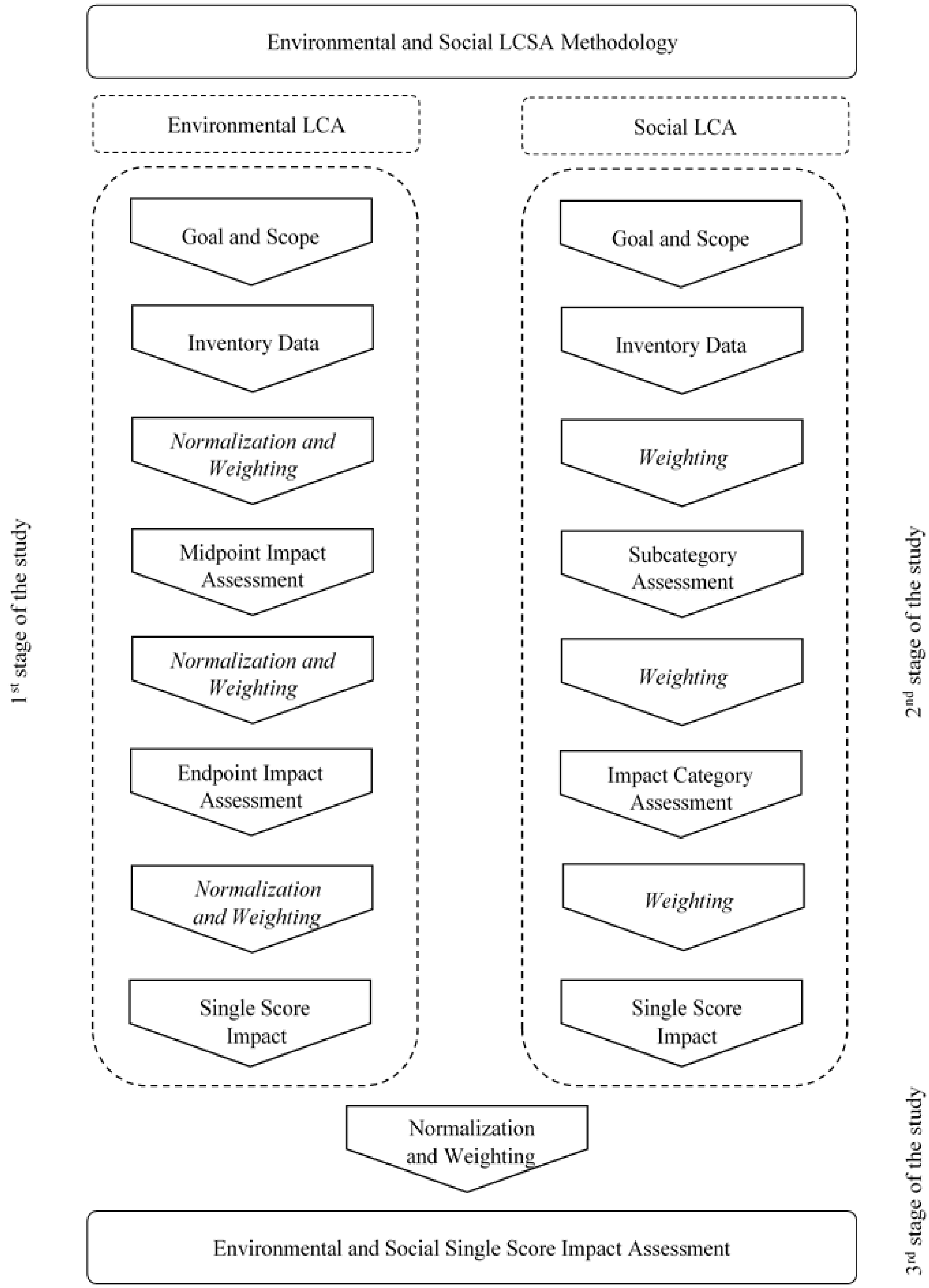

Figure 2.7. Environmental and Social life cycle sustainability assessment methodology used in this study.

3 RESULT AND DISCUSSION

In this section; respecting to determined methodology, results of the study is discussed in three part as ELCA, SLCA and LCSA.

3.1 Environmental Life Cycle Assessment

Results of the ELCA were analyzed in two stages. Firstly, data of the existing system and proposed scenarios were discussed in the inventory analysis stage, without impact assessment. Secondly, outcomes of the impact assessment were analyzed in detail.

3.1.1 Inventory data analysis

3.1.1.1 Research area data analysis

This study states the environmental impact of alternative recycling waste collection systems for Maltepe district located in the suburbs of Turkey's largest city Istanbul. Population and waste generation rate of the selected area are shown in Table 3.1. Because of the data reliability and availability, 2012 selected as based year. In 2012, Maltepe has a population of 460,955 inhabitants (ABPRSR, 2012) and mixed solid waste generated was 174,774.27 tons (MBFR, 2013). On the other hand, site researches showed that 29,196.00 tons of packaging waste were collected informally. Therefore, total household solid waste amount was 203,970.27 tons.

Table 3.1. Household solid waste generation for Maltepe Municipality (ton/year) (MBFR, 2012, 2013, 2014, 2015).

Year	Population	Mixed Solid Waste [Q_M]	Recyclable Waste [Q_F]
2011	452,099	162,970.00	3,158.00
2012	460,955	170,521.00	4,253.27
2013	471,059	170,178.00	4,495.00
2014	476,806	178,761.00	4,693.00

Q_M : These data includes mixed solid waste collected by municipality
Q_F : Formal collection by municipality

Based year's waste generation amounts and rate are shown in Table 3.2.

Household solid waste is the sum of mixed solid waste (kitchen, garden waste, incinerable and non-incinerable waste) and packaging waste. Packaging waste amount is the sum of the formal and informal collection of packaging materials.

Table 3.2. Household solid waste collection data for Maltepe Municipality (ton/year) (MBFR, 2013).

Household Solid Waste [Q_T]	Mixed Solid Waste [Q_M]	Packaging Waste [Q_F]	Packaging Waste [Q_I]
203,970.27 ton	170,521.00 ton	4,253.27 ton	29,196 ton
100%	83.60%	2.09%	14.31%

Q_T : Household solid waste
Q_M : These data includes mixed solid waste collected by municipality
Q_F : Formal collection by municipality
Q_I : Informal collection by scavengers

Table 3.3 gives the transportation distance from collection point to sorting facility and from sorting facility to recycling center. In the existing system, packaging wastes except glass are collected in the same bag. Mixed packaging waste and glass waste are collected separately and transported to the different sorting facilities. Therefore, the travel distance for mixed packaging and glass waste were 33.33 km/ton and 42.50 km/ton, respectively. Electricity, water and collection material consumption were also taken from municipality inventory. Electricity and water consumption were 10.00 kWh/ton and 0.39 m^3/ton for mixed packaging waste and 9.00 kWh/ton and 0.41 m^3/ton for glass sorting facility, respectively.

Table 3.3. Transportation data for packaging materials (km/ton).

Packaging Waste	Sorting Facility (km/ton)	Fuel Consumption (L/ton)	Recycling Centers (km/ton)	Fuel Consumption (L/ton)
Paper-cardboard	33.33	17.49	20.00	8.09
Plastic	33.33	17.49	28.57	11.55
Metal	33.33	17.49	11.42	4.62
Glass	42.50	14.87	13.26	4.69

It is assumed that in all proposed scenarios same vehicle type would be used. Vehicle characteristics for the existing system is given in Table 3.4 were used.

One of the most significant differences between the existing system and alternative scenarios was the material use. Characteristics of basic collection materials are given in Table 3.5. All consumption data for the alternative scenarios were calculated based on the existing system. Further details about the calculations are explained in the following section.

Table 3.4. Packaging waste collection vehicle characteristics for existing system.

Vehicle Model	Year	Volume (L)	Activity Type
ISUZU 66 NPR	2005	7+1 m^3	Collection and transportation
IVECO 80.12	2004	7+1 m^3	Collection and transportation
IVECO 80.12	2009	8+1 m^3	Collection and transportation
FORD CARGO2114	2000	13+1 m^3	Collection and transportation
FORD CARGO2114	2002	13+1 m^3	Collection and transportation
ISUZU NPR 75	2011	7+1 m^3	Collection and transportation
FORD CARGO2114	2011	13+1 m^3	Collection and transportation

Table 3.5. Packaging waste collection material characteristics.

Material	Collection System	Volume (L)	Weight (kg)	Material
Galvanized Steel Container	Drop-off	2	87	Steel
Plastic Container	Curbside	1.1	100	HDPE
Plastic Bag Consumption	Door to Door	0.019	0.01	LDPE

After the selective collection, packaging waste are transported to sorting facility. Electricity and water usage in sorting facility is given in Table 3.6. In the existing system, there were two different sorting facility mainly for mixed packaging waste and glass waste. In the mixed packaging waste sorting facility, materials were sorted by hand, so water consumption was lower than the glass sorting facility where the sorting system was based on the mechanical separation.

Table 3.6. Input and output materials of sorting process.

Waste Type	Input and Output Material Type	Consumptions	Source of Data
Mixed packaging waste	Electricity consumption (kWh/ton)	10	Plant
	Water consumption (m^3 /ton)	0.39	Plant
	Residual waste (ton/ton)	0.22	Plant
Glass waste	Electricity consumption (kWh/ton)	8.97	Plant
	Water consumption (m^3 /ton)	0.41	Plant
	Residual waste (ton/ton)	0.05	Literature

After the sorting, packaging waste materials were transported to related recycling facilities. Transportation data was already discussed above. In recycling centers, packaging wastes were processed as secondary products in order to replace the primary raw materials in the manufacture. For each type sorted of waste energy consumption amounts in the recycling centers are summarized in Table 3.7.

Table 3.7. Inputs of recycling process (Rigamonti et al., 2014).

Packaging Waste	Electrical Energy	Thermal Energy
Paper waste	7 kWh/ton	15 MJ/ton (from diesel)
Glass waste	18.4 kWh/ton	5460 MJ/ton (fuel oil)
Plastic waste	414 kWh/ton	2291 MJ/ton (from natural gas)
Steel waste	671 kWh/ton	-
Aluminum waste	79 kWh/ton	4885 MJ/ton (from natural gas)

In the mass balance of recycling facility, it was assumed that sorted materials were processed in a certain recycling efficiency rates depending on the used technology. Recycling efficiency rates used in this study were taken from literature studies (Table 3.8). In the calculation of avoided product for a recycling process, substitution rate used as an another important parameter. For all type of packaging materials analyzed in this study, it was assumed that each recycled material was substituted to the primary raw material in a ratio of 1:1. For instance, one ton of recycled plastic substituted one ton of virgin plastic granulates. This means 1 ton of raw material of plastic granulates was avoided from production.

Table 3.8. Recycling process and efficiency (Rigamonti et al., 2009 and Ferreira et al., 2014).

Packaging Material	Recycling Efficiency	Substitution Rate	Avoided Product
Paper-cardboard	86 %	1:1	Core board
Glass	88 %	1:1	Glass from virgin materials
Plastic	73.5 %	1:1	Plastic granulates
Steel (ferrous)	84 %	1:1	Pig iron
Aluminum(non-ferrous)	93 %	1:1	Primary aluminum

3.1.1.2 Determination of efficiency indicators

The participation, collection, wastage, and treatable material rate used in the scenarios are presented in Table 3.9. Potential amount of recyclable matter was taken 25 % of the total amount of waste generated in all scenarios and years. For the estimation of participation rate, existing system's formal and informal collection rate was calculated as 2.09 % and 14.31 %. Then participation rate was calculated as 3.20 % for formal collection system. In the informal collection, there was not a participation rate or separate collection; because scavengers would picked the waste from mixed waste bins and this didn't require a specific separate collection. Existing system analysis showed that in the formal collection system 18.51% mixed collected packaging waste was separated in the sorting facility as a residual waste. However, in the informal collection system wastage rate was 0 %, resulting from waste picker's selective collection system. For the scenarios 1 to 8, participation rates were determined based on data from the existing system and targets aimed by Turkish Legislative Decree and literature reviews. Wastage rate for these scenarios were calculated considering the existing system data and Municipality's field observation data analyzed in 2010 for "Maltepe Municipality Packaging Waste Management Plan" preparation studies. As seen on the Table 3.9; in the scenario 9, almost all efficiency rates were similar with ES. Only difference was the exclusion of the informal system's data. In the ES, S10, S11, S12 and S13, packaging waste collection rate was higher than public participation rate as a result of informal or formalized collection systems. In the informal collection systems and formalized scenario suggestions, even if the participation rate was 0 %, source separation rate would not be zero. Similarly, wastage rate will be always zero respecting to scavengers' selective collection system. On the other hand, in the formalized systems S11 and S12, public participation rate was assumed as 2.59 % because only the glass waste would be collected separately in a different container. In Scenario 13, it was assumed that collection rate would be 0.54% for glass and 15.86 % for mixed waste same as S11. Only difference was all packaging wastes were separated by citizens and stored in the collection materials. Therefore, in scenario 13 participation rate were calculated as 0% respecting to this terms.

Table 3.9. Calculated and estimated indicators of existing system and alternative scenarios.

Scenario	Participation Rate (%)	Source Separation Rate (%)	Wastage Rate (%)	Recyclable Waste Rate (%)
Existing System	3.20	2.09+14.31	18.51+0	1.70+14.31
Scenario 1	3.87	2.53	18.51	2.06
Scenario 2	3.53	2.30	40.00	1.38
Scenario 3	2.89	1.89	8.20	1.73
Scenario 4	2.89	1.89	7.90	1.74
Scenario 5	2.59	1.69	18.51	1.38
Scenario 6	2.59	1.69	8.20	1.55
Scenario 7	1.80	1.18	18.51	0.96
Scenario 8	1.80	1.18	8.20	1.08
Scenario 9	3.20	2.09	18.51	1.70
Scenario 10	0	15.86	0	15.86
Scenario 11	2.59	0.54+15.86	5+0	0.51+15.86
Scenario 12	2.59	2.09+10.00	18.51+0	1.70+10.00
Scenario 13	0	0.54+15.86	5+0	0.51+15.86

3.1.1.3 Collection-transportation, sorting-recycling data analysis

After the determination of the participation and collection rates of each scenario, inventory data of collection and transportation of proposed scenarios were calculated. The results of collection, transportation and recycling analysis are given in Appendix 1 and Appendix 2. Analysis results also ranked and illustrated in Figure 3.1-Figure 3.7 in terms of collected material, avoided product, wastage material, fuel, energy and water consumption.

As it is seen on the Figure 3.1, informal and/or formalized system suggestions shows slightly effective collection results than the formal collection systems. In the existing situation, participation rate of citizens was dramatically low. And all formal collection scenarios (from S1 to S9) was almost based on the this participation rate. Differentiations on the participation rate only resulted from the usage of various collection materials. Therefore, the collection rate in the scenarios (S1 to S9) which were depended to public participation rate was lower than the waste picker’s collection systems (ES, S10 to S12). In contrast, even the collection system in Scenario 13 based on the public participation, because it was suggested as an idealized system, collection rate was higher than other formal collection systems scenarios.

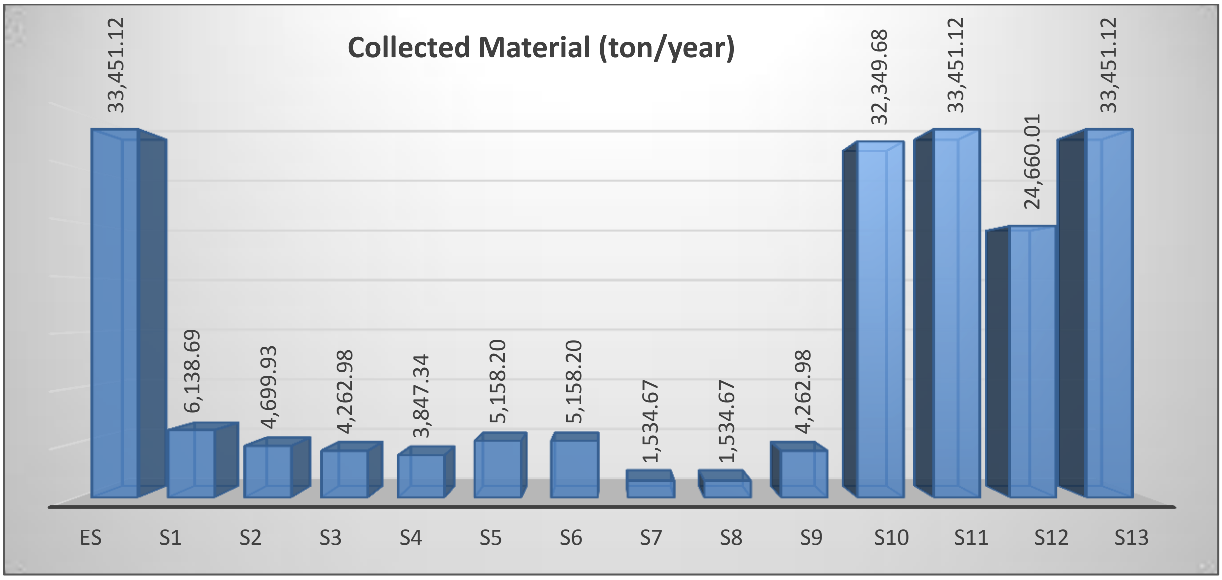

Figure 3.1. Comparison of alternative scenarios and existing system in terms of collected material (ton/year).

Single or multiple fractionated collection system effected the recycled material rate in a noticeable way, as shown in the Figure 3.2. Even ES, S11, and S13 had the same amount of collected material, avoided product amounts showed a differentiation. This was mainly caused by source separate collection system applied in existing system. As stated in Figure 3.3, ES had the highest wastage rate compared to S11 and S13.

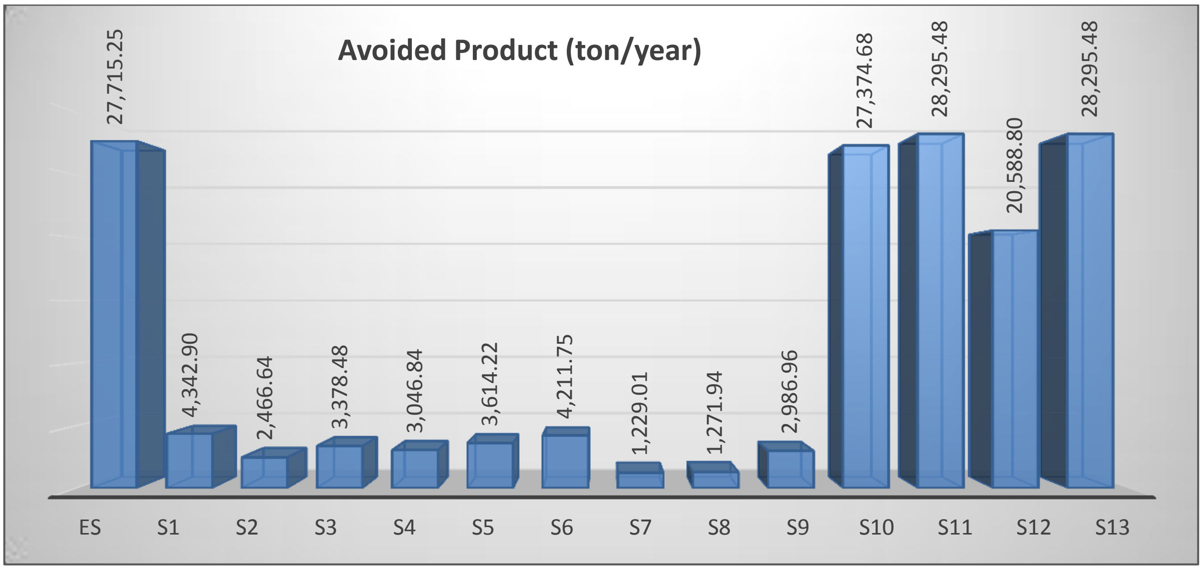

Figure 3.2. Comparison of alternative scenarios and existing system in terms of avoided product (ton/year).

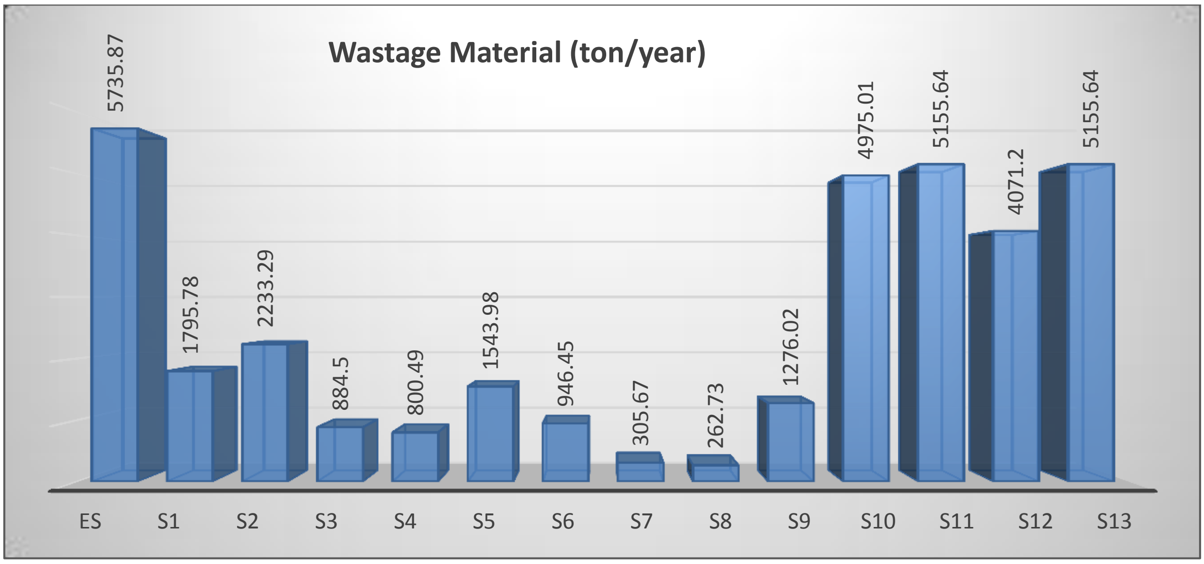

Figure 3.3. Comparison of alternative scenarios and existing system in terms of wastage material (ton/year).

In the analysis of informal and formalized scenario's fuel consumption data which changes regarding to collection system and amount of collected material, S13 had the highest consumption values, although the collected material amount was same as ES and S11. This disparity was related to existence of informal scavengers in ES and S11. Between the formal collection systems (from S1 to S9); considering the fuel consumption, S2 where waste was collected in one fractions with door-to-door collection system, had minimum fuel usage amount. On the other hand, in the four fractionated door-to-door collection system (S4), fuel was used almost 4 times higher than S2. Also it is clear that all door-to-door collection systems had more fuel consumption than curbside and drop-off systems. Compared with curbside collection system, there was also a clear difference on drop-off system in terms of fuel usage (Figure 3.4).

Material consumption amounts in scenarios were differentiated with material type. Among the galvanized steel container used-scenarios, S5 had the minimum material usage where S8 had the maximum. This was mainly depended on collected waste amount and then waste fractionation. Similarly, in plastic bag used-scenarios, one-fractionated scenario (S2) had minimum material consumption whereas four-fractionated scenario (S4) had maximum consumption. Water consumptions were related with only sorting activity, whereas thermal energy and electrical energy were consumed with regard to both sorting and recycling facilities. Therefore, fractionation of waste at source was the dominating factor. When wastes were collected in three and four fractions (Scenario 3 and 4), sorting activity was minimized.

In Scenario 2, wastes were collected in a single fraction, and so water-electricity consumption increased. In the same way, landfilled waste amount was related with fractionated collection. If wastes were separated efficiently, wastage amount would decrease. Hence, landfilled waste amount would also decrease. Because S3 and S4 had minimum wastage amount, landfilling was also found as minimum while S2 had the highest landfilled waste amount. Regarding to these analysis, advantageous scenarios were S7 and S8 regarding the consumption data (Figure 3.5, Figure 3.6, Figure 3.7).

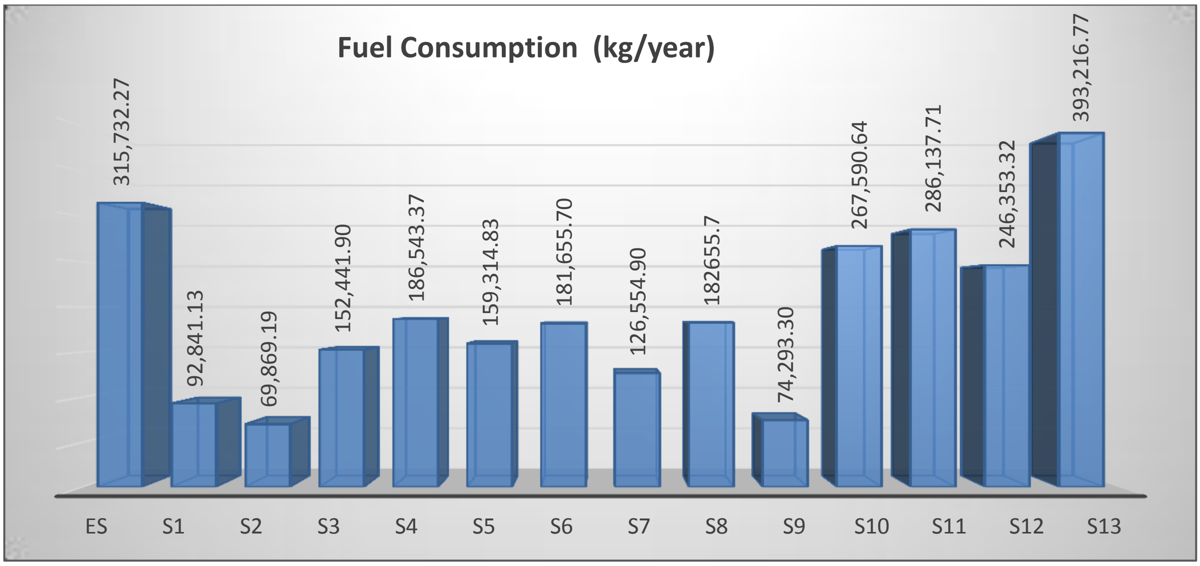

Figure 3.4. Comparison of alternative scenarios and existing system in terms of fuel consumption (kg/year).

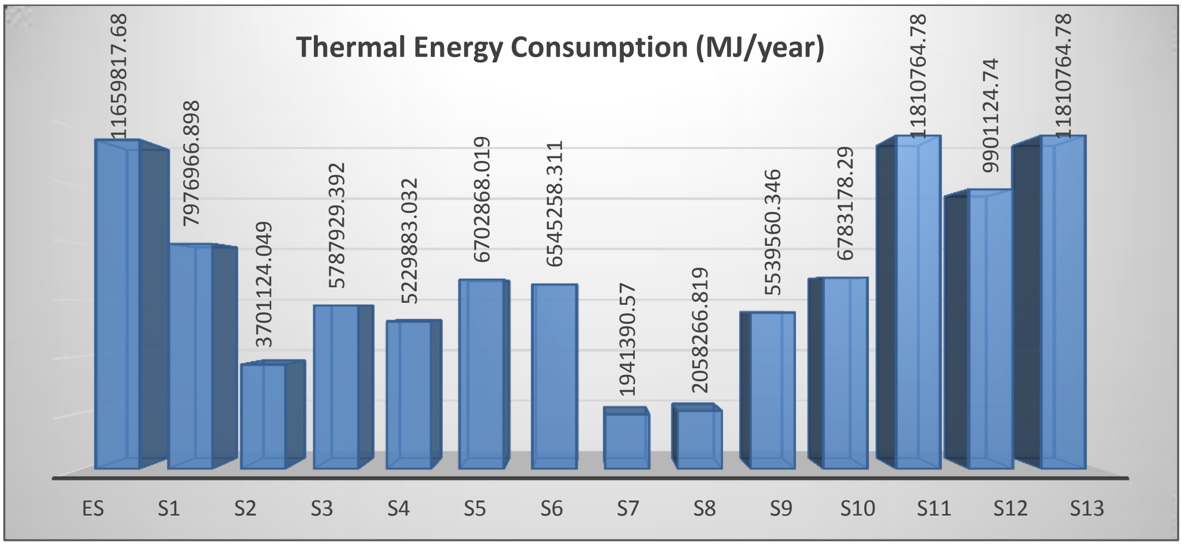

Figure 3.5. Comparison of alternative scenarios and existing system in terms of thermal energy consumption (MJ/year).

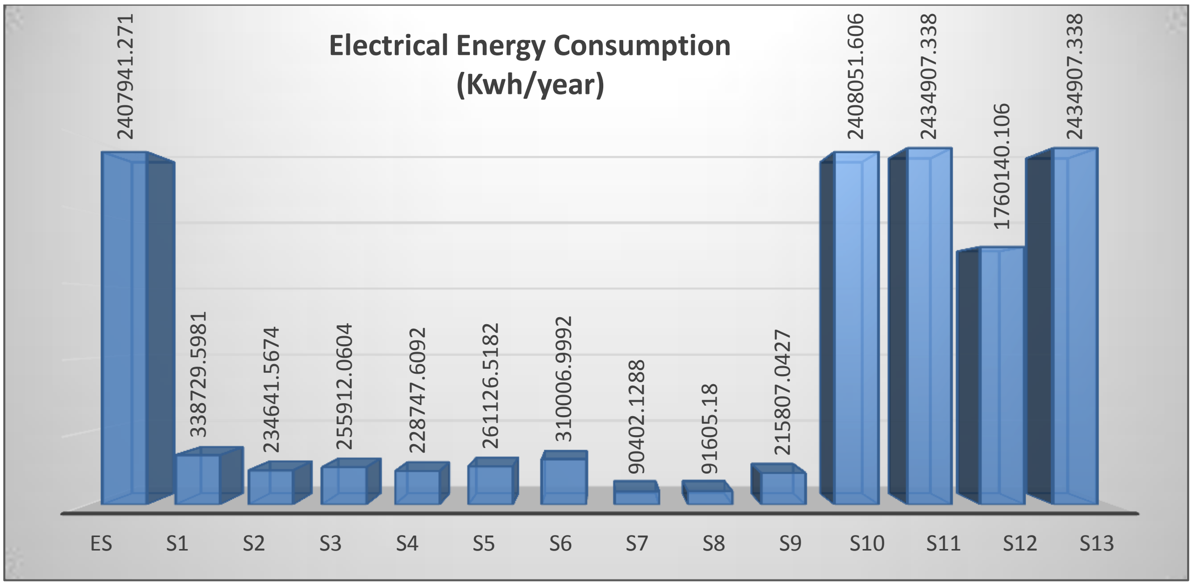

Figure 3.6. Comparison of alternative scenarios and existing system in terms of electrical energy consumption (Kwh/year).

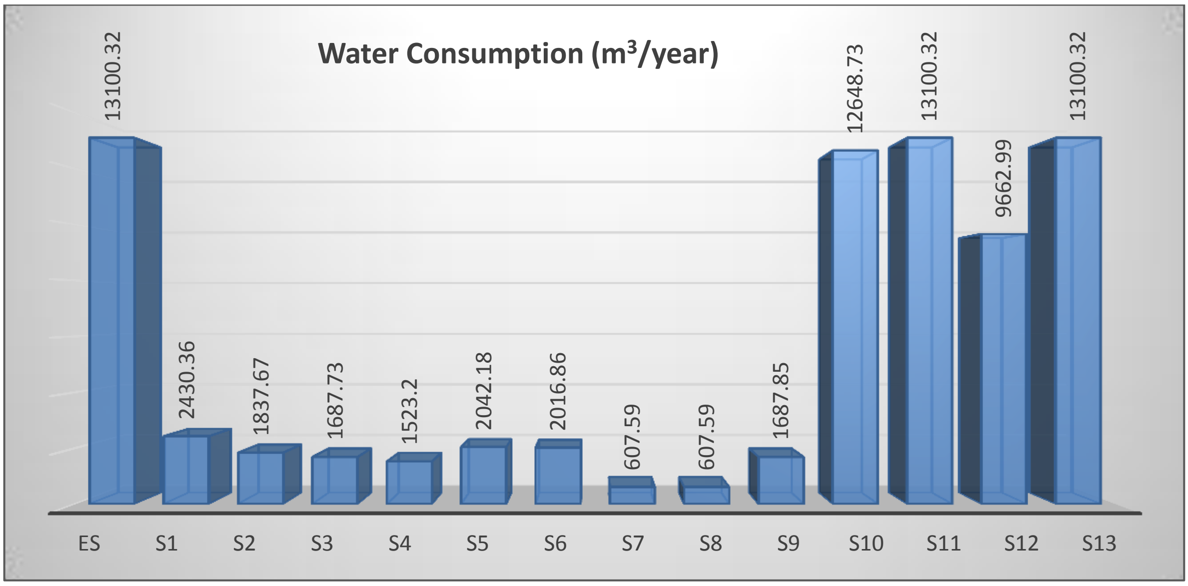

Figure 3.7. Comparison of alternative scenarios and existing system in terms of water consumption (m^3/year).

3.1.1.4 Calculation of Released Emissions

Semi-trailers were employed to transport the packaging waste from collection points to the sorting facility. As there is no precise set of data regarding the emissions of the vehicles in the researched area, the emissions are estimated based on EEA standards. Regarding to these assumptions and calculations, an overview of the emissions released through transportation activity are given in Table 3.10. According to the municipality's reports, the fuel consumption ratio for one ton of wastes for each scenario was calculated by using Equation (2.8) and results were given in Table 3.11 and Table 3.12. Airborne emissions was related the only fuel consumption. Fuel combustion directly consumed in collection and transportation processes of analyzed management system. As it is seen, emissions to air increase linearly depending on the increments on fuel consumption.

Table 3.10. Emission factors for airborne pollutants sourced by fuel consumption.

Airborne Pollutants	Unit	Emission Factor
CO_2	kg / kg fuel	3.14
CO	g / kg fuel	7.58
CH_4	g / km	0.175
N_2O	g / kg fuel	0.051
NOx	g / kg fuel	33.37
NH_3	g / kg fuel	0.013
SO_2	g / kg fuel	0.02
PM	g / kg fuel	0.94
NMVOC	g / kg fuel	1.92
CO_2lub	g / kg fuel	2.54
Pb	mg / kg fuel	0.0521
Cd	mg / kg fuel	0.0087
As	mg / kg fuel	0.0001
Cr	mg / kg fuel	0.03
Cu	mg / kg fuel	0.0212
Hg	mg / kg fuel	0.0053
Ni	mg / kg fuel	0.0088
Se	mg / kg fuel	0.0001
Zn	mg / kg fuel	1.738

Table 3.11. Airborne emissions estimated for packaging waste collection-transportation process.

	CO_2 (kg/year)	CO (g/year)	CH_4 (g/year)	N_2O (g/year)	NO_x (g/year)	NH_3 (g/year)	SO_2 (g/year)	PM (g/year)	NMVOC (g/year)	CO_2lub (g/year)
ES	154,453.15	372,851.88	26,634.27	2,508.63	1,641,433.65	639.46	983.78	46,237.57	94,442.69	124,939.81
S1	154,453.15	372,851.88	26,634.27	2,508.63	1,641,433.65	639.46	983.78	46,237.57	94,442.69	124,939.81
S2	153,758.40	371,174.75	25,411.14	2,497.35	1,634,050.30	636.58	979.35	46,029.59	94,017.88	124,377.82
S3	388,223.54	937,176.58	63,992.05	6,305.54	4,125,802.42	1,607.29	2,472.76	116,219.79	237,385.10	314,040.70
S4	503,991.91	1,216,642.89	83,037.14	8,185.86	5,356,117.86	2,086.59	3,210.14	150,876.56	308,173.40	407,687.72
S5	404,866.91	977,353.88	66,201.62	6,575.86	4,302,677.94	1,676.20	2,578.77	121,202.20	247,561.93	327,503.81
S6	454,088.68	1,096,175.85	74,217.66	7,375.33	4,825,776.78	1,879.98	2,892.28	135,937.37	277,659.32	367,320.14
S7	364,043.22	878,804.98	60,208.50	5,912.80	3,868,828.78	1,507.19	2,318.75	108,981.09	222,599.68	294,480.82
S8	539,188.46	1,301,607.80	89,160.46	8,757.52	5,730,165.23	2,232.31	3,434.32	161,413.11	329,694.85	436,158.82
S9	154,453.15	372,851.88	26,634.27	2,508.63	1,641,433.65	639.46	983.78	46,237.57	94,442.69	124,939.81
S10	-	-	-	-	-	-	-	-	-	-
S11	42,828.37	103,388.22	8,191.96	695.62	455,153.68	177.31	272.79	12,821.23	26,188.04	34,644.60
S12	154,453.15	372,851.88	26,634.27	2,508.63	1,641,433.65	639.46	983.78	46,237.57	94,442.69	124,939.81
S13	371,214.46	896,116.43	62,957.29	6,029.28	3,945,040.26	1,536.88	2,364.42	111,127.89	226,984.64	300,281.76

Table 3.12. Airborne emissions estimated for packaging collection-transportation process.

	Pb (mg/year)	Cd (mg/year)	As (mg/year)	Cr (mg/year)	Cu (mg/year)	Hg (mg/year)	Ni (mg/year)	Se (mg/year)	Zn (mg/year)
ES	2,562.74	427.94	4.92	1,475.67	1,042.80	260.70	432.86	4.92	85,490.31
S1	2,562.74	427.94	4.92	1,475.67	1,042.80	260.70	432.86	4.92	85,490.31
S2	2,551.21	426.02	4.90	1,469.03	1,038.11	259.53	430.92	4.90	85,105.77
S3	6,441.54	1,075.65	12.36	3,709.14	2,621.13	655.28	1,088.02	12.36	214,882.97
S4	8,362.41	1,396.41	16.05	4,815.21	3,402.75	850.69	1,412,46	16.05	278,961.13
S5	6,717.70	1,121.77	12.89	3,868.16	2,733.50	683.37	1,134.66	12.89	224,095.12
S6	7,534.40	1,258.14	14.46	4,338.43	3,065.82	766.46	1,272.61	14,46	251,339.53
S7	6,040.34	1,008.65	11.59	3,478.12	2,457.87	614.47	1,020.25	11,59	201,499.08
S8	8,946.41	1,493.93	17.17	5,151.48	3,640.38	910.10	1,511.10	17,17	298,442.53
S9	2,562.74	427.94	4.92	1,475.67	1,042.80	260.70	432.86	4.92	85,490.31
S10	-	-	-	-	-	-	-	-	-
S11	710.62	118.66	1.36	409.19	289.16	72.29	120.03	1.36	23,705.64
S12	2,562.74	427.94	4.92	1,475.67	1,042.80	260.70	432,86	4.92	85,490.31
S13	6,159.32	1,028.52	11.82	3,546.63	2,506.29	626.57	1,040.35	11.82	205,468.38

3.1.2 Impact assessment analysis

Waste collection-transportation, sorting and recycling data discussed in the previous section were introduced to SimaPro software to quantify the environmental impact indicators according to the existing system and alternative scenarios. Inventory data for collection, transportation and recycling activities were given in Appendix 3, 4 and 5. Table 3.13 summarizes the results of existing system and each scenario in eight impact indicators mentioned in section 2.2.3. The results of EIA were schematically shown in Figure 3.8 to Figure 3.15.

In this study avoided impacts (negative impacts) are higher than added impacts (positive impacts) because the recycling system saves raw material, decreases energy and water consumption and also avoids the emissions related with these activities. Consequently, impact assessment indicators may have negative values suggesting environmental benefits.

As seen on the Table 3.13, in all impact results, informal and/or formalized system suggestions are environmentally more effective than the formal system suggestions as expected. Therefore, in the analysis of the impact results, formal system and informal systems are mostly discussed separately.

Table 3.13. CML-IA impact assessment results of existing system and scenarios.

	Abiotic depletion (kg Sb eq)	Abiotic depletion (MJ)	Global Warming-20a (kg CO_2 eq)	Global warming-100a (kg CO_2 eq)	Ozone layer depletion (kg CFC-11 eq)	Photochemical oxidation (kg C_2H_4 eq)	Acidification (kg SO_2 eq)	Eutrophication (kg PO_4^{-3}eq)
ES	-2.91E+01	-3.51E+08	-1.33E+07	-1.47E+07	-7.48E-01	-6.55E+03	-9.81E+04	-1.64E+04
S1	5.23E+00	-1.52E+07	2.07E+06	8.99E+05	-1.50E-02	1.24E+02	2.25E+03	3.99E+03
S2	-3.48E+00	-2.96E+07	1.19E+06	-1.70E+05	-7.10E-02	-3.90E+02	-9.19E+03	3.15E+03
S3	-5.12E+00	-3.97E+07	-1.26E+06	-1.48E+06	-8.93E-02	-7.33E+02	-1.15E+04	-1.24E+03
S4	-4.65E+00	-3.36E+07	-9.29E+05	-1.13E+06	-6.65E-02	-5.71E+02	-8.02E+03	-8.36E+02
S5	-3.93E+00	-3.59E+07	1.43E+05	-6.67E+05	-7.40E-02	-4.85E+02	-8.79E+03	9.37E+02
S6	-4.05E+00	-4.39E+07	-1.67E+06	-1.68E+06	-8.87E-02	-7.83E+02	-1.24E+04	-1.35E+03
S7	-1.20E+00	-9.59E+06	-8.44E+04	-1.93E+05	-1.16E-02	-1.22E+02	-5.62E+02	-1.44E+01
S8	-9.77E-01	-7.18E+06	2.94E+04	-3.34E+04	2.17E-03	-5.12E+01	1.89E+03	1.60E+02
S9	-4.55E+00	-3.65E+07	-4.44E+05	-1.08E+06	-9.42E-02	-6.23E+02	-1.29E+04	-4.84E+01
S10	-2.72E+01	-3.49E+08	-1.42E+07	-1.51E+07	-7.23E-01	-6.54E+03	-9.46E+04	-1.83E+04
S11	-2.97E+01	-3.62E+08	-1.48E+07	-1.57E+07	-7.74E-01	-6.84E+03	-1.02E+05	-1.91E+04
S12	-2.20E+01	-2.61E+08	-1.02E+07	-1.11E+07	-5.60E-01	-4.89E+03	-7.39E+04	-1.29E+04
S13	-2.41E+01	-3.50E+08	-1.39E+07	-1.48E+07	-7.28E-01	-6.42E+03	-9.52E+04	-1.74E+04

3.1.2.1 Abiotic depletion potential

Abiotic depletion impact is related to mineral extraction and fuel consumption during the collection and transportation activities from collection area to the sorting and finally to the recycling center.

Considering the abiotic depletion associated with mineral consumption, S11 showed environmentally more effective behavior among the all collection scenarios (Figure 3.8). Even S11, S13 and ES have the same collection material amount, different collection materials caused changes in the abiotic depletion potential. Between the formal collection systems, impacts of S1 specifically differed from the other scenarios. S7 and S8 were also significantly different as a result of low material collection and high collection material usage. The main difference between these scenarios was metal and/or plastic material consumption due to the container usage.

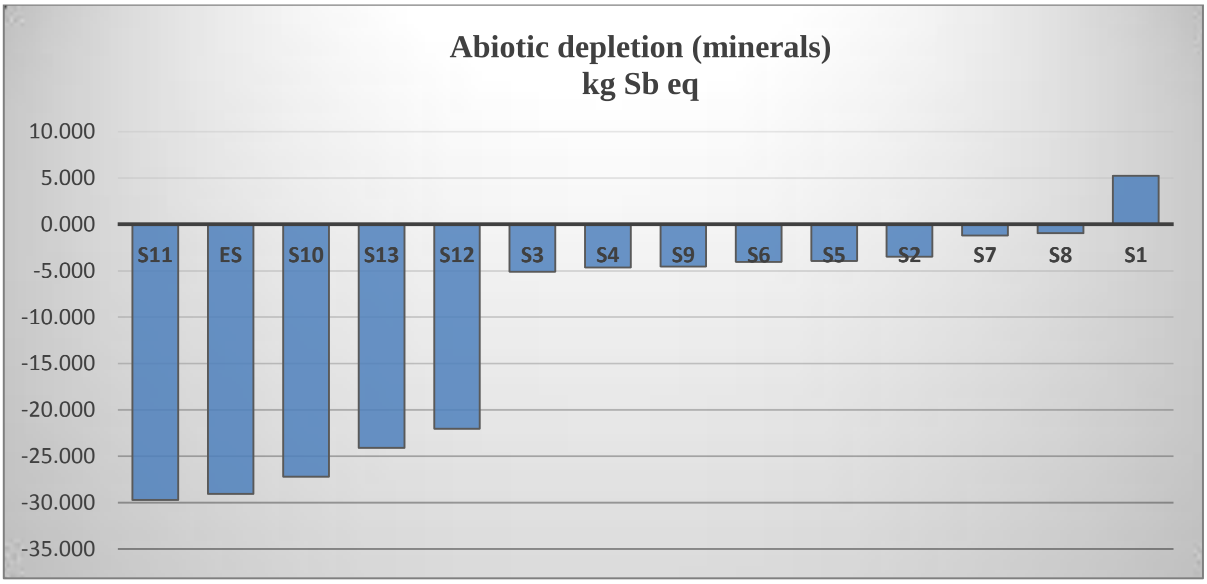

Figure 3.8. Abiotic depletion (Minerals) impact analysis of alternative scenarios and existing system via CML-IA method.

In Figure 3.9 energy related abiotic depletion was illustrated. As we previously discussed in section 3.1.1; activities in S13, ES and S11 consumes more energy resources than the other informal and formalized collection alternatives, respectively. Regarding to abiotic fossil fuel depletion results, S11 expectedly performed as the best scenario. In contrast to the consumption results, idealized scenario S13 showed environmentally better results than ES (S13 had the highest fuel consumption). This could be related with the elimination of virgin material extraction which had the higher amount in S11 than ES. Among the formal collection systems, environmental profile was almost same except S1, S7 and S8. The scenarios S6, S3 and S5 were the first three environmentally beneficial scenarios whereas S1, S7 and S8 were the least effective. Since the collection and transportation system for each scenario was not the same, consumptions of resources such as fossil fuel and electricity were also different.

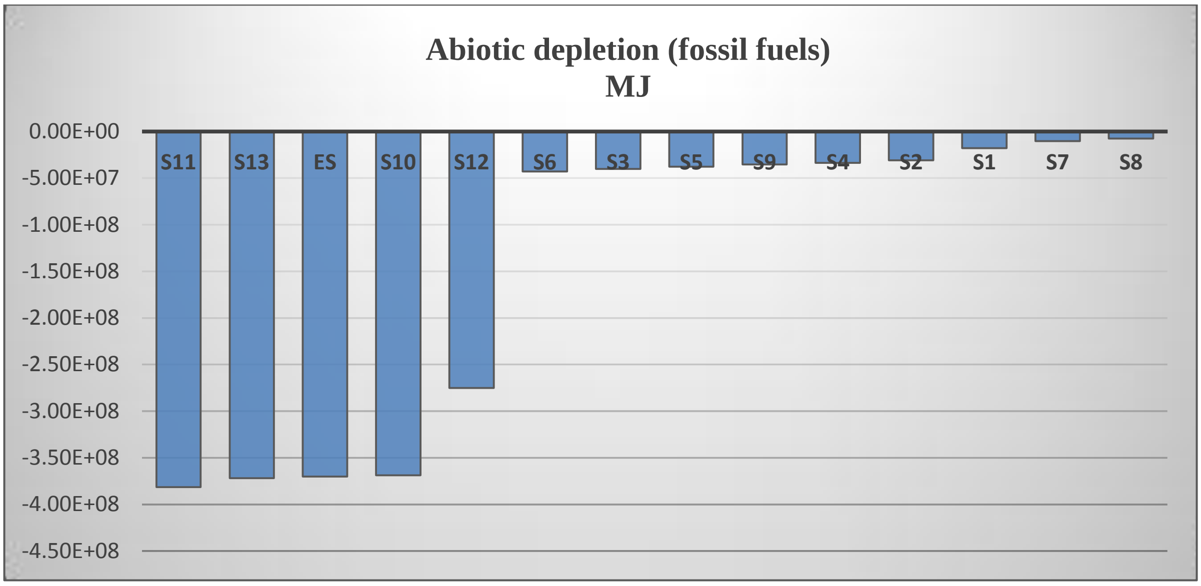

Figure 3.9. Abiotic depletion (fossil fuels) impact analysis of alternative scenarios and existing system via CML-IA method.

3.1.2.2 Acidification potential

The contribution to this impact was mainly associated with fuel consumption resulted from the transportation activity. Therefore, S11 had the less effect on the environment and then flowingly ES and S13 gave the more effective results. Between the formal systems, S9 and S3 had the least score on acidification because the fuel consumption and related emissions (NO_x, SO_x and NH_3) were less than other scenarios. However, S1, S8 and S7 had the biggest score on acidification (Figure 3.10).

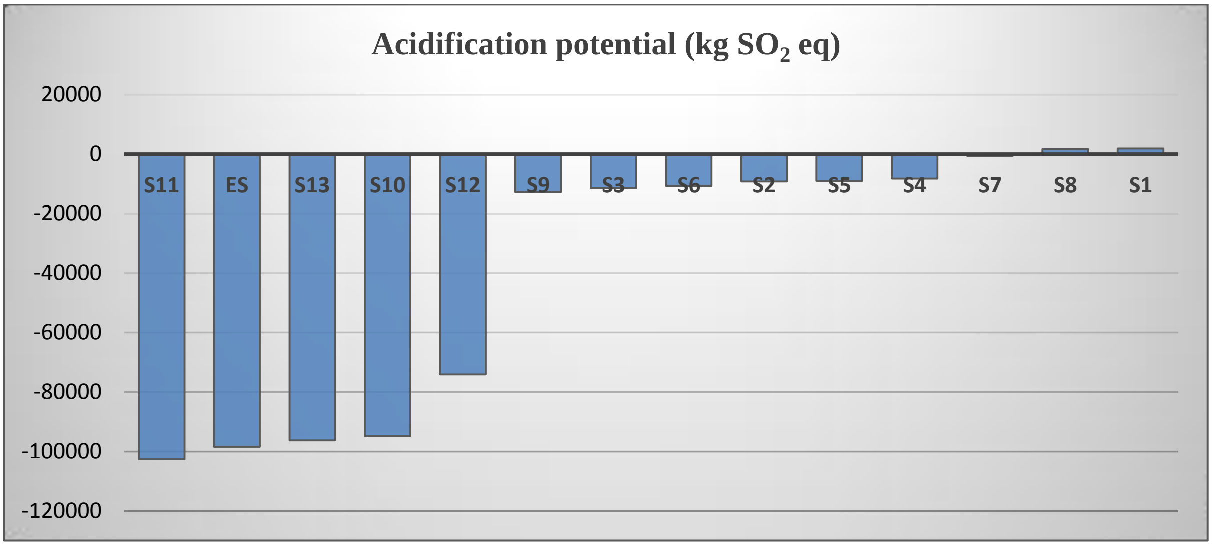

Figure 3.10. Acidification impact analysis of alternative scenarios and existing system via CML-IA method.

3.1.2.3 Eutrophication potential

Landfilling was the main factor for EP. As stated in the Figure 3.11; S11 was the most beneficial scenarios compared with the other informal and formalized systems where S12 had the highest environmental impact among the formalized scenarios. As it is seen on the Figure 3.11, S1 and S2 were the worst scenarios within the formal collection systems respecting to amount of wastage materials send to the landfilling area.

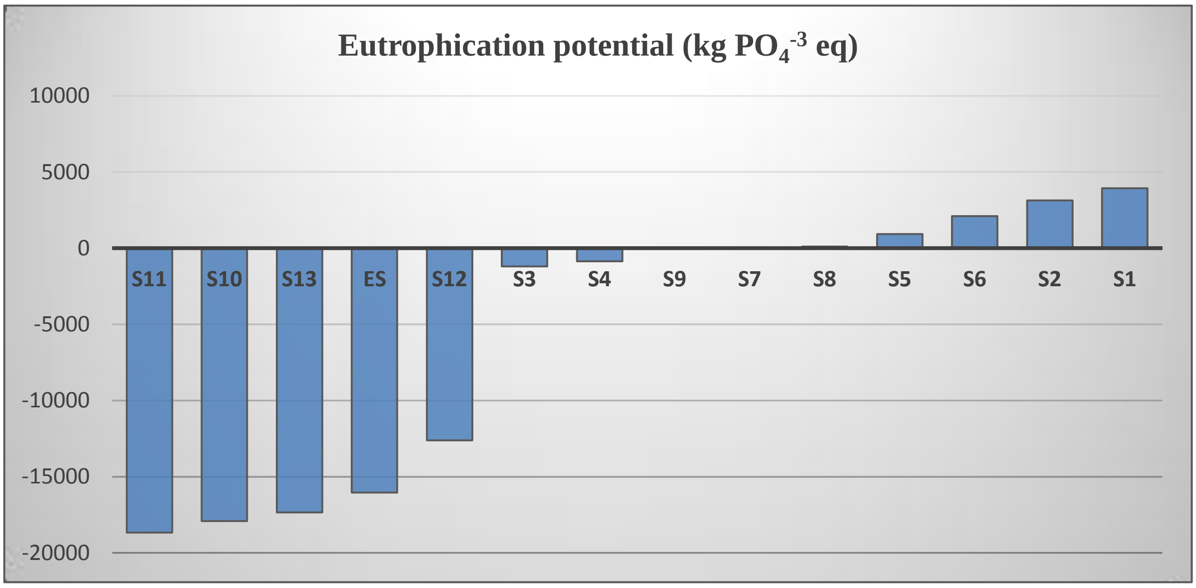

Figure 3.11. Eutrophication impact analysis of alternative scenarios and existing system via CML-IA method.

3.1.2.4 Global warming potential

The greenhouse gases, such as methane escaped from the landfill gas collection systems and carbon dioxide emitted from consumption of fuels were responsible for global warming. Due to the cumulative impact of the landfilling and fuel consumption, S11 had the minimum score where S12 had the highest environmental impact among the informal and formalized scenarios (Figure 3.12). The results showed that even material and fuel consumptions was high and effect the global warming, idealized system S13 was still one of the best alternatives. Within the formal collection system scenarios, S1 seems to be significantly worst scenario, whereas more fractionated scenarios S3 and S4 were the best as a result of fuel consumption and wastage material.

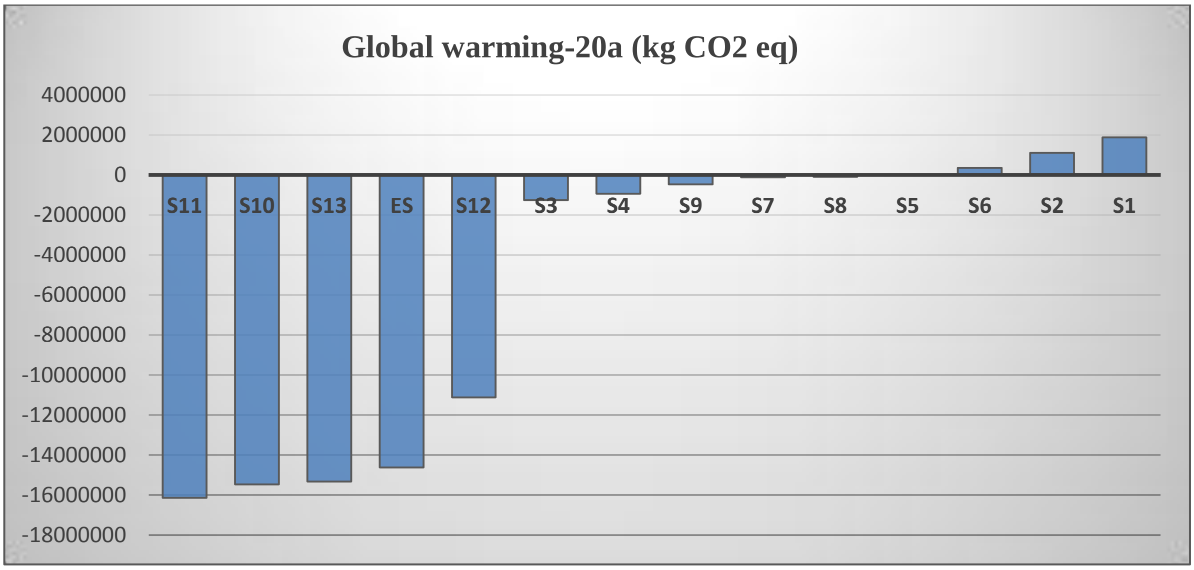

Figure 3.12. Global warming (20a) impact analysis of alternative scenarios and existing system via CML-IA method.

As seen in the Figure 3.13, for GWP100a, S11, S10, S13 and ES were still the best scenarios whereas S1 was the worst. Although Figure 3.12 and Figure 3.13 numerically seemed different, the ranking of the scenarios for GWP20a and GWP100a were almost same. Environmental effects of these two indicators mostly differed in the time period being 20 years and 100 years, respectively.

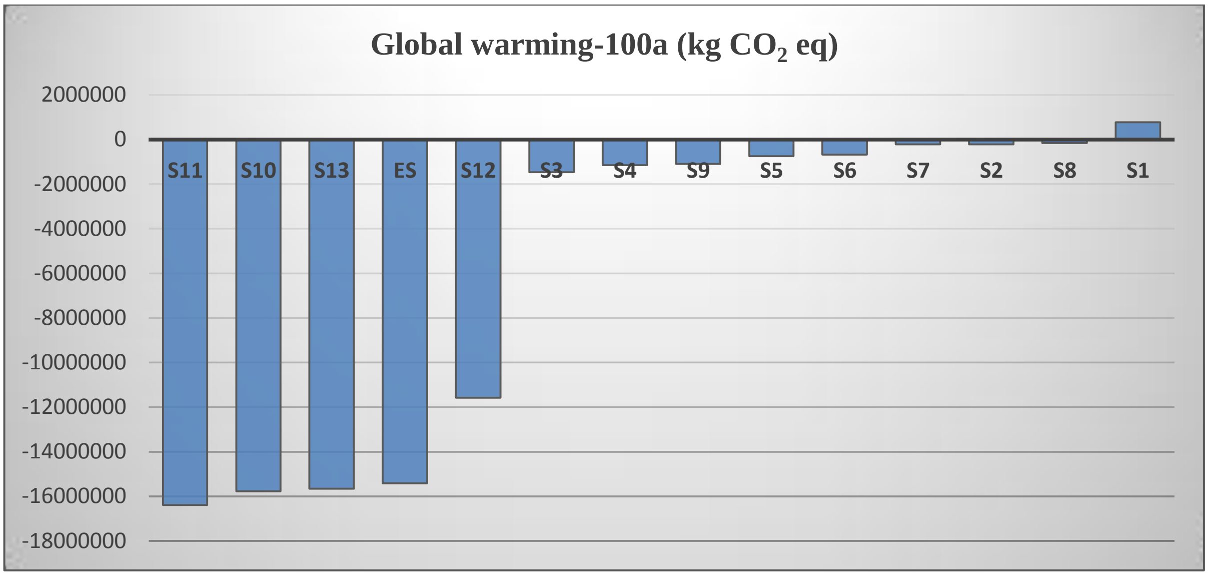

Figure 3.13 .Global warming (100a) impact analysis of alternative scenarios and existing system via CML-IA.

3.1.2.5 Ozone layer depletion potential

ODP had a similar tendency to Acidification Potential because both impact indicators were mainly associated with the transportation activity. Among the formal collection systems, even though S8 and S7 didn't have the highest fuel consumption amounts, they were still the worst scenarios as a result of low avoided product. Therefore, these scenarios had the biggest contribution to ozone layer depletion. In contrast, S9 and S3 were the most beneficial scenarios within the formal scenarios because of lower fuel consumption (Figure 3.14.).

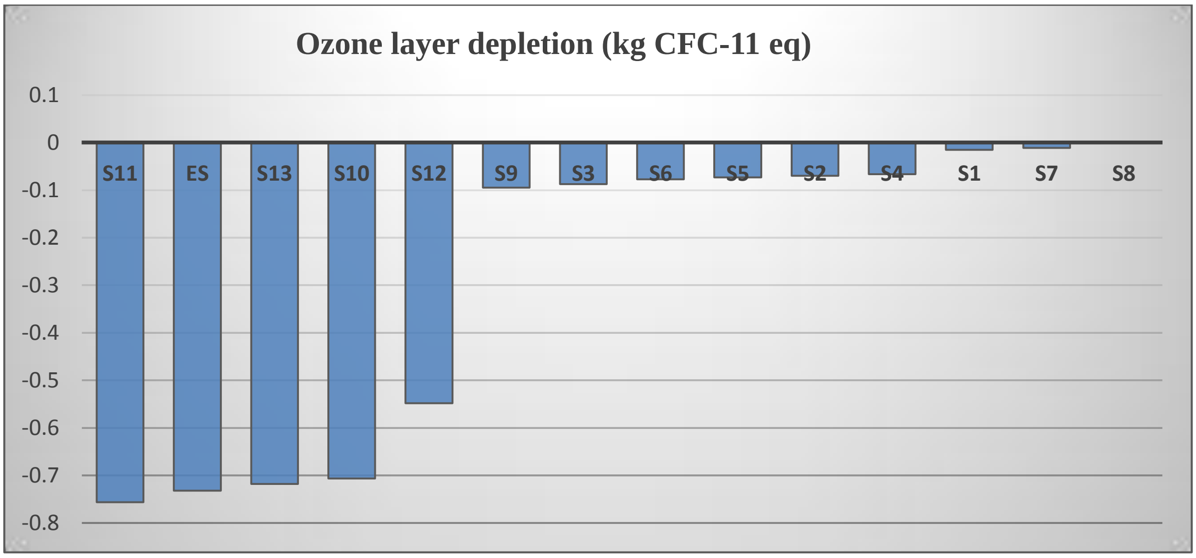

Figure 3.14. Ozone layer depletion impact analysis of alternative scenarios and existing system via CML-IA method.

3.1.2.6 Photochemical oxidation creation potential

POCP impact category depends largely on the amounts of carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxide (NO), ammonium (NH_3) and non-methane volatile organic compounds (NMVOC). The most dominating inputs for Photochemical Oxidation were fuel consumption, material consumption and finally landfilling. Therefore between the informal and formalized systems, S11 was the environmentally most beneficial scenario. There were also no significant difference between ES, S10 and S13 (Figure 3.15).

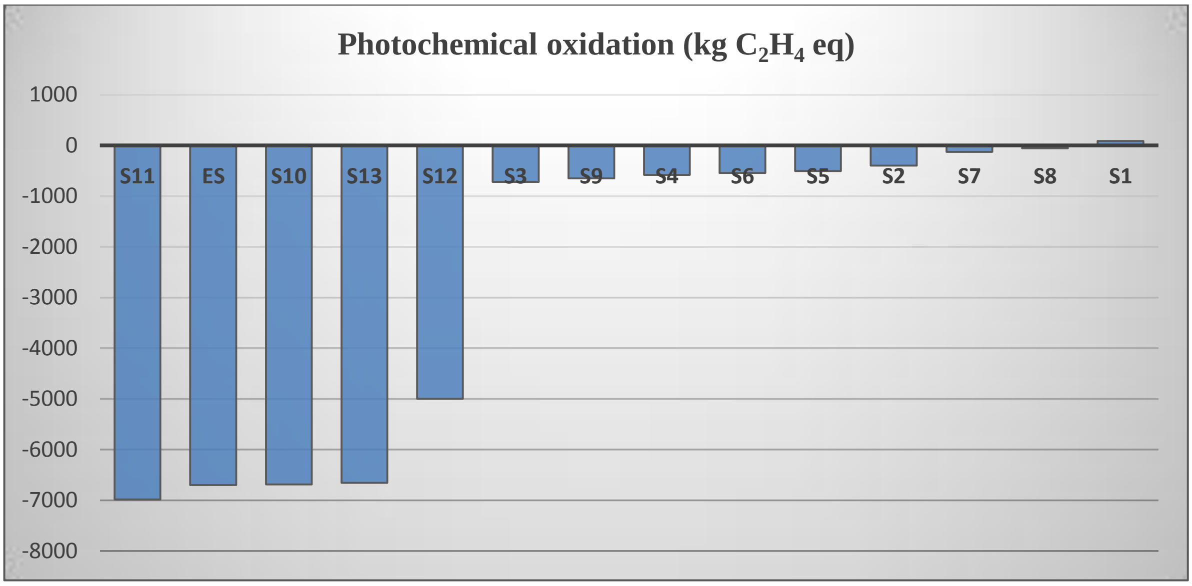

Figure 3.15. Photochemical oxidation impact analysis of alternative scenarios and existing system via CML-IA method.

In brief, with respect to the Air Pollution Indicators—GWP, POCP, AP, ODP; S11, ES, S13 and S10 seemed to be the best alternatives. Considering the Water Pollution Indicators—EP, best results were achieved in S11 and S10 whereas Resource Consumption Indicators—ADP, showed that S11 and ES was more beneficial to avoid mineral resource consumption and S11 and S13 were advantageous on avoiding fuel consumption. In general aspect, the informal collection system (S11) may be considered as the best performing method among the alternative scenarios followed by ES, S13 and S10; on the other hand S12 was the environmentally least favorable scenario among the informal and formalized scenarios.

In the light of the facts mentioned above, each impact assessment indicator was analyzed individually complicating the decision-making process for authorities in MSWS. In order to propose a rational solution, the scores must be aggregated to reach a cumulative value. For this reason, six different Single Score Evaluation Methods were also performed in this study and explained in the following section.

3.1.3 Interpretation

In order to check the consistency of CML-IA method results, six diverse impact assessment methods namely EDIP, IMPACT 2002+, EPS, RECIPE-E, RECIPE-I and RECIPE-H were also conducted. The results of each method were ranked according to their environmental performance (Table 3.14). Even the impact assessment method changed, the results indicated that the scenario 11 was still the best option as shown in Table 3.15. Similar to CML-IA results, the secondly well performing scenario changes between the ES, S10 and S13. On the other hand; among the formal collection systems, S3 based on the two fractionated door-to-door collection system was found to be environmentally most friendly scenario whereas S1 and S8 performed as the worst scenarios.

Considering the both formal and informal scenarios; it is obvious that more material collected-scenarios was always environmentally preferable.

Table 3.14. Single score results of different impact assessment methodology.

	Recipe-E (MPt)	Recipe-H (MPt)	Recipe-I (MPt)	Impact 2002+ (MPt)	EDIP 2003 (kPt)	EPS (MPt)
ES	-2.6116521	-2.06802	-1.6506326	-6.2707987	-47.374033	-13.016731
S1	-0.2074689	0.03888145	0.1971182	0.0251728	3.9559159	5.1391619
S2	-0.2735121	-0.12498643	-0.0500423	-0.4606855	-2.8854198	-1.1253546
S3	-0.4334589	-0.22815054	-0.1795195	-0.7211883	-5.4980245	-1.6967305
S4	-0.3684937	-0.18613409	-0.1437470	-0.5795999	-4.2989773	-1.4398543
S5	-0.3993263	-0.16577063	-0.0841569	-0.5700068	-3.4656137	-0.6746693
S6	-0.4602555	-0.23674697	-0.1845486	-0.7568756	-5.1470736	-1.1255551
S7	-0.1099498	-0.04523403	-0.0262957	-0.1302575	-0.7946633	-0.1648326
S8	-0.0920412	-0.02647412	-0.0096420	-0.0550553	-0.1384242	0.0459981
S9	-0.3972176	-0.19662831	-0.1334483	-0.6775647	-4.9118518	-1.4375511
S10	-2.4551069	-2.0760248	-1.6794613	-6.2628327	-47.28949	-12.84194
S11	-2.705747	-2.1589965	-1.7476342	-6.5735283	-49.770524	-13.456559
S12	-1.9877602	-1.5467443	-1.2400926	-4.7308368	-35.726182	-9.7410706
S13	-2.5651545	-2.0360745	-1.5863659	-6.2067923	-45.067341	-10.122306

Table 3.15. Rankings of single score results of different impact assessment methodology.

Ranking	Recipe (E)	Recipe (H)	Recipe (I)	Impact 2002+	EDIP 2003	EPS
1	S11	S11	S11	S11	S11	S11
2	ES	S10	S10	ES	ES	ES
3	S13	ES	ES	S10	S10	S10
4	S10	S13	S13	S13	S13	S13
5	S12	S12	S12	S12	S12	S12
6	S6	S6	S6	S6	S3	S3
7	S3	S3	S3	S3	S6	S4
8	S5	S9	S4	S9	S9	S9
9	S9	S4	S9	S4	S4	S6
10	S4	S5	S5	S5	S5	S2
11	S2	S2	S2	S2	S2	S5
12	S1	S7	S7	S7	S7	S7
13	S7	S8	S8	S8	S8	S8
14	S8	S1	S1	S1	S1	S1

3.2 Social Life Cycle Impact Assessment

Results of the SLCA were analyzed in two stages. Firstly, data of the existing system and proposed scenarios were discussed in the inventory analysis stage, without impact assessment. Secondly, outcomes of the impact assessment were analyzed in detail.

3.2.1 Inventory data analysis

For the determination of social impacts, 26 social indicator were measured. Result of the site observations, company records and literature were characterized by semi-quantitative indicators, and so all results were dimensionless.

Measurement results of the characterization study is shown in Table 3.16. In this study, indicators were not analyzed individually; instead, they were assessed in terms of subcategories and impact categories in the impact assessment part of the SLCA. Details of the site observation and interview result are also given in Appendix 6.

Table 3.16. Inventory data results of existing system and proposed scenarios in the researched case study area.

Performance Indicator	ES	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13
Work incidents	0	0.5	0.5	1	1	0.5	1	0.5	0	0.5	0	0.5	0.5	1
Risk of the getting occupational health problems	0	0.5	0.5	1	1	0.5	1	0.5	0	0.5	0	0.5	0.5	1
Health and safety awareness	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0	0.5	0.5	1
Safety risk of the system	0	1	1	1	1	1	1	1	1	1	0	0.5	0.5	1
Health and safety training	0	1	1	1	1	1	1	1	1	1	0	1	1	1
Working with appropriate equipment	0	1	1	1	1	1	1	1	1	1	0	0.5	0.5	1
Local community's health and safe living conditions	0	1	1	1	1	1	1	1	1	1	0	0.5	0.5	1
Local community's secure living conditions	0	1	1	1	1	1	1	1	1	1	0	1	1	1
Work satisfaction	0.5	0.5	0.5	0.5	0.5	1	1	1	1	0.5	0.5	1	0.5	1
Legal working hours limit	0	1	1	1	1	1	1	1	1	1	0	1	1	1
Night work	0	1	1	1	1	1	1	1	1	1	0	1	1	1
Wage standards	0	1	1	1	1	1	1	1	1	1	0	1	1	1
Regular payment	0.5	1	1	1	1	1	1	1	1	1	0.5	1	1	1
Legal working contracts	0	1	1	1	1	1	1	1	1	1	0	1	1	1
Retirement rights	0	1	1	1	1	1	1	1	1	1	0	1	1	1
Social security	0	1	1	1	1	1	1	1	1	1	0	1	1	1
Training programs	0	1	1	1	1	1	1	1	1	1	0	1	1	1
Forced labour	0.5	1	1	1	1	1	1	1	1	1	0.5	1	1	1
Child labour	0	1	1	1	1	1	1	1	1	1	0	1	1	1
Rights of the associations or bargain collectively	0	1	1	1	1	1	1	1	1	1	0	1	1	1
Political, regional and religious discrimination	0	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0	0.5	0.5	1
Job creation potential	1	0	0	0	0	0	0	0	0	0	1	1	0	1
Job lose	1	0	0	0	0	0	0	0	0	0	1	1	0	1
Supporting the system	0.5	0	0	0	0	0	0	0	0	0	0.5	0.5	0.5	1
Identification of complaints	1	0	0	0	0	1	1	0	0	0	1	0.5	0.5	1
Contribution of the system to economic development	1	0	0	0	0	0	0	0	0	0	1	1	1	1

3.2.2 Impact assessment analysis

3.2.2.1 "Health and safety" impact analysis

Health and safety-security issues concerns to all social group in different aspects. Therefore, in this study workers' health and safe working conditions, participants, local community and society's health and safe living conditions and secure living conditions were researched.

In the informal collection system, workers separate and collect the packaging waste from mixed waste bin. To sort the useful material quickly, scavengers often prefer to work barehanded or without using any protective equipment. This separation technique may cause health problems, because the waste may contain broken glass, construction materials, or hospital waste, such as syringes. Avcı and Oğur (2004) listed inflectional diseases (hepatitis B, HIV/AIDS) and malaria as the most prominent health problems of waste collection systems. On the other hand, workers may catch chronic illnesses which affect their lives negatively. For instance, long term and hard working conditions may cause some psychological problems such as stress, night-time working risks, and social exclusions. Moreover, transportation of waste without any vehicle and lifting heavy objects with little equipment may result in bone and muscle injuries in long term (Avci and Oğur, 2004; Binion and Gutlerberk, 2012).

Safety is also a distinctive and one of the most important topic. Our field observations and interview results showed that some accidents happened due to collection system of the informal collectors. Scavengers worked at all hours of the day especially in the evening. Since they don't use any transportation vehicle and/or protective equipment, traffic accidents occur more frequently in this informal collection system. Another safety problem was the collection of waste from the underground containers. Usages of underground container become widespread around the studied area. Informal collectors picked the waste from these 2-3 m heighted-containers.

All these safety issues showed that collectors worked under risky conditions. In the formal collection scenarios (S1 to S9) these kinds of health and safety risks were minimized because of source separation system. Workers did not directly contact with waste in collection phase, they collected already separated packaging waste.

Figure 3.16 shows the health and safe working conditions of the informal and formal collection system. As seen on the figure, informal collection scenarios are more risky than formal collection system. It is also seen that there is a slight difference among the formal collection system scenarios. In the formal collection, when packaging waste is collected in a single bin or bag, a separation process is required. Company records and interviews with workers showed that there was some hand injuries resulted from separation of waste. However, it was obvious that even separation process contains some health and safety risk these cannot be compared with the risk of the informal system.

As seen in Figure 3.16, social effect of the health and safe living conditions and secure living conditions in the scenarios S10 and ES scored zero compared with the scenarios from S1 to S9 and S11 to S13. Our field researches and interviews showed that informal collection affected and endangered citizens (participants, local community and society) life respecting to the unhygienic environment conditions resulted from collection activity and potential crime risk considering the criminal profile of worker. Although there were no records of crime in the sector, interviews with the governmental organizations showed that people who had criminal record chose to work in this sector because they couldn’t find any legal job. Therefore, it is concluded that informal collection system had the potential crime risk and endangered the local community’s secure living conditions. Moreover, Binion and Gutlerberk (2012) pointed out that working with solid waste may affect not only individual health, but also the environmental health of the local community and society. When waste is collected from waste bins in the public area, mixed waste spreads to streets. This may cause the spread of diseases. After the collection of packaging waste, these are moved to illegal sorting facilities. In these facilities, waste is sorted and waste which is not useful disposed to environment. And waste also transported to disposal sites along with its’ all negative aspects. Regarding the all these negative aspects, formal collection systems have advantageous because the systematic collection in respect to safe and secure living conditions. As a result of all these effects, there are a certain difference between the formal and formalized scenarios (S1 to S9 and S11 to S13) and informal scenarios (ES and S10).

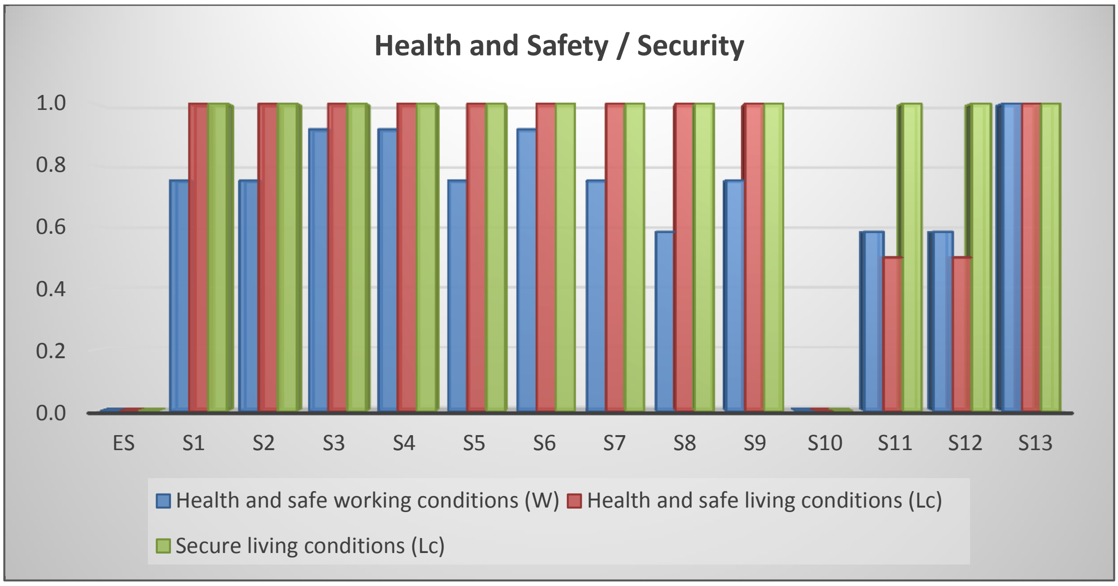

Figure 3.16. Comparative analysis of alternative scenarios in terms of health and safety-security subcategory-level impact.

3.2.2.2 "Working conditions" impact analysis

Compliance of the working hours with legal standards, existence of the social security issues, fulfillment of the living wage, presence of forced labour, presence of training and education programs and employees' job satisfaction are strongly correlated subcategories with working conditions.

In Figure 3.17, social scores of working hours and social security issues are compared. Regarding to working hours, ES and S10 showed the minimum social score whereas formal and formalized collection system scenarios (from S1 to S9 and S11 to S13) scored maximum. In the TIK (2003), weekly working hours are limited to maximum 45 hours. Our research showed that weekly working hours and social security issues in formal system was complied with the country standards, whereas there was no time limitations and social security in informal collection system. In the case of informal collection, working hours may change between 4 to 12 hours in a day.

Because scavengers are not registered employee in a company, they don't have any social insurance. Even they want to get a social insurance individually, their income level is insufficient. Thus, they may not use any free health service, don't have retirement rights and in case of accident or death they or their relatives cannot claim any rights.

Considering the living wages and regular payments, it seems that formal collectors have advantageous. In the formal system, amount and type of collected waste does not directly affect the workers' wage or payment issues. However, in the informal collection, these criteria are directly related to material type and amount. Scavengers' daily income changes with how much and what kind of waste they collect. And our survey results showed that this income was lower than standard living wage.

To determine the job satisfaction degree, all employees were asked to compare their existing job with the suggested collection system. For suggested systems, they were asked whether they wanted to work for the system suggestion in each scenario or not. They answered to question considering the compliance of above given criteria. These results showed that assurance of formal collection system satisfied the formal collectors. Especially, they definitely didn't want to work informally because of the absence of social security and retirement rights in the informal sector. On the other hand, when we asked them to compare only formal systems, they mostly considered the difficulties caused by collection differences. The score variations between the formal collection scenarios were caused by these collection difficulties (Figure 3.17). Collection with curbside and drop-off containers (S5, S6, S7 and S8) shows the least social impact whereas door-to-door collection scenarios (S1, S2, S3 and S4).

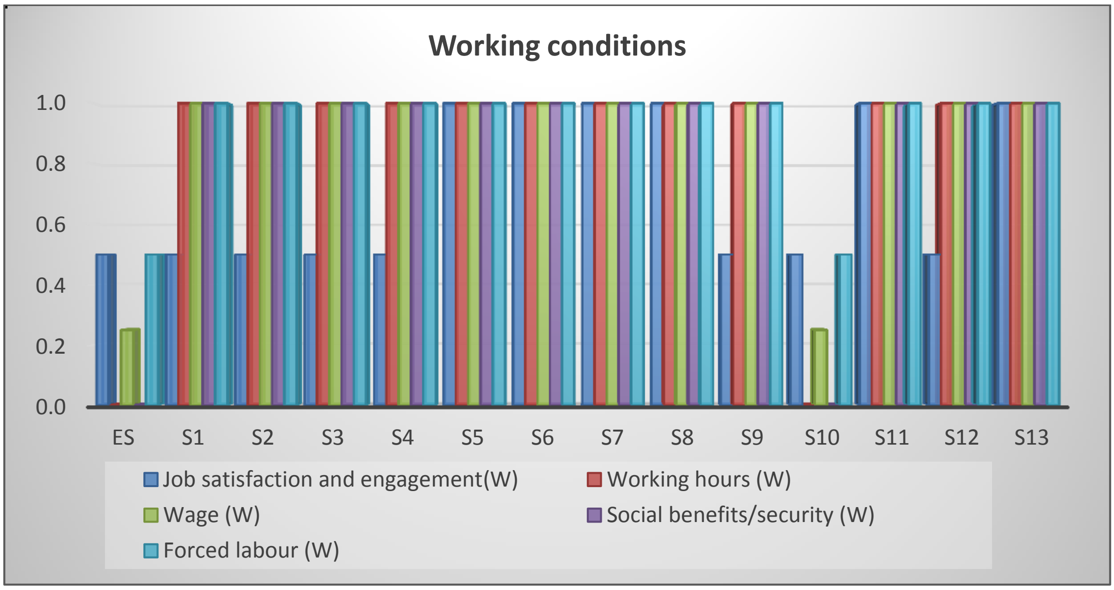

Figure 3.17. Comparative analysis of alternative scenarios in terms of working conditions subcategory-level impact.

3.2.2.3 “Human rights” impact analysis

Human rights impact assessment consists of three subcategories as child labour, freedom of association and collective bargaining, and discrimination.

The minimum age of labour force is set at 15 years by the ILO (1973) and the national minimum age for employment is also determined as 15 by TIK (2003). Our survey results showed that in the formal collection, age of employees were between 30 and 50 as a result of these legal limitations. However, in the informal collection determination of child labour existence was quite difficult regarding to unregistered working conditions. Despite of these difficulties, we monitored the existence of child labour through the field observation. Because informal system is uncontrolled it is easy to employed child labour. Therefore, as seen in the Figure 3.18formal collection scenarios(S1 to S9) and formalized scenarios (S11 to S13) have least social impact than the existing system (ES) and informal collection scenario (S10). In the formalized collection scenarios, we assumed that child labour wouldn’t be allowed, so it had the same score with formal collection.

According to ILO (1948), “Workers, without distinction, shall have the right to establish and, subject only to the rules of the organization concerned, to join organizations of their own choosing without previous authorization.” In Turkey, there are legally supported organizations and unions who represents workers’ rights. Our research showed that even formal collection systems gave workers the right of the association and collective bargaining; none of the workers were members of these organizations or unions. On the other hand, there were not any associations which protect the workers’ rights in the informal system. In the scope of this study, we didn’t measure if the workers were members of any association or not. Only the existence of the right of association and collective bargaining was researched. Even workers were not member of any association or unions in the scenarios from S1 to S9 and S11 to S13, they still had the right of the be a member of any association. Therefore, formal and formalized scenarios had the less social impact than the informal scenarios, ES and S10.

As previously explained, discrimination states any political, regional, national, sexual, distinction where the employees faced with in their work place. Existence of political and regional discrimination in the informal collection system was pointed out by Özsoy,

2012. The author interviewed with scavengers face to face, and found that regional variations affected the employment issues. In the field research, we observed that political and regional discriminations were occurred in the recycling material collection systems. Especially in the informal system, collection was handled by certain groups whom were members of a specific region. However, it was found that at formal collection, regional differences were less important than political differences. In the proposed systems, even political insight cannot be easily prevented; it was considered there wouldn't be any regional discrimination. Considering these impacts, ES and S10 seems to be worst options, whereas formal and formalized system suggestions was the best.

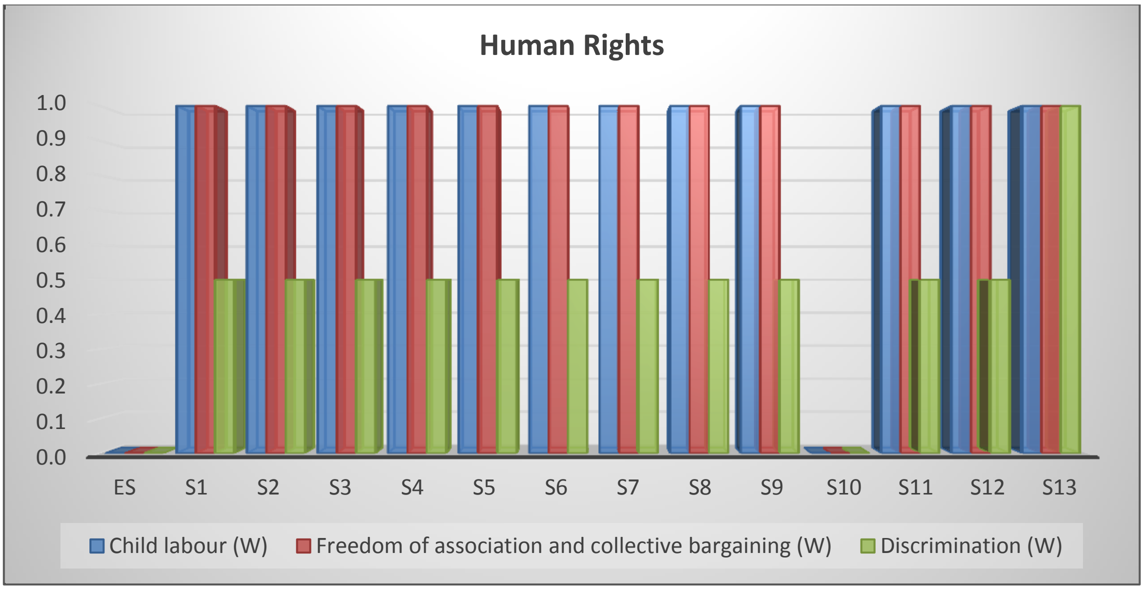

Figure 3.18. Comparative analysis of alternative scenarios in terms of human right subcategory-level impact.

3.2.2.4 "Socio-economic repercussion" impact analysis

As we previously indicated rate of the source separated collection system was only 2.09 % in total 20 % in the existing situation because of the low awareness of citizens. Our research showed that in the existing system (ES); 50 fulltime person worked in the formal collection whereas 850 part time or fulltime collectors were employed in the informal sector. So, If the collection was done only formally (scenarios from S1 to S9); employment rate would be lower than informal collection scenarios (ES and S10) as seen in Figure 3.19. However; in the formalized collection scenario (S11, S12 and S13), social effects of employment couldn't be minimized. Because of companies employed only limited numbers of scavengers.

Results of local community interviews showed that informal collection was socially more acceptable than formal collection (Figure 3.19). While local communities answer the social acceptability question, they basically took into consideration the employment opportunities for low income people. Participants thought that informal system was socially more acceptable because it provided more employment opportunities than the formal systems. Besides, most of the survey participants pointed out that, between the informal and formalized system suggestions, formalized systems (S11, S12 and S13) would be more preferable than informal systems. And the other but less effective reason influence the social acceptability of proposed systems was the environmental benefits of informal system.

With respect to the service satisfaction; the scenarios ES, S5, S6, S10 and S13 were slightly differed from the other scenarios (Figure 3.19). This difference was mainly resulted from the characterization of collection system. Questionnaire results showed that participants would complain for a special storage area requirement of bags in door-to-door collection system (S1, S2, S3, S4 and S9). In contrast, drop-off collection systems did not require a household storage, because collection materials were placed in the range of between 500 and 1000 m. Participants reported that, these drop-off points would expose a transportation problem of high-volume packaging wastes. It can be concluded that participation rate is obviously effected from the drop-off container locations. If the distance is too far, participation rate will be low. Thus, S7 and S8 would be also not satisfying options. On the other hand, we found that formalized scenarios S11 and S12 were also preferable due to minimum requirement of storage, transport or any other separation efforts, in terms of participants.

On the contrary of the working conditions and human rights, our researches showed that informal collection was socially more acceptable than formal collection in terms of contribution to economic development (Figure 3.19). This result related with amount of collected material. For the research area, economical contribution of different collection systems increases drastically when amount of packaging waste collected increases. As stated in our previous study, because participation to the formal collection system was low, amount of collected material was 2.09 % whereas 17.91 % were collected by scavengers. Therefore; ES, S10, S11, S12 and S13 which are the scenarios based on the informal collection and idealized collection systems, performed better scores than the scenarios from S1 to S9.

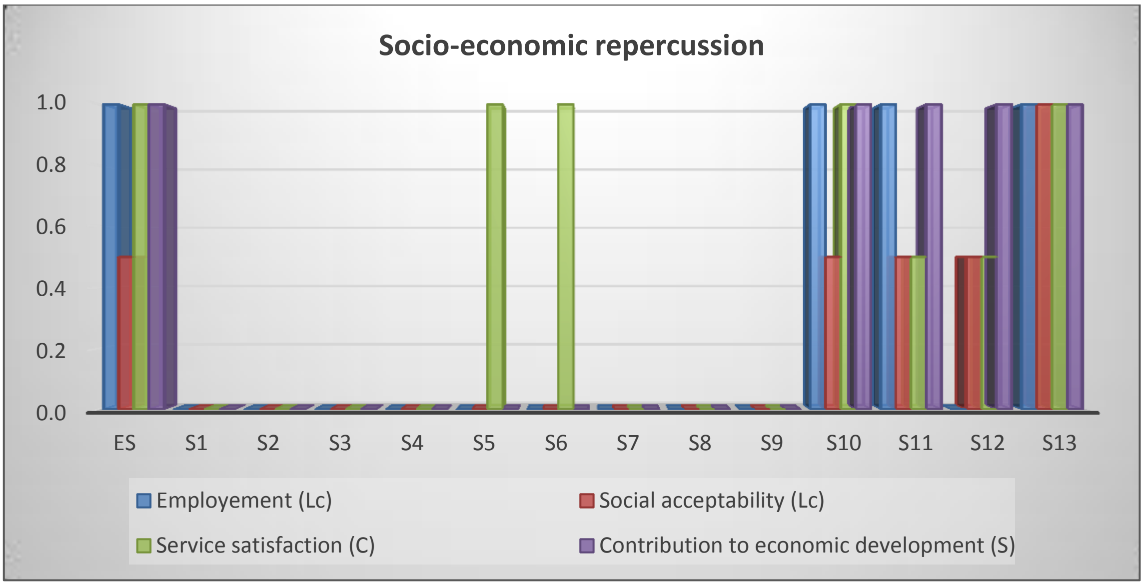

Figure 3.19. Comparative analysis of alternative scenarios in terms of socio-economic repercussion subcategory-level impact.

3.2.2.5 General impact analysis

Figure 3.20 shows the social analysis results of the study without any allocation and weighting between impact categories. Scenario 13 was modelled as socially idealized system. Therefore, it performed socially better in all categories. In brief, ES and S10 had the worst social score respecting to health-safety and security, human rights and working conditions, whereas they performed as the best scenarios in terms of socio-economic repercussion impact. The scenarios from S1 to S9 were better than the existing system in almost all impact categories apart from socio-economic repercussion. As seen on Figure 3.20, S11 didn't perform as the best scenario. Because a full integration and recovery would be only accomplish in a long time period with a huge effort. Considering the reel situations, only the critical impacts were minimized and analyzed.

Figure 3.21 shows the single score impacts of existing system and alternative scenarios. Existing system (ES) and informal system (S10) were the worst scenarios. Formal and formalized collection scenarios were obviously performed better. Between the formal collection scenarios, more fractionated collections scored better than less fractionated collection systems concerning the negative health and safety effects of separation process. On the other hand, curbside collection systems were more preferable subject to the easy access for participants and less effort for workers. In contrary, door-to-door and drop-off systems were not satisfying. Finally, even we couldn't minimize all the social impact of S11; it still seemed as one of the best option. And environmentally idealized system S13 is also socially performed as the best scenario.

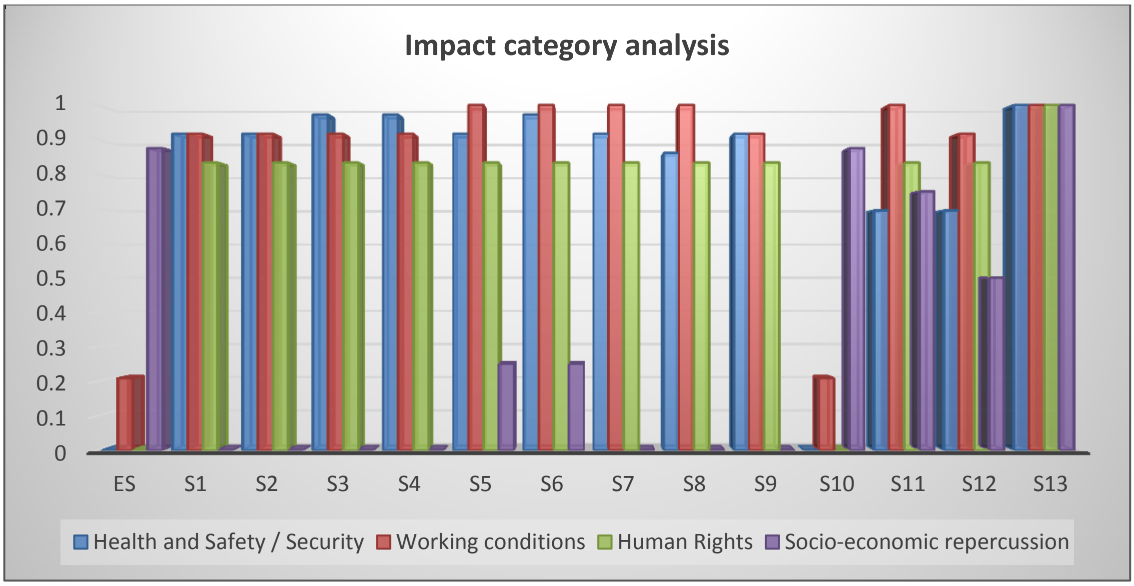

Figure 3.20. Impact category level social analysis of existing system and alternative scenarios without 3rd degree weighting.

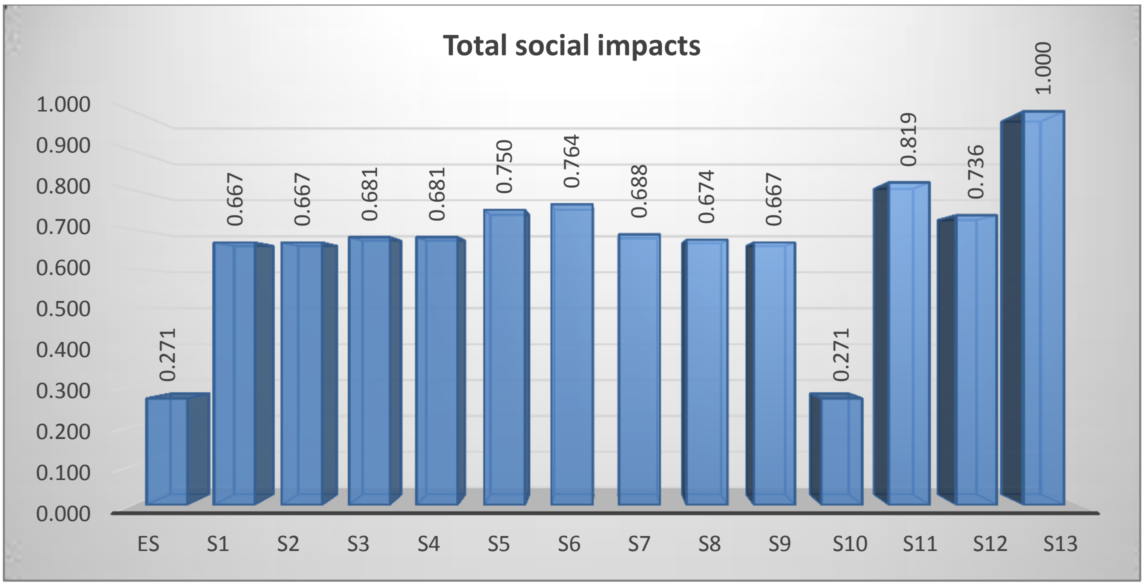

Figure 3.21. Single score social impact analysis of existing system and alternative scenarios. After the 3rd degree weighting.

3.3 Environmental and Social Life Cycle Sustainability Assessment

After an individual analysis of environmental and social impact of packaging waste collection systems, in this section we integrated these impacts in a single score called sustainability. In Figure 3.22, normalized values of environmental and social impact results are provided in the same figure without integration and weighting. The figure clearly shows that existing, informal and formalized system environmentally performs better than other scenarios. However, it is also obvious that social performances of the informal systems (ES and S10) have a converse effect compared to environmental performance. On the other hand, formalized scenarios S11, S12 and S13 achieves better results in terms of social impacts. On the contrary of the informal and formalized systems, looking at the formal system scenarios in detail, almost all formal system collection activities have the low impact score, so they cause high environmental impacts. The reasons of these results has been already discussed in the previous sections in detail.

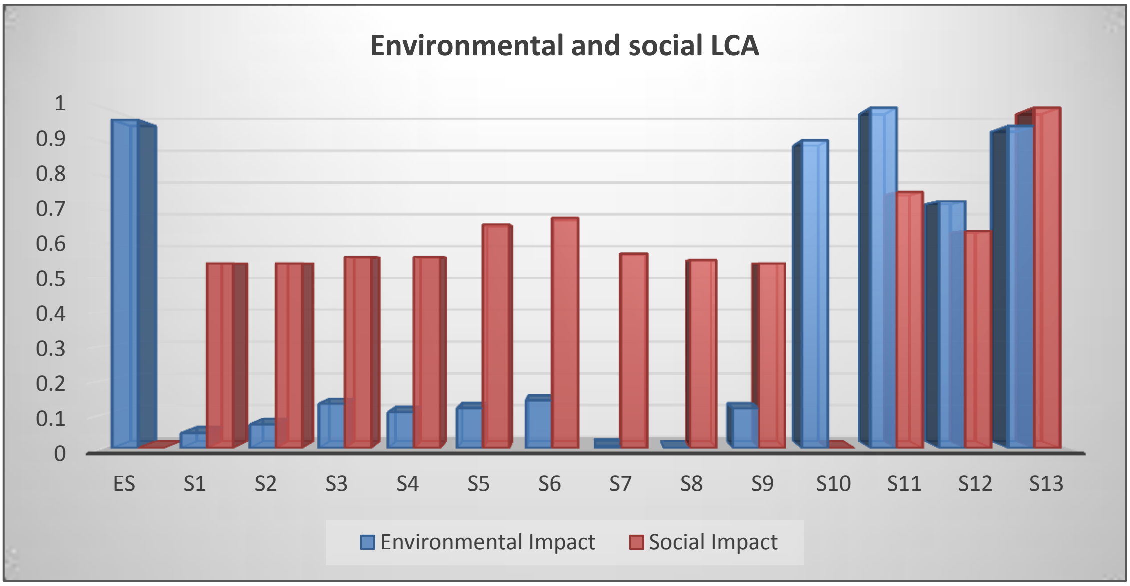

Figure 3.22. Social and environmental life cycle assessment analysis of existing system and alternative scenarios.

After the providing single scores results for the environmental and social indicators for each scenario, the next step was to assign a weighting factor to both sustainability indicators. As we previously indicated, because there are only two sustainability indicators, we used ranking method weighting and analyzed all weighting possibilities for this methodology.

From an environmental perspective, ranking method weighting results is illustrated in Figure 3.23. When environmental impacts have the precedence to social impacts, it is apparent that all informal and formalized collection scenarios have the most outstanding scores as expectedly. This is because these scenarios has avoided product in a considerable margin. The environmentally best performing scenario, after the idealized system (S13), is scenario 11.

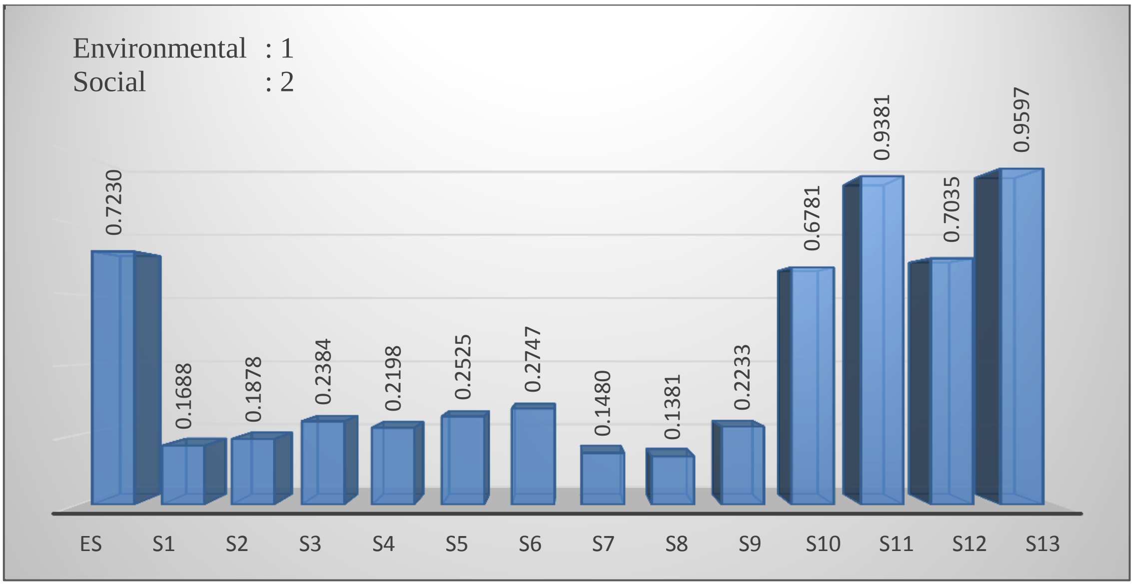

Figure 3.23. Environmental and social life cycle sustainability assessment analysis of existing system and alternative scenarios in terms of rank-order method weighting.

On the other hand, when social weighting score is bigger than the environmental weighting, scores of informal collection scenarios—ES and S10, are dramatically decreased as a result of social disadvantageous of the systems (Figure 3.24). Formal collection systems are also showed a slight change by increasing which indicates the positive aspect of LCSA. In the socially privileged weighting results, formalized scenarios didn't show any remarkable changes compared to environmentally privileged-weighting results. S13 and S11 still perform as the best scenarios. This is because, these scenarios refer the socially and environmentally ameliorated systems.

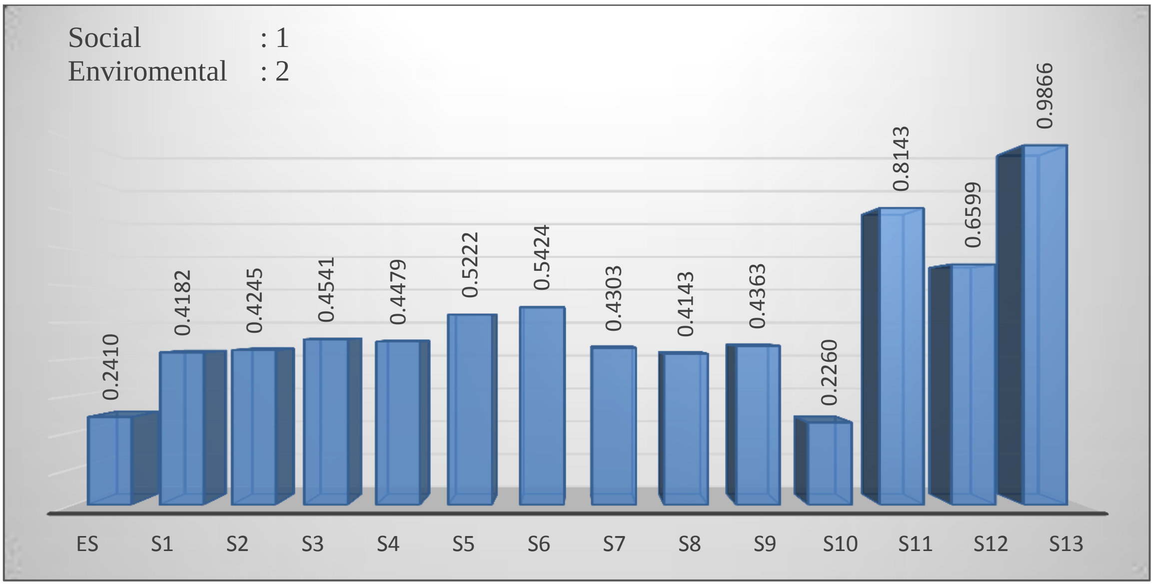

Figure 3.24. Social and environmental life cycle sustainability assessment analysis of existing system and alternative scenarios in terms of rank-order method weighting.

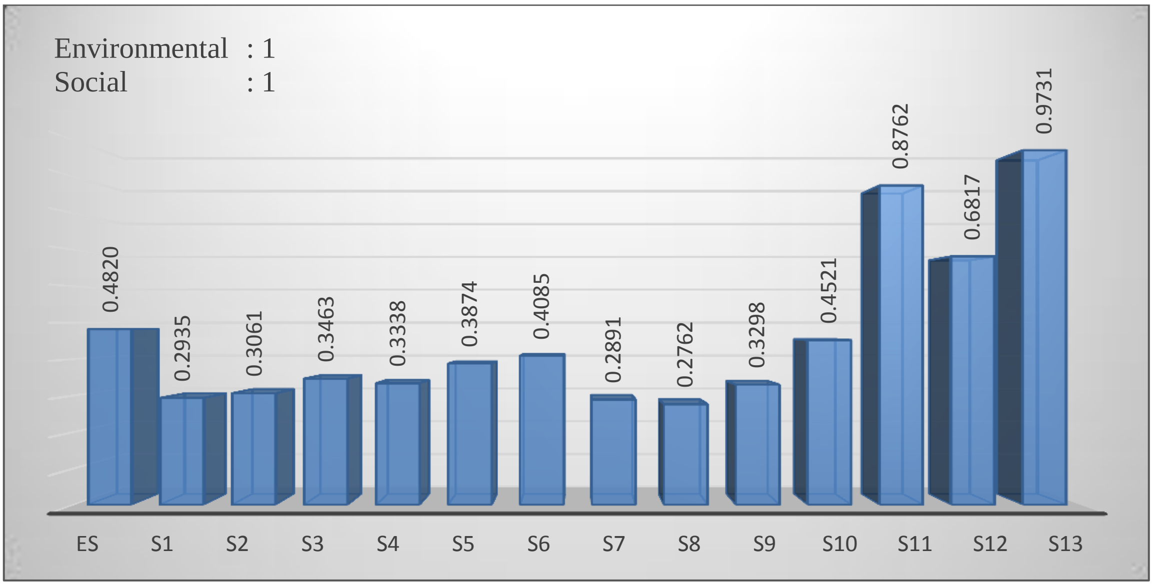

Figure 3.25. Social and environmental life cycle sustainability assessment analysis of existing system and alternative scenarios in terms of rank-order method weighting.

Figure 3.25 shows the equal weighting results. Expectedly, formalized system suggestions were still best performing scenarios. Ranking of the equal weighting almost shows similar behavior with environmentally privileged-weighting results.

Comparing the three rank-order method weighting results; it is obvious that application of different weighting scores doesn't make any significant change on the ranking of formalized scenarios. The data would seem to suggest that formalized systems is socially and environmentally applicable.

4 CONCLUSION

The present dissertation focused on the environmental and social analysis of different packaging waste collection systems for Maltepe-Istanbul, Turkey. A comprehensive analysis of source separation, collection and transportation system of packaging wastes was performed via environmental and social LCSA methodology, discussed together first in Turkey. Eight different proposed collection scenarios, existing formal and informal collection systems (separately and in a combination) and three formalized system suggestion (integration of formal and informal collection systems) were compared to determine the environmental and social weaknesses and strengths of the system. The results are expected to construct a reference point for further studies and will give a different aspect to decision makers of packaging waste collection systems to accomplish a sustainable life concept.

Results of this study are concluded in three aspects as environmental life cycle assessment, social life cycle assessment and as a combination of these two impacts, life cycle sustainability assessment.

From an environmental life cycle assessment perspective, the major findings of this study are:

- Regarding to CML-IA results, almost all impact assessment indicators have negative values suggesting the environmental impacts of the recycling systems. By all manner of means, the results noticeably showed that recycling of packaging materials is always environmentally beneficial respecting to analyzed scenarios in this study.
- Considering the recycled packaging waste amounts and material consumptions in the scenarios; formalized collection system S11 performed as the best scenario among the all alternative scenarios in terms of CML_IA methodology and all single score impact assessment methodologies, expectedly. On the other hand, there is also not a clear change among the informal and formalized scenarios. Waste picker's collection systems also achieves environmentally better results. The reason of this effective collection by scavengers is the informal systems is mostly not depend on the public participation rate in the collection system.
- The ELCA results also showed that between the formal collection scenarios S3, S9 and S4 performed better than all of the alternative scenarios proposed. Since the

performance of the scenarios dramatically changes with the assumptions, one can be misled about the results according to the variables taken into consideration. For this reason, the scientific basis of assumptions plays a crucial role in the process evaluation. As stated in this study, neither of the formal scenarios performed better than the informal scenarios. But even an increment on the assumptions like participation rate, a slight change in material type or system formalization studies may result in an environmentally more beneficial outcome. To evaluate more realistic results, the study may be broaden with adding the factors like socio-economic level, education, socio-demographic characteristics, collection frequency, collection materials.

- When resource consumption data were analyzed without E-LCA methodology, curbside collection system performed better than door-to-door and drop-off collection systems. However, LCIA result showed that door-to-door collection systems were mostly more advantageous than curbside and drop-off systems. In comparison of the single and multiple fractionated collection systems; although, collection of waste in two and four fractions reduced the wastage amount, collection in three fractions performed better in all types of formal collection systems. Among the same type collection scenarios, there fractionated door-to-door system (S3) and three fractionated curbside system (S6) were environmentally optimum models.
- Since each impact assessment indicator was analyzed individually, numerous parameters for decision-makers to take into consideration exist. In order to propose a rational solution, the scores must be aggregated to reach a cumulative value. To provide a different perspective to decision-makers, six different single score methods were also run in SimaPro 8.0.1 software. According to these single score evaluation methods, Scenario 11 was proved to be the environmentally best solution, whereas S12 was less beneficial among the more material collected scenarios. On the contrary of the CML-IA results, three fractionated-curbside collection system (S6) was mostly the more preferable scenario than the three fractionated-door-to-door collection system (S3) and existing system suggestion without informal collection (S9).

From a social life cycle assessment perspective, the major findings of this study are:

- LCA results showed that ES and S10 which were mainly based on informal collection had the highest social load. Formal collection rate in the existing system socially didn’t change the system obviously. Thus, ES and S10 had exactly same score and so worst social impacts. As expected, formal system scenarios were socially more beneficial than informal collection systems. Although, most of the formal system scenarios scored almost same value, there were slightly little differences respecting to waste fractionation and collection-separation difficulties. In this context, curbside collection system performed better than the drop-off and door-to-door collection system for formal scenarios.

- When impacts of the health and safety, working conditions and human rights stand out in the existing system and informal collection scenario (S10); socio-economic repercussion impacts was significantly noticeable in the formal collection scenario. Social effect of service satisfaction and employment sub-categories in accordance with participant and society social groups were the weakest part of formal collection systems. On the other hand, it may concluded that formal collection was socially less acceptable and also economical contribution was not favorable comparing with informal system. These negative impacts may be recovered in formalized scenario.
- The result of this study showed that it is crucial to consider an amelioration on the informal collection system. Concerning the social impacts of integrated scenario (S11) or idealized scenario (S13), social performance of informal collection can be improved by eliminating child and forced labour and improving the health-safety and working conditions. In the existing situations even the all social impacts couldn’t be minimized, S11 is still the best scenario closed to ideal system.

From an environmental and social life cycle sustainability assessment perspective, the major findings of this study are:

- It is obvious that depending on the weighting rate of the each impact, life cycle sustainability results may change.
- Recycling scenarios involving the informal collection offer higher environmental benefits due to the recycled material amount compared to formal collection systems. On the contrary, they had social disadvantageous. Therefore, integration of the scavengers to formal system will be obviously preferable for environmental and social perspective of the recycling material management system.

- This study has outlined that even informal collection had socially negative effects, an improvement on this system would avoid the social impacts significantly. So, it is highly recommended to local authorities and decision-makers to reconsider the arrangement of legal regulations and encourage the application of the integrated and formalized system suggestion.
- Base on the these environmental and social life cycle sustainability results, decision makers such as governmental organizations, can also design more applicable and effective packaging waste management policies or strengthen the law enforcement.

Finally, respecting to these research findings some future research recommendation has been listed below:

- In a life cycle assessment study, inventory data collection is an extremely important whether to indicate the studied systems inputs and outputs correctly. Especially in the determination of the social indicator, because there is not a commonly agreed methodology and certain social input data, every effort to advance the application for SLCA is particularly recommended.
- This thesis mainly searched the social and environmental implementation of packaging waste collection system in a certain system boundaries as collection, transportation, sorting and recycling processes. Even most of the data used in the study were specific data, some of the inventories were provided from literature as a generic data, especially in the recycling facility.
- The thesis only focused on the packaging waste as a part of the municipal solid waste because the currently applied system in the country still need to be evaluated. However, other municipal solid waste such as electronic waste, medical waste, construction and demolition waste may also be researched to implement an integrated solid waste management system. The environmental and social modeling approach used in this study may be applied to analysis of these waste.
- Another relevant research area is the evaluation of social life cycle assessment model based on the quantitative data sets. A broad scale scoring will make the more comparable social results.

- Instead of equal and ranking method weighting; pairwise comparison, Delphi method, semantic differential method or other relative weighting methods should be used to straightened the single score aggregation of ELCA and SLCA.
- Each part of the scenario 11 and 13 should be analyzed in detail considering the storing of collected and sorted materials, landfilling of mixed and recycled waste.
- Apart from the researched environmental impacts; human toxicity, terrestrial toxicity, fresh water and marine aquatic eco-toxicity should be considered to determine the total impacts on natural system.
- Scope of the social impacts may also be broaden; such as risk on labor, secure life and labor conditions should be analyzed.

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APPENDICES

Appendix 1. Resource consumption and avoided product inventory data of existing system and alternative scenarios.

	Collected Material (ton/year)	Sorted Material (ton/year)	Avoided Product (ton/year)	Residual Waste (ton/year)	Fuel Consumption (kg/ton)	Material Consumption (p/ton)	Water Consumption (m3/ton)	Thermal Energy Consumption (MJ/year)	Electrical Energy Consumption (Kwh/ton)
ES	33,451.12	32,676.17	27,715.25	5,735.87	49,188.90	910,566.05	13,100.32	11,659,817.68	2,407,941.27
S1	6,138.69	5,022.75	4,342.90	1,795.78	56,690.80	1,309,984.72	2,430.36	7,976,966.90	338,729.60
S2	4,699.93	2,819.96	2,466.64	2,233.29	48,967.64	870,090.65	1,837.67	3,701,124.05	234,641.57
S3	4,262.98	3,944.25	3,378.48	884.50	123,638.07	1,363,460.47	1,687.75	5,787,929.39	255,912.06
S4	3,847.34	3,564.19	3,046.84	800.49	160,506.98	1,271,743.18	1,523.20	5,229,883.03	228,747.61
S5	5,158.20	4,220.51	3,614.22	1,543.98	128,938.51	520.80	2,042.18	6,702,868.02	261,126.52
S6	5,158.20	4,929.29	4,211.75	946.45	144,614.23	781.20	2,042.18	6,545,258.31	310,007.00
S7	1,534.67	1,438.11	1,229.01	305.67	115,937.33	252.00	607.59	1,941,390.57	90,402.13
S8	1,534.67	1,487.66	1,271.94	262.73	171,716.07	378.00	607.59	2,058,266.82	91,605.18
S9	4,262.98	3,488.02	2,986.96	1,276.02	49,188.90	5,649,674.75	1,687.75	5,539,560.35	215,807.04
S10	32,349.68	32,349.68	27,374.68	4,975.01	-	850.00	12,648.73	6,783,178.29	2,408,051.61
S11	33,451.12	33,396.05	28,295.48	5,155.64	13,639.61	883.60	13,100.32	11,810,764.78	2,434,907.34
S12	24,660.01	24,288.78	20,588.80	4,071.20	49,188.90	910,166.05	9,662.99	9,901,124.74	1,760,140.11
S13	33,451.12	33,396.05	28,295.48	5,155.64	120,718.67	2,896.59	13,100.32	11,810,764.78	2,434,907.34

Appendix 2. Avoided product inventory data of existing system and alternative scenarios.

	Glass (ton/year)	Paper cardboard (ton/year)	PE (ton/year)	PET (ton/year)	PP (ton/year)	PS (ton/year)	PVC (ton/year)	Steel (ton/year)	Aluminum (ton/year)
ES	920.80	22906.49	1334.16	477.36	566.10	52.02	18.36	1300.70	139.25
S1	1325.96	2546.30	148.31	53.06	62.93	5.78	2.04	183.05	15.48
S2	595.58	1552.11	90.37	32.33	38.34	3.52	1.24	143.71	9.44
S3	945.04	2060.66	126.68	45.33	53.75	4.94	1.74	127.11	13.22
S4	852.89	1859.74	115.50	41.33	49.01	4.50	1.59	110.07	12.21
S5	1114.17	2139.60	124.62	44.59	52.88	4.86	1.71	118.79	13.01
S6	1055.53	2701.18	157.32	56.29	66.75	6.13	2.16	149.96	16.42
S7	314.04	783.05	45.61	16.32	19.35	1.78	0.63	43.47	4.76
S8	334.98	803.66	46.09	16.49	19.55	1.80	0.63	43.93	4.81
S9	920.80	1768.26	102.99	36.85	43.70	4.02	1.42	98.17	10.75
S10	0.00	23427.84	1364.53	488.23	578.99	53.20	18.78	1300.70	142.42
S11	920.80	23427.84	1364.53	488.23	578.99	53.20	18.78	1300.70	142.42
S12	920.80	16832.29	980.38	350.78	415.99	38.23	13.49	934.52	102.33
S13	920.80	23427.84	1364.53	488.23	578.99	53.20	18.78	1300.70	142.42

Appendix 3. Inventory data of environmental life cycle assessment study.

SimaPro Program Inputs	Existing System			Scenario 1		Scenario 2	Scenario 3		
	Mp	Mpi	G	Mp	G	PW	Pc	G	HL
Known outputs to technosphere (products and/or co-products)									
Collected Material (tonne/year)	3,161.54	29,188.15	1,101.44	4,552.62	1,586.07	4,699.93	2,662.35	1,101.44	499.19
Known inputs from technosphere									
Fuel Consumption (kg/year)	35,549.30	-	13,639.61	38,839.30	17,851.50	48,967.64	44,148.59	40,456.92	39,032.55
Distance (km/year)	105,384.64	-	46,811.18	115,276.74	61,350.18	145,206.53	130,717.03	119,617.23	115,334.57
Material Consumption (p/year)	909,682.45	850.00	33.60	1,310,542.72	42.00	870,090.65	663,513.72	157,348.49	542,598.26
Collected Material (tonne/year)	3,161.54	29,188.15	1,101.44	4,552.62	1,586.07	4,699.93	2,662.35	1,101.44	499.19
Emissions to air									
CO_2 (kg/year)	111,624.79	-	42,828.37	121,955.41	56,053.70	153,758.40	138,626.59	127,034.73	122,562.22
CO (g/year)	269,463.66	-	103,388.22	294,401.91	135,314.35	371,174.75	334,646.35	306,663.46	295,866.76
CH_4 (g/year)	18,442.31	-	8,191.96	20,173.43	10,736.28	25,411.14	22,875.48	20,933.02	20,183.55
N_2O (g/year)	1,813.01	-	695.62	1,980.80	910.43	2,497.35	2,251.58	2,063.30	1,990.66
NOx (g/year)	1,186,279.98	-	455,153.68	1,296,067.52	595,704.46	1,634,050.30	1,473,238.61	1,350,047.46	1,302,516.35
NH_3 (g/year)	462.14	-	177.31	504.91	232.07	636.58	573.93	525.94	507.42
SO_2 (g/year)	710.99	-	272.79	776.79	357.03	979.35	882.97	809.14	780.65
PM (g/year)	33,416.34	-	12,821.23	36,508.94	16,780.41	46,029.59	41,499.68	38,029.51	36,690.60
NMVOC (g/year)	68,254.65	-	26,188.04	74,571.46	34,274.87	94,017.88	84,765.30	77,677.29	74,942.50
CO_2lub (g/year)	90,295.21	-	34,644.60	98,651.83	45,342.80	124,377.82	112,137.43	102,760.58	99,142.69
Pb (mg/year)	1,852.12	-	710.62	2,023.53	930.06	2,551.21	2,300.14	2,107.81	2,033.60
Cd (mg/year)	309.28	-	118.66	337.90	155.31	426.02	384.09	351.98	339.58
As (mg/year)	3.55	-	1.36	3.88	1.79	4.90	4.41	4.05	3.90
Cr (mg/year)	1,066.48	-	409.19	1,165.18	535.54	1,469.03	1,324.46	1,213.71	1,170.98
Cu (mg/year)	753.65	-	289.16	823.39	378.45	1,038.11	935.95	857.69	827.49
Hg (mg/year)	188.41	-	72.29	205.85	94.61	259.53	233.99	214.42	206.87
Ni (mg/year)	312.83	-	120.03	341.79	157.09	430.92	388.51	356.02	343.49
Se (mg/year)	3.55	-	1.36	3.88	1.79	4.90	4.41	4.05	3.90
Zn (mg/year)	61,784.67	-	23,705.64	67,502.71	31,025.90	85,105.77	76,730.26	70,314.13	67,838.58

Appendix 3 (continued). Inventory data of environmental life cycle assessment study.

SimaPro Program Inputs	Scenario 4				Scenario 5		Scenario 6		
	Pc	G	Lw	Hw	Mp	G	Pc	G	HL
Known outputs to technosphere (products and/or co-products)									
Collected Material (tonne/year)	2,402.77	994.05	300.35	150.17	3,825.46	1,332.74	3,221.44	1,332.74	604.02
Known inputs from technosphere									
Fuel Consumption (kg/year)	43,534.67	40,202.93	38,562.27	38,207.10	68,047.40	60,891.10	66,618.85	17,566.95	60,428.44
Distance (km/year)	128,871.14	118,853.57	113,920.57	112,852.67	199,905.95	178,389.03	195,610.69	51,492.29	176,997.92
Material Consumption (p/year)	598,821.13	142,007.02	417,147.53	113,767.51	260.40	260.40	260.40	260.40	260.40
Collected Material (tonne/year)	2,402.77	994.05	300.35	150.17	3,825.46	1,332.74	3,221.44	1,332.74	604.02
Emissions to air									
CO_2 (kg/year)	136,698.86	126,237.21	121,085.54	119,970.30	213,668.84	191,198.07	209,183.17	55,160.21	189,745.29
CO (g/year)	329,992.80	304,738.24	292,302.03	289,609.83	515,799.30	461,554.57	504,970.85	133,157.45	458,047.55
CH_4 (g/year)	22,552.45	20,799.37	19,936.10	19,749.22	34,983.54	31,218.08	34,231.87	9,011.15	30,974.64
N_2O (g/year)	2,220.27	2,050.35	1,966.68	1,948.56	3,470.42	3,105.45	3,397.56	895.91	3,081.85
NOx (g/year)	1,452,751.94	1,341,571.92	1,286,823.03	1,274,970.97	2,270,741.78	2,031,936.16	2,223,070.87	586,208.97	2,016,496.94
NH_3 (g/year)	565.95	522.64	501.31	496.69	884.62	791.58	866.04	228.37	785.57
SO_2 (g/year)	870.69	804.06	771.25	764.14	1,360.95	1,217.82	1,332.38	351.34	1,208.57
PM (g/year)	40,922.59	37,790.76	36,248.54	35,914.68	63,964.56	57,237.64	62,621.71	16,512.93	56,802.73
NMVOC (g/year)	83,586.57	77,189.63	74,039.56	73,357.63	130,651.01	116,910.92	127,908.18	33,728.54	116,022.60
CO_2lub (g/year)	110,578.06	102,115.45	97,948.17	97,046.04	172,840.40	154,663.41	169,211.87	44,620.04	153,488.23
Pb (mg/year)	2,268.16	2,094.57	2,009.09	1,990.59	3,545.27	3,172.43	3,470.84	915.24	3,148.32
Cd (mg/year)	378.75	349.77	335.49	332.40	592.01	529.75	579.58	152.83	525.73
As (mg/year)	4.35	4.02	3.86	3.82	6.80	6.09	6.66	1.76	6.04
Cr (mg/year)	1,306.04	1,206.09	1,156.87	1,146.21	2,041.42	1,826.73	1,998.57	527.01	1,812.85
Cu (mg/year)	922.94	852.30	817.52	809.99	1,442.60	1,290.89	1,412.32	372.42	1,281.08
Hg (mg/year)	230.73	213.08	204.38	202.50	360.65	322.72	353.08	93.10	320.27
Ni (mg/year)	383.11	353.79	339.35	336.22	598.82	535.84	586.25	154.59	531.77
Se (mg/year)	4.35	4.02	3.86	3.82	6.80	6.09	6.66	1.76	6.04
Zn (mg/year)	75,663.26	69,872.70	67,021.23	66,403.94	118,266.38	105,828.74	115,783.55	30,531.35	105,024.62

Appendix 3 (continued). Inventory data of environmental life cycle assessment study.

SimaPro Program Inputs	Scenario 7		Scenario 8			Scenario 9		Scenario 10
	Mp	G	Pc	G	HL	Mp	G	PW
Known outputs to technosphere (products and/or co-products)								
Collected Material (tonne/year)	1,138.15	396.52	958.45	396.52	179.71	3,161.54	1,101.44	32,349.68
Known inputs from technosphere								
Fuel Consumption (kg/year)	59,033.24	56,904.09	58,608.21	56,341.41	56,766.44	35,549.30	13,639.61	-
Distance (km/year)	175,225.15	168,823.42	173,947.22	167,131.61	168,409.53	105,384.64	46,811.18	-
Material Consumption (p/year)	126.00	126.00	126.00	126.00	126.00	5,649,641.15	33.60	850.00
Collected Material (tonne/year)	1,138.15	396.52	958.45	396.52	179.71	3,161.54	1,101.44	32,349.68
Emissions to air								
CO_2 (kg/year)	185,364.37	178,678.85	184,029.79	176,912.04	178,246.62	111,624.79	42,828.37	-
CO (g/year)	447,471.95	431,333.03	444,250.26	427,067.93	430,289.61	269,463.66	103,388.22	-
CH_4 (g/year)	30,664.40	29,544.10	30,440.76	29,248.03	29,471.67	18,442.31	8,191.96	-
N_2O (g/year)	3,010.70	2,902.11	2,989.02	2,873.41	2,895.09	1,813.01	695.62	-
NOx (g/year)	1,969,939.19	1,898,889.59	1,955,756.11	1,880,113.02	1,894,296.10	1,186,279.98	455,153.68	-
NH_3 (g/year)	767.43	739.75	761.91	732.44	737.96	462.14	177.31	-
SO_2 (g/year)	1,180.66	1,138.08	1,172.16	1,126.83	1,135.33	710.99	272.79	-
PM (g/year)	55,491.24	53,489.85	55,091.72	52,960.93	53,360.45	33,416.34	12,821.23	-
NMVOC (g/year)	113,343.82	109,255.86	112,527.77	108,175.52	108,991.56	68,254.65	26,188.04	-
CO_2lub (g/year)	149,944.43	144,536.40	148,864.86	143,107.19	144,186.76	90,295.21	34,644.60	-
Pb (mg/year)	3,075.63	2,964.70	3,053.49	2,935.39	2,957.53	1,852.12	710.62	-
Cd (mg/year)	513.59	495.07	509.89	490.17	493.87	309.28	118.66	-
As (mg/year)	5.90	5.69	5.86	5.63	5.68	3.55	1.36	-
Cr (mg/year)	1,771.00	1,707.12	1,758.25	1,690.24	1,702.99	1,066.48	409.19	-
Cu (mg/year)	1,251.50	1,206.37	1,242.49	1,194.44	1,203.45	753.65	289.16	-
Hg (mg/year)	312.88	301.59	310.62	298.61	300.86	188.41	72.29	-
Ni (mg/year)	519.49	500.76	515.75	495.80	499.54	312.83	120.03	-
Se (mg/year)	5.90	5.69	5.86	5.63	5.68	3.55	1.36	-
Zn (mg/year)	102,599.77	98,899.31	101,861.08	97,921.38	98,660.07	61,784.67	23,705.64	-

Appendix 3 (continued). Inventory data of separation and collection stage for environmental life cycle assessment study.

SimaPro Program Inputs	Scenario 11		Scenario 12			Scenario 13	
	PW	G	Mp	Mpi	G	PW	G
Known outputs to technosphere (products and/or co-products)							
Collected Material (tonne/year)	32,349.68	1,101.44	3,161.54	20,397.03	1,101.44	32,349.68	1,101.44
Known inputs from technosphere							
Fuel Consumption (kg/year)	-	13,639.61	35,549.30	-	13,639.61	107,079.06	13,639.61
Distance (km/year)	-	46,811.18	105,384.64	-	46,811.18	312,944.79	46,811.18
Material Consumption (p/year)	850.00	33.60	909,682.45	450.00	33.60	2,862.99	33.60
Collected Material (tonne/year)	32,349.68	1,101.44	3,161.54	20,397.03	1,101.44	32,349.68	1,101.44
Emissions to air							
CO_2 (kg/year)	-	42,828.37	111,624.79	-	42,828.37	336,228.26	42,828.37
CO (g/year)	-	103,388.22	269,463.66	-	103,388.22	811,659.31	103,388.22
CH_4 (g/year)	-	8,191.96	18,442.31	-	8,191.96	54,765.34	8,191.96
N_2O (g/year)	-	695.62	1,813.01	-	695.62	5,461.03	695.62
NOx (g/year)	-	455,153.68	1,186,279.98	-	455,153.68	3,573,228.37	455,153.68
NH_3 (g/year)	-	177.31	462.14	-	177.31	1,392.03	177.31
SO_2 (g/year)	-	272.79	710.99	-	272.79	2,141.58	272.79
PM (g/year)	-	12,821.23	33,416.34	-	12,821.23	100,654.32	12,821.23
NMVOC (g/year)	-	26,188.04	68,254.65	-	26,188.04	205,591.80	26,188.04
CO_2lub (g/year)	-	34,644.60	90,295.21	-	34,644.60	271,980.82	34,644.60
Pb (mg/year)	-	710.62	1,852.12	-	710.62	5,578.82	710.62
Cd (mg/year)	-	118.66	309.28	-	118.66	931.59	118.66
As (mg/year)	-	1.36	3.55	-	1.36	10.71	1.36
Cr (mg/year)	-	409.19	1,066.48	-	409.19	3,212.37	409.19
Cu (mg/year)	-	289.16	753.65	-	289.16	2,270.08	289.16
Hg (mg/year)	-	72.29	188.41	-	72.29	567.52	72.29
Ni (mg/year)	-	120.03	312.83	-	120.03	942.30	120.03
Se (mg/year)	-	1.36	3.55	-	1.36	10.71	1.36
Zn (mg/year)	-	23,705.64	61,784.67	-	23,705.64	186,103.41	23,705.64

Appendix 4. Inventory data of sorting stage for environmental life cycle assessment study.

SimaPro Program Inputs		Existing System			Scenario 1		Scenario 2	Scenario 3			Scenario 4			
		Mp	Mpi	G	Mp	G	PW	Pc	G	HL	Pc	G	Lw	Hw
Known outputs to technosphere (products and/or co-products)														
Sorted Material (tonne/year)		2441.66	29188.15	1046.3	3515.99	1506	2819.96	2396.1	1073.9	474.23	2162.49	969.20	288.3	144.1
Known inputs from technosphere (resources-materials/fuels-electricity/heat)														
Collected Material (tonne/year)		3161.54	29188.15	1101.4	4552.62	1586	4699.93	2662.3	1101.4	499.19	2402.77	994.05	300.3	150.1
Water Consumption (m3/year)		1236.16	11412.56	451.59	1780.07	650.2	1837.67	1040.9	451.59	195.18	939.48	407.56	117.4	58.72
Electricity (kWh/year)		31615.3	291881.4	9912.9	45526.1	14274	46999.3	26623	9912.9	4991.9	24027	8946.4	3003	1501
Fuel Consumptions (kg/year)	Transportation of sorted Glass	0.00	0.00	4907.4	0.00	7066	3174.15	0.00	5036.6	0.00	0.00	4545.5	0.00	0.00
	Transportation of sorted Paper	16634.0	198846.8	0.00	23952.9	0.00	14600.6	19384	0.00	0.00	17494.5	0.00	0.00	0.00
	Transportation of sorted Plastic	2969.58	35499.06	0.00	4276.19	0.00	2605.64	0.00	0.00	3652.8	0.00	0.00	3330	0.00
	Transportation of sorted Metal	593.35	7093.07	0.00	854.43	0.00	521.13	0.00	0.00	729.80	0.00	0.00	0.00	666.0
Known outputs to technosphere (waste)														
Wastage Material (tonne/year)		719.88	0.00	55.07	1036.63	79.30	1879.97	266.23	27.54	24.96	240.28	24.85	12.01	6.01

Appendix 4 (continued). Inventory data of sorting stage for environmental life cycle assessment study.

SimaPro Program Inputs		Scenario 5		Scenario 6			Scenario 7		Scenario8		
		Mp	**G**	**Pc**	**G**	**HL**	**Mp**	**G**	**Pc**	**G**	**HL**
Known outputs to technosphere (products and/or co-products)											
Sorted Material (tonne/year)		2954.40	1266.10	3140.91	1199.47	588.92	1081.25	356.87	934.48	380.66	172.52
Known inputs from technosphere (resources-materials/fuels-electricity/heat)											
Collected Material (tonne/year)		3825.46	1332.74	3221.44	1332.74	604.02	1138.15	396.52	958.45	396.52	179.71
Water Consumption (m3/year)		1495.76	546.42	1259.58	546.42	236.17	445.02	162.57	374.75	162.57	70.27
Electricity (kWh/year)		38254.62	11994.68	32214.42	11994.68	6040.20	11381.54	3568.66	9584.46	3568.66	1797.09
Fuel Consumptions (kg/year)	Transportation of sorted Glass	0.00	5938.03	0.00	5625.50	0.00	0.00	1673.70	0.00	1785.28	0.00
	Transportation of sorted Paper	20127.14	0.00	25409.93	0.00	0.00	7366.09	0.00	7559.98	0.00	0.00
	Transportation of sorted Plastic	3593.19	0.00	0.00	0.00	4536.27	1315.03	0.00	0.00	0.00	1328.87
	Transportation of sorted Metal	717.96	0.00	0.00	0.00	906.30	262.76	0.00	0.00	0.00	265.50
Known outputs to technosphere (waste)											
Wastage Material (tonne/year)		871.06	66.64	80.54	133.27	15.10	56.91	39.65	23.96	15.86	7.19

Appendix 4 (continued). Inventory data of sorting stage for environmental life cycle assessment study.

SimaPro Program Inputs		Scenario 9		Scenario 10	Scenario 11		Scenario 12			Scenario 13	
		Mp	G	PW	Mpi	G	Mp	Mpi	G	Mpi	G
Known outputs to technosphere (products and/or co-products)											
Sorted Material (tonne/year)		2441.66	1046.37	32349.68	32349.68	1046.37	2845.39	20397.03	1046.37	32349.68	1046.37
Known inputs from technosphere (resources-materials/fuels-electricity/heat)											
Collected Material (tonne/year)		3161.54	1101.44	32349.68	32349.68	1101.44	3161.54	20397.03	1101.44	32349.68	1101.44
Water Consumption (m3/year)		1236.16	451.59	12648.73	12648.73	451.59	1236.16	7975.24	451.59	12648.73	451.59
Electricity (kWh/year)		31615.39	9912.96	323496.85	323496.85	9912.96	31615.39	203970.27	9912.96	323496.85	9912.96
Fuel Consumptions (kg/year)	Transportation of sorted Glass	0.00	4907.46	0.00	0.00	4907.46	0.00	0.00	4907.46	0.00	4907.46
	Transportation of sorted Paper	16634.00	0.00	220385.11	220385.11	0.00	19384.44	138956.56	0.00	220385.11	0.00
	Transportation of sorted Plastic	2969.58	0.00	39344.17	39344.17	0.00	3460.60	24807.17	0.00	39344.17	0.00
	Transportation of sorted Metal	593.35	0.00	7861.36	7861.36	0.00	691.46	4956.72	0.00	7861.36	0.00
Known outputs to technosphere (waste)											
Wastage Material (tonne/year)		719.88	55.07	0.00	0.00	55.07	316.15	0.00	55.07	0.00	55.07

Appendix 5. Inventory data of recycling stage for environmental life cycle assessment study.

SimaPro Program Inputs		Existing System			Scenario 1	
		Mp	Mpi	G	Mp	G
Known outputs to technosphere (products and/or co-products)						
Recycled Material		2095.10	24699.35	920.80	3016.95	1325.96
Avoided Product						
Glass		0.00	0.00	920.80	0.00	1325.96
Paper_cardboard		1768.26	21138.23	0.00	2546.30	0.00
PE		102.99	1231.17	0.00	148.31	0.00
PET		36.85	440.51	0.00	53.06	0.00
PP		43.70	522.40	0.00	62.93	0.00
PS		4.02	48.00	0.00	5.78	0.00
PVC		1.42	16.94	0.00	2.04	0.00
Steel		127.12	1173.58	0.00	183.05	0.00
Aluminium		10.75	128.50	0.00	15.48	0.00
Known inputs from technosphere (resources-materials/fuels-electricity/heat)						
Sorted Material (ton)		2441.66	29188.15	1046.37	3515.99	1506.77
Electrical Energy	Glass	0.00	0.00	16942.78	0.00	24397.61
	Paper_cardboard	12377.84	147967.61	0.00	17824.09	0.00
	Plastic	78234.92	935238.89	0.00	112658.29	0.00
	Steel	85295.77	787472.59	0.00	122825.91	0.00
	Aluminium	849.23	10151.84	0.00	1222.88	0.00
Thermal Energy	Glass	0.00	0.00	5027586.49	0.00	7239724.55
	Paper_cardboard	26523.94	317073.45	0.00	38194.47	0.00
	Plastic	432937.70	5175440.31	0.00	623430.28	0.00
	Steel	0.00	0.00	0.00	0.00	0.00
	Aluminium	52512.22	627743.57	0.00	75617.60	0.00
Known outputs to technosphere (waste)						
Paper_cardboard		291.83	3780.02	0.00	420.24	0.00
Glass		0.00	0.00	125.56	0.00	180.81
Plastic		36.49	472.67	0.00	52.55	0.00
Metal		18.23	236.11	0.00	26.25	0.00
Total		346.55	4488.80	125.56	499.04	180.81

Appendix 5 (continued). Inventory data of recycling stage for environmental life cycle assessment study.

SimaPro Program Inputs		Scenario 2	Scenario 3		
		PW	Pc	G	HL
Known outputs to technosphere (products and/or co-products)					
Recycled Material		2466.64	2060.66	945.04	372.78
Avoided Product					
Glass		595.58	0.00	945.04	0.00
Paper_cardboard		1552.11	2060.66	0.00	0.00
PE		90.37	0.00	0.00	126.68
PET		32.33	0.00	0.00	45.33
PP		38.34	0.00	0.00	53.75
PS		3.52	0.00	0.00	4.94
PVC		1.24	0.00	0.00	1.74
Steel		143.71	0.00	0.00	127.11
Aluminium		9.44	0.00	0.00	13.22
Known inputs from technosphere (resources-materials/fuels-electricity/heat)					
Sorted Material (ton)		2819.96	2396.11	1073.90	474.23
Electrical Energy	Glass	10958.59	0.00	17388.65	0.00
	Paper_cardboard	10864.74	14424.61	0.00	0.00
	Plastic	68646.86	0.00	0.00	96232.94
	Steel	96426.18	0.00	0.00	85292.93
	Aluminium	745.86	0.00	0.00	1044.59
Thermal Energy	Glass	3251842.94	0.00	5159891.40	0.00
	Paper_cardboard	23281.59	30909.87	0.00	0.00
	Plastic	379879.12	0.00	0.00	532535.42
	Steel	0.00	0.00	0.00	0.00
	Aluminium	46120.40	0.00	0.00	64592.70
Known outputs to technosphere (waste)					
Paper_cardboard		226.12	335.46	0.00	0.00
Glass		84.80	0.00	128.87	0.00
Plastic		28.27	0.00	0.00	67.66
Metal		14.13	0.00	0.00	33.79
Total		353.32	335.46	128.87	101.45

Appendix 5 (continued). Inventory data of recycling stage for environmental life cycle assessment study.

SimaPro Program Inputs		Scenario 4				Scenario5	
		Pc	**G**	**Lw**	**Hw**	**Mp**	**G**
Known outputs to technosphere (products and/or co-products)							
Recycled Material		1859.74	852.89	211.92	122.28	2500.05	1114.17
Avoided Product							
Glass		0.00	852.89	0.00	0.00	0.00	1114.17
Paper_cardboard		1859.74	0.00	0.00	0.00	2139.60	0.00
PE		0.00	0.00	115.50	0.00	124.62	0.00
PET		0.00	0.00	41.33	0.00	44.59	0.00
PP		0.00	0.00	49.01	0.00	52.88	0.00
PS		0.00	0.00	4.50	0.00	4.86	0.00
PVC		0.00	0.00	1.59	0.00	1.71	0.00
Steel		0.00	0.00	0.00	110.07	118.79	0.00
Aluminum		0.00	0.00	0.00	12.21	13.01	0.00
Known inputs from technosphere (resources-materials/fuels-electricity/heat)							
Sorted Material (ton)		2162.49	969.20	288.33	144.17	2954.40	1266.10
Electrical Energy	Glass	0.00	15693.25	0.00	0.00	0.00	20500.77
	Paper_cardboard	13018.21	0.00	0.00	0.00	14977.18	0.00
	Plastic	0.00	0.00	87736.66	0.00	94664.26	0.00
	Steel	0.00	0.00	0.00	73855.24	79707.45	0.00
	Aluminum	0.00	0.00	0.00	964.92	1027.56	0.00
Thermal Energy	Glass	0.00	4656801.	0.00	0.00	0.00	6083379.66
	Paper_cardboard	27896.1	0.00	0.00	0.00	32093.96	0.00
	Plastic	0.00	0.00	485518.56	0.00	523854.61	0.00
	Steel	0.00	0.00	0.00	0.00	0.00	0.00
	Aluminum	0.00	0.00	0.00	59666.33	63539.79	0.00
Known outputs to technosphere (waste)							
Paper_cardboard		302.75	0.00	0.00	0.00	382.61	0.00
Glass		0.00	116.30	0.00	0.00	0.00	151.93
Plastic		0.00	0.00	76.41	0.00	47.84	0.00
Metal		0.00	0.00	0.00	21.88	23.90	0.00
Total		302.75	116.30	76.41	21.88	454.35	151.93

Appendix 5 (continued). Inventory data of recycling stage for environmental life cycle assessment study.

SimaPro Program Inputs		Scenario 6			Scenario7	
		Pc	G	HL	Mp	G
Known outputs to technosphere (products and/or co-products)						
Recycled Material		2701.18	1055.53	455.04	914.96	314.04
Avoided Product						
Glass		0.00	1055.53	0.00	0.00	314.04
Paper_cardboard		2701.18	0.00	0.00	783.05	0.00
PE		0.00	0.00	157.32	45.61	0.00
PET		0.00	0.00	56.29	16.32	0.00
PP		0.00	0.00	66.75	19.35	0.00
PS		0.00	0.00	6.13	1.78	0.00
PVC		0.00	0.00	2.16	0.63	0.00
Steel		0.00	0.00	149.96	43.47	0.00
Aluminum		0.00	0.00	16.42	4.76	0.00
Known inputs from technosphere (resources-materials/fuels-electricity/heat)						
Sorted Material (ton)		3140.91	1199.47	588.92	1081.25	356.87
Electrical Energy	Glass	0.00	19421.78	0.00	0.00	5778.38
	Paper_cardboard	18908.25	0.00	0.00	5481.32	0.00
	Plastic	0.00	0.00	119506.12	34645.01	0.00
	Steel	0.00	0.00	100624.33	29171.15	0.00
	Aluminum	0.00	0.00	1297.22	376.07	0.00
Thermal Energy	Glass	0.00	5763201.78	0.00	0.00	1714671.60
	Paper_cardboard	40517.69	0.00	0.00	11745.68	0.00
	Plastic	0.00	0.00	661324.90	191719.14	0.00
	Steel	0.00	0.00	0.00	0.00	0.00
	Aluminum	0.00	0.00	80213.94	23254.15	0.00
Known outputs to technosphere (waste)						
Paper_cardboard		439.73	0.00	0.00	140.03	0.00
Glass		0.00	143.94	0.00	0.00	42.82
Plastic		0.00	0.00	89.28	17.51	0.00
Metal		0.00	0.00	44.59	8.75	0.00
Total		439.73	143.94	133.88	166.28	42.82

Appendix 5 (continued). Inventory data of recycling stage for environmental life cycle assessment study.

SimaPro Program Inputs		Scenario 8			Scenario 9	
		Pc	G	HL	Mp	G
Known outputs to technosphere (products and/or co-products)						
Recycled Material		803.66	334.98	133.30	2066.16	920.80
Avoided Product						
Glass		0.00	334.98	0.00	0.00	920.80
Paper_cardboard		803.66	0.00	0.00	1768.26	0.00
PE		0.00	0.00	46.09	102.99	0.00
PET		0.00	0.00	16.49	36.85	0.00
PP		0.00	0.00	19.55	43.70	0.00
PS		0.00	0.00	1.80	4.02	0.00
PVC		0.00	0.00	0.63	1.42	0.00
Steel		0.00	0.00	43.93	98.17	0.00
Aluminum		0.00	0.00	4.81	10.75	0.00
Known inputs from technosphere (resources-materials/fuels-electricity/heat)						
Sorted Material (ton)		934.48	380.66	172.52	2441.66	1046.37
Electrical Energy	Glass	0.00	6163.61	0.00	0.00	16942.78
	Paper_cardboard	5625.60	0.00	0.00	12377.84	0.00
	Plastic	0.00	0.00	35008.53	78234.92	0.00
	Steel	0.00	0.00	29477.24	65873.93	0.00
	Aluminum	0.00	0.00	380.01	849.23	0.00
Thermal Energy	Glass	0.00	1828983.04	0.00	0.00	5027586.49
	Paper_cardboard	12054.85	0.00	0.00	26523.94	0.00
	Plastic	0.00	0.00	193730.78	432937.70	0.00
	Steel	0.00	0.00	0.00	0.00	0.00
	Aluminum	0.00	0.00	23498.15	52512.22	0.00
Known outputs to technosphere (waste)						
Paper_cardboard		130.83	0.00	0.00	316.21	0.00
Glass		0.00	45.68	0.00	0.00	125.56
Plastic		0.00	0.00	26.15	39.54	0.00
Metal		0.00	0.00	13.06	19.75	0.00
Total		130.83	45.68	39.22	375.50	125.56

Appendix 5 (continued). Inventory data of recycling stage for environmental life cycle assessment study.

SimaPro Program Inputs		Scenario 10	Scenario 11	
		PW	**Mpi**	**G**
Known outputs to technosphere (products and/or co-products)				
Recycled Material		27374.68	27374.68	920.80
Avoided Product				
Glass		0.00	0.00	920.80
Paper_cardboard		23427.84	23427.84	0.00
PE		1364.53	1364.53	0.00
PET		488.23	488.23	0.00
PP		578.99	578.99	0.00
PS		53.20	53.20	0.00
PVC		18.78	18.78	0.00
Steel		1300.70	1300.70	0.00
Aluminum		142.42	142.42	0.00
Known inputs from technosphere (resources-materials/fuels-electricity/heat)				
Sorted Material (ton)		32349.68	32349.68	1046.37
Electrical Energy	Glass	0.00	0.00	16942.78
	Paper_cardboard	163994.85	163994.85	0.00
	Plastic	1036540.09	1036540.09	0.00
	Steel	872768.37	872768.37	0.00
	Aluminum	11251.45	11251.45	0.00
Thermal Energy	Glass	0.00	0.00	5027586.49
	Paper_cardboard	351417.54	351417.54	0.00
	Plastic	5736022.59	5736022.59	0.00
	Steel	0.00	0.00	0.00
	Aluminum	695738.16	695738.16	0.00
Known outputs to technosphere (waste)				
Paper_cardboard		4189.45	4189.45	105.74
Glass		0.00	0.00	0.00
Plastic		523.87	523.87	13.22
Metal		261.69	261.69	6.60
Total		4975.01	4975.01	125.56

Appendix 5 (continued). Inventory data of recycling stage for environmental life cycle assessment study.

SimaPro Program Inputs		Scenario 12			Scenario 13	
		Mp	Mpi	G	Mpi	G
Known outputs to technosphere (products and/or co-products)						
Recycled Material		2407.80	17260.20	920.80	27374.68	920.80
Avoided Product						
Glass		0.00	0.00	920.80	0.00	920.80
Paper_cardboard		2060.65	14771.65	0.00	23427.84	0.00
PE		120.02	860.36	0.00	1364.53	0.00
PET		42.94	307.83	0.00	488.23	0.00
PP		50.93	365.06	0.00	578.99	0.00
PS		4.68	33.55	0.00	53.20	0.00
PVC		1.65	11.84	0.00	18.78	0.00
Steel		114.41	820.11	0.00	1300.70	0.00
Aluminum		12.53	89.80	0.00	142.42	0.00
Known inputs from technosphere (resources-materials/fuels-electricity/heat)						
Sorted Material (ton)		2845.39	20397.03	1046.37	32349.68	1046.37
Electrical Energy	Glass	0.00	0.00	16942.78	0.00	16942.78
	Paper_cardboard	14424.52	103401.55	0.00	163994.85	0.00
	Plastic	91171.09	653556.17	0.00	1036540.09	0.00
	Steel	76766.20	550295.31	0.00	872768.37	0.00
	Aluminum	989.64	7094.23	0.00	11251.45	0.00
Thermal Energy	Glass	0.00	0.00	5027586.49	0.00	5027586.49
	Paper_cardboard	30909.68	221574.74	0.00	351417.54	0.00
	Plastic	504524.06	3616659.89	0.00	5736022.59	0.00
	Steel	0.00	0.00	0.00	0.00	0.00
	Aluminum	61195.13	438674.75	0.00	695738.16	0.00
Known outputs to technosphere (waste)						
Paper_cardboard		368.49	2641.52	0.00	4189.45	0.00
Glass		0.00	0.00	125.56	0.00	125.56
Plastic		46.08	330.31	0.00	523.87	0.00
Metal		23.02	165.00	0.00	261.69	0.00
Total		437.59	3136.83	125.56	4975.01	125.56

Appendix 6. Inventory data of social life cycle assessment study.

Performance Indicator	Measurement	Reference Point	S0	S1	S2	S3
Incident risk	Existence of risk	No	Yes	Y/N	Y/N	No
Occupational health risk	Existence of risk	No	Yes	Y/N	Y/N	No
Health and safety awareness	Existence of awareness	Yes	No	Y/N	Y/N	Y/N
Safety risk of the system	Existence of risk	No	Yes	No	No	No
Health and safety training	Existence of training	Yes	No	Yes	Yes	Yes
Working with appropriate equipment	Existence	Yes	No	Yes	Yes	Yes
Local community's health and safe living conditions	Existence of danger	No	Yes	No	No	No
Local community's secure living conditions	Existence of danger	No	Yes	No	No	No
Work satisfaction	Existence of satisfaction	Yes	Y/N	Y/N	Y/N	Y/N
Legal working hours limit	Existence of limit	Yes	No	Yes	Yes	Yes
Night work	Existence	No	Yes	No	No	No
Payment in the living wage standards	Existence of standards	Yes	No	Yes	Yes	Yes
Regular payment	Existence	Yes	Y/N	Yes	Yes	Yes
Legal working contracts	Existence	Yes	No	Yes	Yes	Yes
Retirement rights	Existence	Yes	No	Yes	Yes	Yes
Social security rights	Existence	Yes	No	Yes	Yes	Yes
Training programs	Existence	Yes	No	Yes	Yes	Yes
Forced labour	Existence	No	Y/N	No	No	No
Child labour	Existence	No	Yes	No	No	No
Rights of the associations or bargain collectively	Existence	Yes	No	Yes	Yes	Yes
Political, regional and religious discrimination	Existence	No	Yes	Y/N	Y/N	Y/N
Job creation potential	Number of person	Ranking	900	50	50	50
Job lose potential	Number of person	Ranking	0	850	850	850
Supporting the system	Number of person	Ranking	Y/N	No	No	No
Identification of complaints	Number of complaints	Ranking	No	Yes	Yes	Yes
Contribution of the system to economic development	Amount of recycled waste	Ranking	35451.12	6138.69	4699.93	4262.98

Appendix 6 (continued). Inventory data of social life cycle assessment study.

Performance Indicator	Measurement	Reference Point	S4	S5	S6	S7
Incident risk	Existence of risk	No	No	Y/N	No	Y/N
Occupational health risk	Existence of risk	No	No	Y/N	No	Y/N
Health and safety awareness	Existence of awareness	Yes	Y/N	Y/N	Y/N	Y/N
Safety risk of the system	Existence of risk	No	No	No	No	No
Health and safety training	Existence of training	Yes	Yes	Yes	Yes	Yes
Working with appropriate equipment	Existence	Yes	Yes	Yes	Yes	Yes
Local community's health and safe living conditions	Existence of danger	No	No	No	No	No
Local community's secure living conditions	Existence of danger	No	No	No	No	No
Work satisfaction	Existence of satisfaction	Yes	Y/N	Yes	Yes	Yes
Legal working hours limit	Existence of limit	Yes	Yes	Yes	Yes	Yes
Night work	Existence	No	No	No	No	No
Payment in the living wage standards	Existence of standards	Yes	Yes	Yes	Yes	Yes
Regular payment	Existence	Yes	Yes	Yes	Yes	Yes
Legal working contracts	Existence	Yes	Yes	Yes	Yes	Yes
Retirement rights	Existence	Yes	Yes	Yes	Yes	Yes
Social security rights	Existence	Yes	Yes	Yes	Yes	Yes
Training programs	Existence	Yes	Yes	Yes	Yes	Yes
Forced labour	Existence	No	No	No	No	No
Child labour	Existence	No	No	No	No	No
Rights of the associations or bargain collectively	Existence	Yes	Yes	Yes	Yes	Yes
Political, regional and religious discrimination	Existence	No	Y/N	Y/N	Y/N	Y/N
Job creation potential	Number of person	Ranking	50	50	50	50
Job lose potential	Number of person	Ranking	850	850	850	850
Supporting the system	Number of person	Ranking	No	No	No	No
Identification of complaints	Number of complaints	Ranking	Yes	Yes	Yes	Yes
Contribution of the system to economic development	Amount of recycled waste	Ranking	3847.34	5158.20	5158.20	1534.67

Appendix 6 (continued). Inventory data of social life cycle assessment study.

Performance Indicator	Measurement	Reference Point	S9	S10	S11	S12	S13
Incident risk	Existence of risk	No	Y/N	Yes	Y/N	Y/N	No
Occupational health risk	Existence of risk	No	Y/N	Yes	Y/N	Y/N	No
Health and safety awareness	Existence of awareness	Yes	Y/N	No	Y/N	Y/N	Yes
Safety risk of the system	Existence of risk	No	No	Yes	Y/N	Y/N	No
Health and safety training	Existence of training	Yes	Yes	No	Yes	Yes	Yes
Working with appropriate equipment	Existence	Yes	Yes	No	Y/N	Y/N	Yes
Local community's health and safe living conditions	Existence of danger	No	No	Yes	Y/N	Y/N	No
Local community's secure living conditions	Existence of danger	No	No	Yes	No	No	No
Work satisfaction	Existence of satisfaction	Yes	Y/N	Y/N	Yes	Y/N	Yes
Legal working hours limit	Existence of limit	Yes	Yes	No	Yes	Yes	Yes
Night work	Existence	No	No	Yes	No	No	No
Payment in the living wage standards	Existence of standards	Yes	Yes	No	Yes	Yes	Yes
Regular payment	Existence	Yes	Yes	Y/N	Yes	Yes	Yes
Legal working contracts	Existence	Yes	Yes	No	Yes	Yes	Yes
Retirement rights	Existence	Yes	Yes	No	Yes	Yes	Yes
Social security rights	Existence	Yes	Yes	No	Yes	Yes	Yes
Training programs	Existence	Yes	Yes	No	Yes	Yes	Yes
Forced labour	Existence	No	No	Y/N	No	No	No
Child labour	Existence	No	No	Yes	No	No	No
Rights of the associations or bargain collectively	Existence	Yes	Yes	No	Yes	Yes	Yes
Political, regional and religious discrimination	Existence	No	Y/N	Yes	Y/N	Y/N	No
Job creation potential	Number of person	Ranking	50	850	900	410	900
Job lose potential	Number of person	Ranking	850	50	0	490	0
Supporting the system	Number of person	Ranking	No	Y/N	Y/N	Y/N	Yes
Identification of complaints	Number of complaints	Ranking	Yes	No	Y/N	Y/N	No
Contribution of the system to economic development	Amount of recycled waste	Ranking	4262.9	32349.6	33451.1	24660.0	33451

Appendix 7. Packaging waste collection system social acceptability questionnaire

1. **Do you separate the packaging waste at source?**

…… Yes …… No …… Partially

2. **If you don't separate the waste, which one is the reason?**

…… There is not any collection service
…… Waste is not collected regularly
…… I don't have any idea
…… Other

3. **How do you separate the packaging waste?**

…… By giving the municipal service
…… Packaging waste container
…… Near the mixed waste container
…… Other

4. **Are you pleased the existing system?**

…… Yes …… No …… Partially

5. **How the packaging waste should be collected**

…… Separation at source …… Separation from mixed waste

Please answer the below given questions considering the social conditions.

6. **Who should collect the packaging waste**

…… Municipality …… Scavengers

7. **Please answer the above given question again considering the below given conditions**

Health and safety conditions of municipal workers
Health and safety conditions of scavengers
Providing employment
Environmental impacts of scavengers and municipality
…… Municipality …… Scavengers

8. **Which conditions effect your answer**

…… Health and safety conditions of municipal workers
…… Health and safety conditions of scavengers
…… Providing employment
…… Environmental impacts of scavengers and municipality

9. **If the waste separated at source, which below given system would you prefer?**

…… Door-to-door collection
…… Curbside collection
…… Drop off collection

10. **Please answer the above given question again considering the below given conditions**

…… Door-to-door collection (weekly collection, storage at buildings)
…… Curbside collection (storage at curbside bins located on the streets)
…… Drop off collection system (storage at curbside bins located on the streets)

11. **How the packaging waste should be separated**

…… One fraction (mixed collection)
…… 2 fractions (paper-plastic-metal ; glass)
…… 3 fractions (paper-plastic; metal ; glass)
…… 4 fractions (paper ; plastic ; metal ; glass)

CV

Name Surname	: Eren YILDIZ GEYHAN
Place and Date of Birth	: Rize / 07.06.1981
Foreign Language	: English
E-mail	: rnyildiz@yahoo.com

Education

Degree	**Department**	**University**	**Graduation Year**
Master of Science	Environmental Engineering	Yıldız Technical University	2007
Bachelor of Science	Environmental Engineering	Trakya University	2003
High School	Mathematic Science	Fındıklı High School	1999

Work Experience

Year	**Company**	**Position**
2009 - ….	Maltepe Municipality	Environmental Engineer
2008-2009	Hidrotek Consultancy	Environmental Engineer
2007-2008	Tempo Engineering	Environmental Engineer
2005-2006	Gelişim Engineering	Environmental Engineer
2005-2005	SDS Engineering	Environmental Engineer

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