

# **ADDIS ABABA UNIVERSITY**



## **ADDIS ABABA INSTITUTE OF TECHNOLOGY**

### **SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING**

#### **REVERSE LOGISTIC NETWORK DESIGN AND ANALYSIS FOR E-WASTE MANAGEMENT SYSTEM: A CASE OF AKAKI COMPUTER REFURBISHMENT AND TRAINING FACILITY**

**Addis Ababa, Ethiopia, 2019**

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**REVERSE LOGISTIC NETWORK DESIGN AND ANALYSIS FOR E-WASTE  
MANAGEMENT SYSTEM: A CASE OF AKAKI COMPUTE REFURBISHMENT  
AND TRAINING FACILITY**

By: Sisay Negesse

A Thesis Submitted to School of Mechanical and Industrial Engineering Presented  
in Partial Fulfillment of the Requirements for the Degree of Master of Science in  
Mechanical Engineering with the Specialization of Industrial Engineering.

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Addis Ababa, Ethiopia  
2019

ADDIS ABABA UNIVERSITY  
ADDIS ABABA INSTITUTE OF TECHNOLOGY  
SCHOOL OF MECHANICAL AND INDUSTRIAL ENGINEERING

This is to certify that the thesis prepared by Sisay Negesse, entitled Reverse logistic network design and evaluation for e-waste management system and submitted in partial fulfillments of the requirements for the degree of Master of Science in Mechanical Engineering with the specialization of Industrial Engineering complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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### Declaration

I, Sisay Negesse, declare that the Masters Research thesis entitled “Reverse logistic network design and analysis for e-waste management system” is my original research work and no material has been submitted previously for the award of any other academic degree. The research work was done under the guidance of Dr.-Ir Kassahun Yimer and Wogene Tesfaye (PhD Candidate), at Addis Ababa University, Addis Ababa Institute of Technology, School of Mechanical and Industrial Engineering.

By: Sisay Negesse (Candidate)                      Signature \_\_\_\_\_ Date \_\_\_\_\_

This is to certify that the above declaration made by the author is correct to the best of my knowledge.

Dr.-Ir. Kassahun Yimer (Thesis Advisor)                      Signature \_\_\_\_\_ Date \_\_\_\_\_

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I also thankful Addis Ababa Solid Waste Management Agency, Akaki-Kality Computer Refurbishment and Training Center, Institute of Technology and School of Mechanical and Industrial Engineering and all the organizations where the research data are collected for they gave me opportunity and provided all facilities needed for me to Study and complete my research work. I would also to extend my thankfulness to all Addis Ababa University, institute of Technology, industrial engineering stream staffs for their valuable comment through the progress of the study.

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## Abstract

Electrical and electronic equipment waste, (E-Waste) in short is a recent emerging waste. It is known that sales of electronics and electrical equipment have undergone explosive growth worldwide, while at the same time, the life cycles of equipment have been getting shorter. This has resulted in large numbers of e-waste being generated, which causes problems of environmental sustainability, health and economic loss that each country has to face. To manage these problems, the concept of Reverse Logistic (RL) has gained much attention due to the growing concern of environment and efficient utilization of resources. This study identified existence of improper network for e-waste collection system, undetermined collection center capacity and costs for e-waste collection and lack of properly designed e-waste reprocessing system problems and solved for Akaki Computer Refurbishment and Training Facility (ACRTF). The thesis focused on designing and analyzing a reverse logistics network of e-waste management system for ACRTF with a goal of designing optimal collection system, selecting location facility from potential generating sites, suggesting methods of re-processing e-waste and design of RL network for e-waste management.

To achieve the research objective, primary and secondary data were collected and analyzed to develop clear concepts and design the research. Data was collected from the case facility and analyzed focusing on identifying potential generating site, future accumulation of e-wastes, designing optimal collection facility and formulating methods of re-processing e-waste. The study used certain tools to analysis collected data and to design the RL network. MS excel and SPSS for categorizing and analyzing collected data from the case study, Google Earth Pro to locate e-waste generating sites and collection facilities and LINGO 18.0 to evaluate and select the optimal collection facility are the tools used in this study.

From the results of analyzed data, the study found that 71,124 sales and 53,344 waste amount of e-waste is expected to be generated from potential generating sites (PGS) at 2025. Decentralized collection system is optimal with 44.14 ton of e-waste, 2,214.94 Km of total distance, incurred total cost of 1385.856 birr from PGS to re-processing facility (RF) and total profit 499,799.52 birr from collected e-waste. Hence, the study found out that such amount of opportunity can be exploited if appropriate design of reverse logistics networks is implemented. In the study, it is recommended that end user of electrical and electronic equipment, the government policy on the sustainable environmental protection and resource recovery and the reprocessing facility should be awaked and all of which have a great implication on strategic implementation of reverse logistics network design.

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## Abbreviations

<b>AAIT</b>	<b>Addis Ababa Institute of Technology</b>
AAU	Addis Ababa University
ACRTCF	Akaki Computer Refurbishment and Training Center Facility
CCC	Centralized Collection Center
CE	Circular Economy
CNS	College of Natural Science
CRLN	Centralized Reverse Logistics Network
CRTC	Computer Refurbishing and Training Center
DC	Desktop Computer
DCC	Decentralized Collection Center
DRLN	Decentralized Reverse Logistics Network
EEE	Electrical and Electronic Equipment
EoL	End-of-Life
EoU	End-of-Use
EPC	Entoto Polytechnic college
ETC	Educational Training Colleges
EW	E-waste
EWM	E-Waste Management
EWMS	E-Waste Management System
FBE	Faculty of Business and Economics
GSCM	Sustainable/Green Supply Chain Management
HEI	Higher Educational Institute
IEWM	Integrated Electronic Waste Management
LM	Logistics Management
PC	Pearson Correlation
PC	Personal Computer
RL	Reverse Logistics
RF	Re-processing Facility
RLND	Reverse Logistic Network Design
RLSCM	Reverse Logistics Supply Chain Management
SC	School of Commerce
SCMS	Supply Chain Management System
SW	Solid Waste
TPC	Tegebareid Polytechnic College
VETC	Vocational and Educational Training Colleges
WMS	Waste Management System

## CHAPTER ONE

### BACKGROUND AND JUSTIFICATION OF THE STUDY

#### 1.1. Introduction

Man's quest for knowledge has led him to discover an innumerable amount of materials and processes through the advancements of science and technology that have helped to shape today's world. However, with the ever growing human population and the uncontrolled use of the planet's resources, creations that echo man's amassed intellect now strike back with toxic and hazardous implications that need to be reduced these detrimental consequences and even take advantage of them to continue the path of progress. Through this progress, Sustainability maintained by principles of called Circular Economy – increasing wastes and pollutions are redirected and not end at waste disposal sites (MacArthur, 2015).

The new emerging electronic equipment and devices are one of the results of science and technological advancements and they have been considered as an important part of human's daily life. They revolutionized the way people communicate, entertain, and retrieve information. The rapid developments in the electronics sector over the past few decades achieved an unprecedented growth. Accordingly, this development causes enhancements of new products with decreasing short life span which creates the rate of disposal to be raised.

The amount of E-Waste (EW) is grown to 50 million metric tons in 2018, with a growth rate of 4 to 5 percent per year (Baldé, Forti, Gray, Kuehr, & Stegmann, The Global E-waste Monitor, 2017). This large creation of EW has become an immediate and long term concern as its unregulated and improper accumulation and disposal can lead to major environmental problems due to toxic and other dangerous materials available in them.

In most developed countries, the Integrated Electronic Waste Management (IEWM), integrative thinking concept in which the entire waste streams are evaluated to achieve proper waste management (Mahdi, 2017). For instance, e-waste management in Europe provides a good example for dealing with the growing e-waste issues through serious laws and regulation and high customer awareness for preventing wastes.

They have to manage their discarded product in a friendly manner through the principles of extended producer's responsibilities for the entire life cycle of the product, especially for take back system, recycling processes and final disposal of the product (I.C. Nnorom, 2009). On the contrary, most developing countries have not yet implement E-Waste Management (EWM) where the recycling rate of e-waste is still relatively low due to lack of recycling infrastructure and national regulations which affects both the human health and the environment (Alaa Gaber Mahmoud, 2014). Those problems occurred when EWs are disposed to the environment in spite of its recover, reuse, recycle or remanufacture which requires appropriate establishment of remanufacturing, recycling and collection facilities for its managements which can be achieved by principles of Reverse Logistic (RL) system. RL used in connection with the role of logistics in recycling, waste disposal and managing hazardous materials (Wassenhove, 2013). RL is a part of closed loop supply chain that has forward as well as reverse component.

This study focused on the design and analysis of RL Network Design (RLND) for managing EWs. Many researches are done considering how to manage e-wastes by reverse logistics approaches. Rupesh Kumar, 2014: cost optimization model in recycled e-waste reverse logistics, Sajan T. John, Sridharan, ram Kumar, 2017: reverse logistics network design: a case of mobile phones and digital cameras, yang Xiang, 2016: research on environmental assessment of e-waste reverse logistics, Antony Sije, Pamela Awuoro Ochieng, 2013: mobile phone disposal and strategic evaluation of electronic waste management in Kenya and Rahaballah, Nashat Fors, 2015: e-waste reverse logistics optimization in Egypt mainly focus on model development, cost optimization and policy strategies of e-wastes management.

In Ethiopia, researches were conducted for how to manage solid wastes. Tadesse Amera, 2010: Awareness Rising on EWM in Ethiopia, Andreas Manhart, Mehari Belay 2013: EW country study Ethiopia, Gudeta Hika, Akhila S. Nair, 2015: electronic waste generation and its management in Bole and Akaki Kality sub cities of Addis Ababa Ethiopia. Those researches were focused on general principles for management to properly dispose to the landfills, not how to reuse, recycle or recovery system. This research intends to develop the methods, through which e-waste recovered, reused, recycled or manufactured by designing RLN and re-processing system.

## 1.2. Statements of the Problem

Currently, environmental sustainability and limited availability of natural resource is raising attention and becoming critical issue. The increasing number of End-of-Life (EoL) and End-of-Use (EoU) products disrupts the ecosystem of the environment and demands for natural resource are rising, due to industrial developments. Effective management of products at their end of life stage and careful use of resources is now becoming a major problem in developing countries where environmental and resource utilization regulations are not strictly enforced.

Electronics equipment have become an inherent part of human life, accrued benefits to individuals and nations as a whole. Despite the many advantages from this wasted equipment in developing countries, it gives off harmful consequences, which affect human health which penetrates the human body and affects the cell structure (Suhag A. K., 2016). During the disposal processes of these wastes, some chemicals can be released into the environment and may pose a threat to health. Therefore, it is essential that unwanted e-wastes do not end up in landfills and incinerators. Therefore, proper management of discarded EW for how to recover to solve the problems resulted from its waste is an issue of growing concern.

In Ethiopia, specifically, Addis Ababa city, there is least awareness and adaptations of return, reuse, recycle of remanufacture of waste products. These are mainly due to the following reasons: (Addis Ababa Solid Waste Management Agency, 2019)

- Lack of government supports to initiate and implement policies and strategies of e-waste managements
- Absence of formal e-waste dealer which collects with e-waste with optimum collection network
- Un awareness of EEE end users due to absence of facilities of e-waste RL, government policies and strategies on the e-waste managements
- Un-aware effects e-waste on health, environment as well as economy benefits

The concepts of e-waste management system is new in Ethiopia where few e-wastes are collected from the end users and reprocessed only in Akaki- Kality sub-city of Addis Ababa through the country. This e-waste reprocessing facility, Akaki Computer Refurbishment and

Training center (ACRTC), refurbish, de-manufacture Electronics and Electrical Equipment (EEE) and give training on how to maintain EEE. This study designed and analyzed a reverse logistics network for e-waste management system for ACRTC that can develop the optimal collection system and location facility from potential generating sites to solve the following identified problems of ACRTC.

- Improper network for e-waste collection system (Addis Ababa Solid Waste Management Agency, 2019)
- Undetermined collection center capacity and costs for e-waste collection (Akaki Computer Refurbishment and Training center, 2019)
- Lack of properly designed e-waste reprocessing system (Gudeta Hika and Akhila Nair, 2015)

### **1.3. Research questions**

The following questions were answered by this research.

1. What are the common reverse logistic activities in E-waste collection and processing system?
2. What are the reverse logistic barriers in e-waste reprocessing system of Akaki Computer Refurbishment and Training center?
3. What amounts of e-waste future generation from potential generating sites which supply e-waste to Akaki Computer Refurbishment and Training center?
4. How e-waste can be collected from generating sources and reprocessed in Akaki Computer Refurbishment and Training center facility?

## **1.4. Objectives of the study**

### **1.4.1. General objective**

The general objective of this research is to design and analyze a reverse logistics network for e-waste management system for Akaki Computer Refurbishment and Training Facility that can develop the optimal collection system and location facility from potential generating sites.

### **1.4.2. Specific objectives**

The specific objectives of the research are:

1. To identify reverse logistics activities in E-waste collection and reprocessing system
2. To identify and analyze reverse logistic barriers for e-waste management system of Akaki Computer Refurbishment and Training Facility
3. To identify potential generating sites and forecast their future EEE sales and e-waste generate
4. To design optimal e-waste collection network and method of e-waste reprocessing system for Akaki Computer Refurbishment and Training Facility
5. To develop RLN for e-waste management system

## **1.5. The Scope of the Study**

This research is limited to reverse logistic network design and analysis for e-waste management system in a Case of Akaki Compute Refurbishment and Training Facility. The data for the analysis would be collected from the case facility to analysis and identify the significant reverse logistic barrier, from potential e-waste generating sites in Addis Ababa city to forecast future sales and e-waste generate and to know and design the collection facilities, Addis Ababa solid waste management agency to know the existing e-waste management system. The study designed e-waste collection and reprocessing system and develop reverse logistic network for the management system of e-waste. Finally, this study does not include all varieties of e-wastes. The study focused on the major product of the case facility which identified as personal computer especially desktop computer.

## 1.6. Significance of the Study

The outcome of this research will contribute to the body of knowledge in RL operation and identifies literature gaps to be considered in future research areas. A general RL network for EoL product recycling will be modeled and validated for waste desktop computer in selected sites of Addis Ababa city. The design shall assist third party stakeholder or government to take part and develop RL programs; this will contribute to the country's economy and to create a sustainable environment by:

- Creating an opportunity of substitution of raw materials with value added waste products through collection and recycling process
- Making a considerable impact on Ethiopian manufacturing companies to collect their products at the EoL and control their recovery or disposal
- Creating a way for both academicians and industries to do further research, and develop reverse logistic programs. In addition, researchers, policy makers, consultants and academicians will be benefited from the research output as a source of reference.

## 1.7. Limitation of the Study

Currently reverse logistics system is a new concept which not previously applied correctly in Ethiopia, Especially on e-waste management system. Data's needed for model validations are limited and not available for public. The main constraints include, lack of data to know fixed opening and variable costs for facilities in the network. Therefore, the study has conducted with limited data, a preliminary survey and considered an observation of stated case and estimate data for the study. However, the limitation does not affect the end result or the quality of the research for the assumption is taken to estimate this limited data.

## 1.8. Structure of the Research

The Thesis is organized into five chapters. The first chapter gives overview on the general background and justification, problem statement and illustration of the objective of the study. The second chapter deals with a literature review of the concept of reverse logistics, process and activities of reverse logistics, reverse logistics network characteristics and problem, an overview on e-waste and finally presents the literature gap and summery. The third chapter focuses on the research design and methodology to give a clear view on the direction of the research design used in the study and presents the reverse logistics network model formulation for e-waste. Chapter four deals with the data analysis, interpretation and model design of the study. Lastly, chapter five covers the conclusion and recommendation of the study.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1. Introduction

This chapter assesses different literatures on the general concepts Supply Chain Management System (SCMS) which incorporate – Supply Chain Management (SCM) theories, Logistics Management (LM), Circular Economy (CE), Sustainable/Green Supply Chain Management (GSCM) from which the concepts of Reverse Logistic (RL) is bear out. Principles and concepts of RL are analyzed so as to manage Solid Wastes (SW), specifically E-Wastes (EW) and concepts and methods of RL design networks of previous literatures are studied to draw gap.

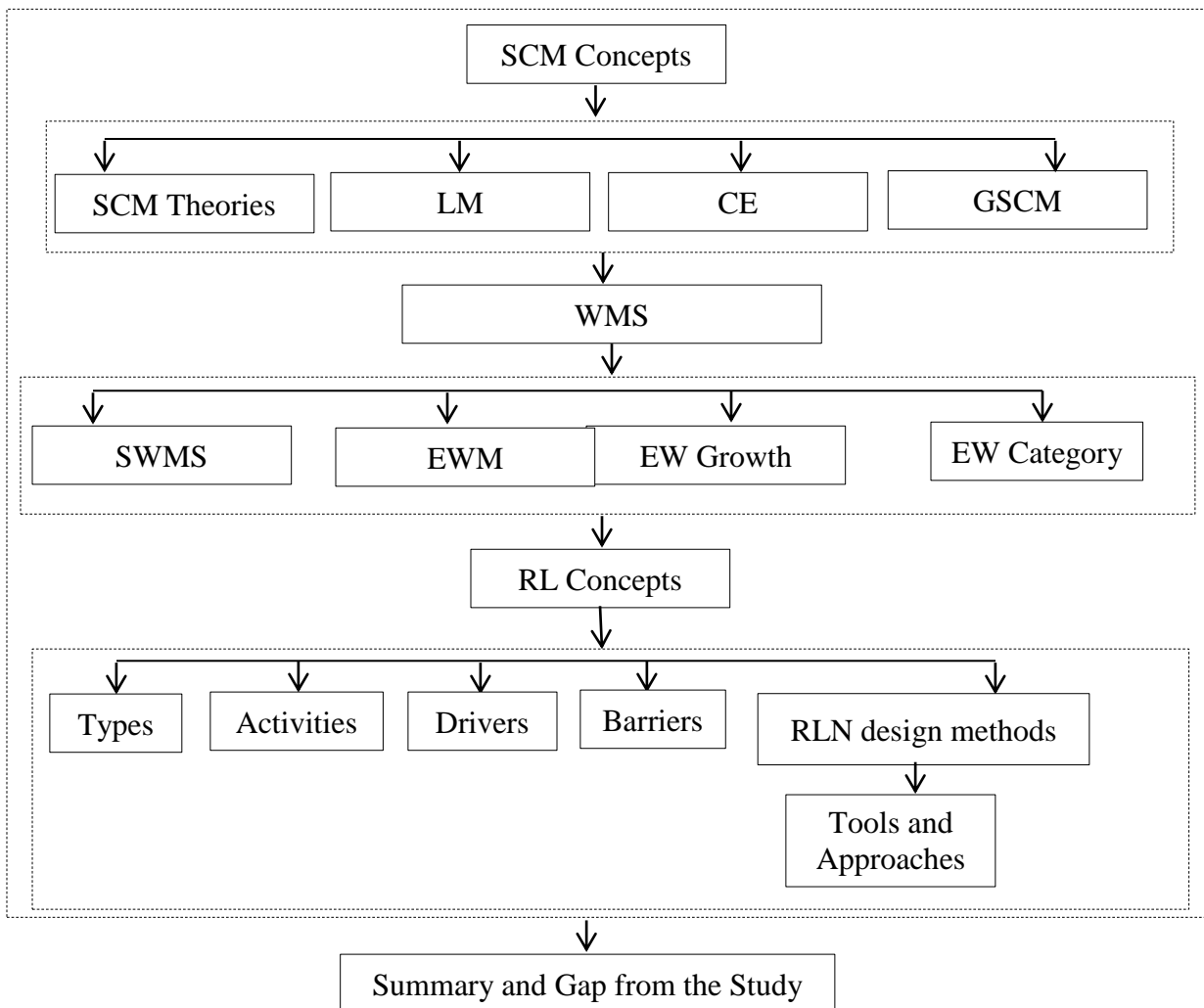


Fig. 2. 1: literature review methodology flow chart

An in-depth review of literatures was completed to lay groundwork for the research and identify potential gaps in the literature. In an effort to be as thorough as possible, the research analyzed the journals in logistics, operations management, information systems, environmental economics, and management.

**Journal selection:** Due to its diversity of operations and activities, the reverse logistics process spans across a number of different research fields. The process operates within the supply chain domain, but it has facets of production planning, scheduling, transportation networks, information collection and transmittal, recycling, hazardous materials disposal and handling, management support for resource allocation, training and education of personnel, and customer service. To ensure comprehensiveness top academic journals in the fields of logistics, operations management, information systems, environmental economics, and business management were examined.

**Criteria for article selection:** The selection of articles was not limited to empirical based research only. Because of the nature and immaturity of the reverse logistics field, all types of research papers were included, such as conceptual or framework building articles. The literature search was limited to reverse logistics, product recovery, and green logistics. The reverse logistics concept in the varying journals and disciplines were reviewed. Each article was analyzed to confirm that its focus was indeed on reverse logistics. Academic interest in reverse logistics has grown, an increasing number of articles are being written on reverse logistics and its impact on the supply chain.

Generally, the years, publishers and journals and number of reviewed literatures are summarized below.

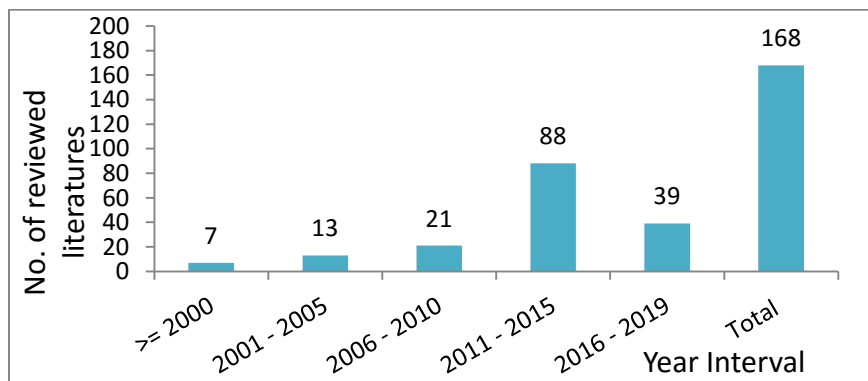


Fig. 2. 2: Number of reviewed literatures in year interval

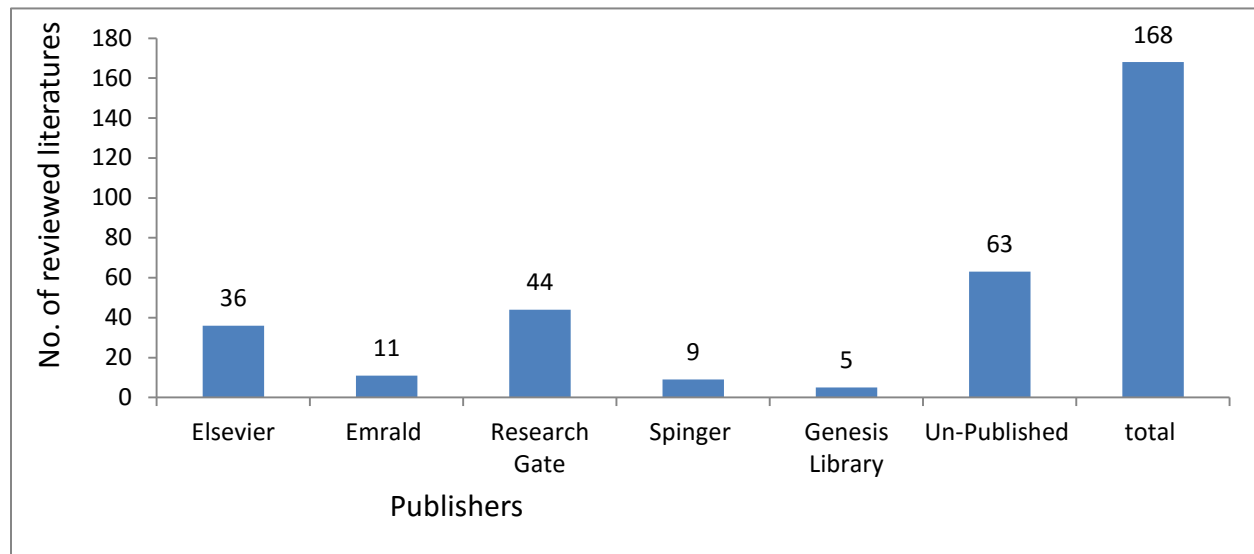


Fig. 2. 3: Number of reviewed literatures from common publishers

## 2.2. Supply chain Management system Concepts

In today’s globalized era with increasing competition, supply chain managers are facing many new challenges as complexities in it are increasing and advancement in technical and functional aspects of it is rapidly taking momentum. Supply chain management system (SCMS) is the management of linkage of interactions within an organization, interdependent companies and small business entities comprising of suppliers of raw materials, procurement, manufacturing processes, logistics, advertisement, and other associated systems, that stimulates the onward and inverse flow of materials services, investments and information from the producer to final consumer, with the aim of adding value, increase profitability through efficient processes, and achieving customer satisfaction (Rabiu & Aliyu, 2018). It is the Perspectives of managing flow and information from a company’s suppliers through the company’s operations and then on to its customers (Santosh & Khadse, 2018), (Jack Van, 2014).

SCMS is well developed through performance indicators which establish benchmarks and assess changes over time. Supply Chain Operations Reference, (SCOR) model developed by the Supply-Chain Council (SCC) set standards for SCM by providing an integrated, heuristic approach for supply chain improvement via (i) the modeling of business processes, (ii) the definition of SCM metrics for evaluating the supply chain and rapidly identifying high value

opportunities and (iii) the identification of best practices to provide a candidate list of improvement options (Lambert & Martha, 2000).

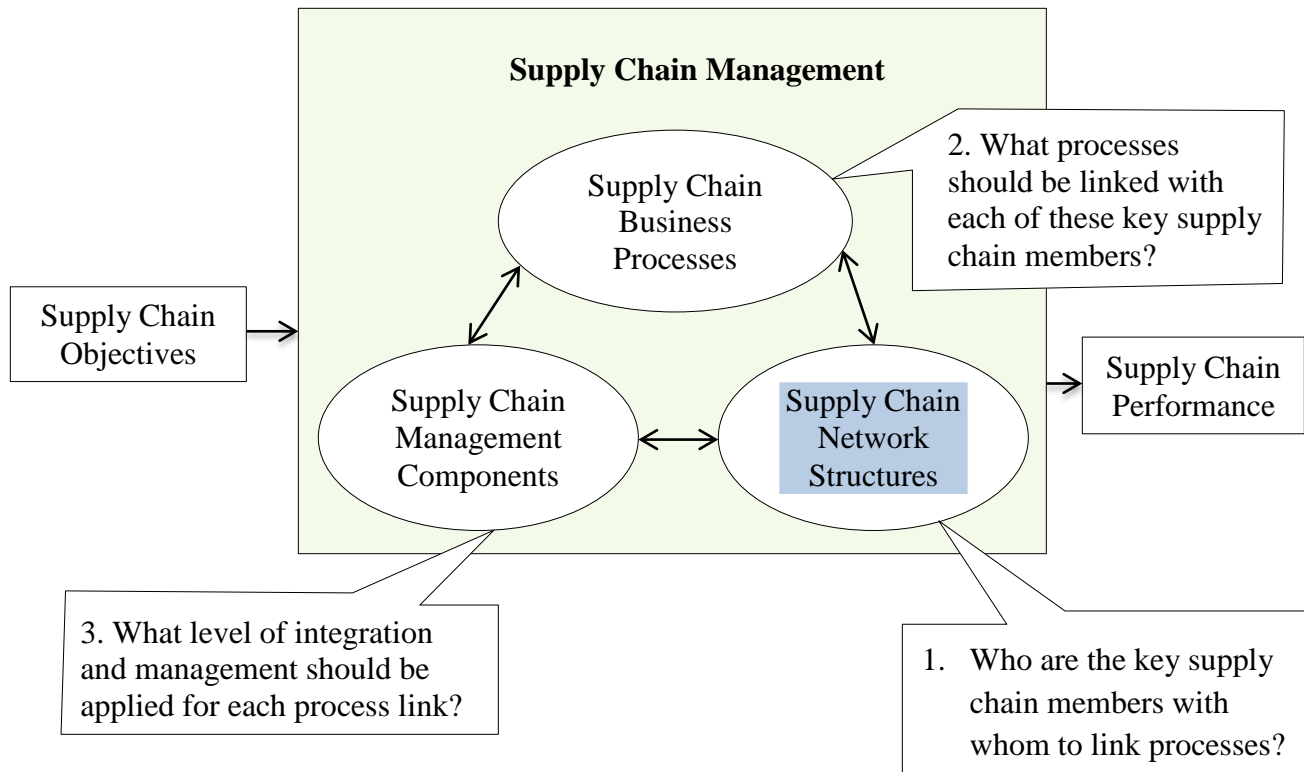


Fig. 2. 4: Key decisions in SCM

### 2.2.1 Supply Chain Management Theories

Evidence from the literature shows that researchers (Miles & Snow, 2007) and (Shook, Adams, J., & Craighead, 2009) have called for greater application of organizational theories to explain, describe and predict complex organizational behaviors in the supply chain management (Lavassani, Movahedi, & Kumar, 2009) have studied the roots of different organizational theories or views. This theory is in contrast with shareholder view of the organization, which indicates that the responsibility of organization is defined in regards with its shareholders and specifically to increase organizational shareholders profitability (van den Berg, Braun, & Otgaar, 2004). Moreover, many researchers have provided “normative justifications for stakeholder theory” (Phillips, Freeman, & C, 20013).

Table: Application of Organizational Theories in Supply Chain Management Studies (Kayvan & Bahar, 2010)

Table 2. 1: Theories of SCM

Theories	Theory in describing SCM studies
Transaction Cost Analysis	Provision of intra-organizational level guidelines, Attention to indirect costs; Addressing personal and human relations among actors in the supply chain.
Resource-based view	Value creation through collaboration; Propose strategies for organizations to acquire the resources; Intangible resources. Multi-party relationships with open system view
Knowledge-based View	Value creation through collaboration, Multi-party relationships with open system view
Strategic choice Theory	How organizational processes should function (vs. What governance structure and political forces should be), Mechanism to explore and identify stakeholders
Agency theory	Dynamic view of stakeholders, Mechanism to explore and identify stakeholders
Institutional theory	Shaping organizational strategies is mostly influenced by “external pressure”; hence over the time organizations become homogeneous
Systems Theory	Dominant of functional view of operations
Network Perspective	Describing more mature integration mechanisms beyond networking

### 2.2.2 Logistics and Logistics Management

In today’s World, it has been realized that concept of logistics is not only about physical distribution; also a connective and integrative function (Tek & Karaduman, 2012). “Logistics; the process of planning, implementing, and controlling procedures for the efficient and effective transportation and storage of goods including services, and related information from the point of origin to the point of consumption for the purpose of conforming to customer requirements (Ghiani, 2013) which is a part of supply chain management that plans, implements, and controls

the efficient, effective forward and reverses flow and storage of goods, services, and related information between the point of origin and the point of consumption in order to meet customers' requirements (Council of Supply Chain Management Professionals, 2015).

### 2.2.3 Circular Economy

Circular Economy (CE) is a concept that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value, distinguishing between technical and biological cycles (Eva & Benny, 2019). CE incorporates some activities, such as collect, maintain, reuse/redistribute, refurbish/remanufacture and recycle which maximize design for reuse to return to the biosphere and retain value through innovations across fields (Nicolò & Marcello, 2018). CE principles applicable to activities which include economical optimization – minimum number of contaminated product and pollution during refurbish activities; and waste elimination, it indicates to minimize the products that cannot be reused (Ip-Shing, Benny, & Eva, 2016).

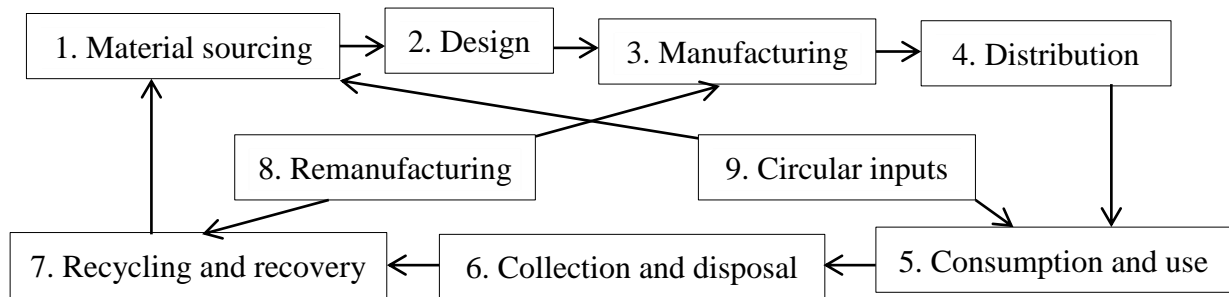


Fig. 2. 5: Resource flows through circular economy, sources: (Yuliya, Madumita, & Leonardo, 2018)

### 2.3.7 Green Supply Chain Management

Green supply chain management is not just about considering environment in supply chain decision making processes, but also about productivity and making more profit (Farahani, Asgari, & Davarzani, 2009). Green (sustainable) supply chain management (GSCM) is the ‘alignment and integration of environmental management within supply chain management’ (Klassen & Johnson, 2004). It is based on the recognition that an individual firm’s environmental impact extends well beyond its corporate boundaries.

The origins of GSCM can be traced back to two functional areas in which companies’ environmental responsibilities interfaced with external agencies: green purchasing/supply and reverse logistics (McKinnon, Browne, & Whiteing, 2012). Green supply chain can be explained as a whole interaction of green procurement, green manufacturing, green distribution/marketing and reverse logistics (Büyüközkan & Vardaroğlu, 2015).

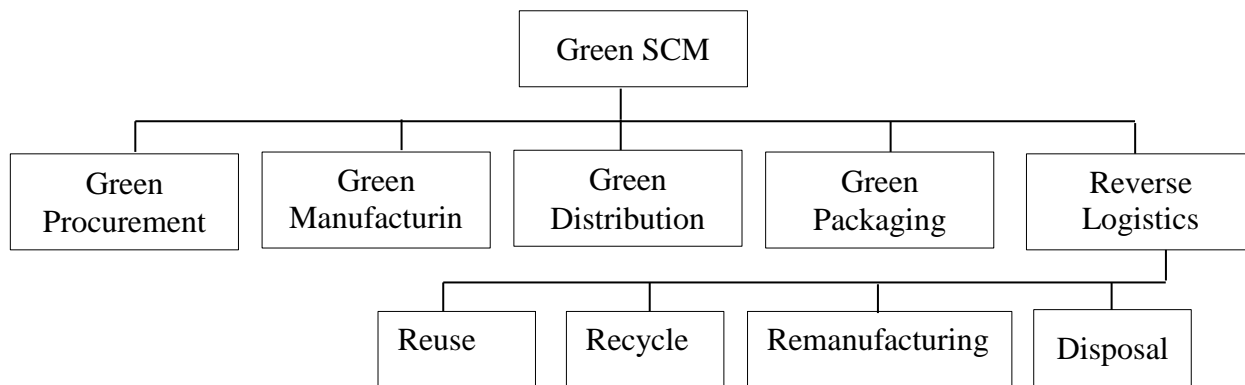


Fig. 2. 6: Sustainable Supply Chain Management

UK Institute of Logistics, defined logistics as ‘the movement of materials from the earth through production, distribution and consumption back to the earth’. This incorporates the return of waste product and packaging for reuse, recycling and disposal, an activity that is now regarded as a key part of green logistics. This fundamentally transformed the logistics of waste management and stimulated research interest in the return flow of product back along the supply chain (McKinnon, Browne, & Whiteing, 2012).

## 2.4. Overviews of Solid Wastes Management System

Exponential growth of population and urbanization and the development of social economy, coupled with the improvement of living standard, have resulted in an increase in the amount of MSW generation throughout the world. Recent estimates suggest that the MSW generation globally exceeds 2 billion tons per year, which is a potential threat to environmental dilapidation. On average the developed countries typically generate 521.95–759.2 kg per person per year (kpc) and 109.5–525.6 kpc typically by developing countries (Tanmoy, Bhagat, & Pradip, 2012). According to Environmental Protection Authority (EPA) and World Bank study conducted in

2004, per capita amount of waste generated in Ethiopia ranged from 0.17 to 0.48 kg/person/day for urban areas to about 0.11 to 0.35 kg/capita/day for rural areas.

Waste production has increased exponentially over the years (Hao Yu, 2016) and continues to show an upward trend (Samantha E. Cruz-Sotelo, 2017), scholars as well as municipalities and private companies have researched ways to improve the efficiency of dealing with waste by optimizing waste management processes (Pop, 2017) and making adjustments to the ways resources are used and product systems are created (Parajuly & Wenzel, 2017).

Waste management challenges range from reducing generation of waste, separation, change of habits, collection, transport, treatment, reuse and disposal of the waste (Kassaye, 2018), (Gidarakos, Havas, & Ntzamilis, 2016). European directives on waste management promote programs that focus on reducing waste volume, the valorization of waste, the optimization of waste disposal, and the reduction of its impact on the environment (Salvia, Cosmi, Macchiato, & Mangiamele, 2012). In most countries, the waste management process is the responsibility of municipalities (Tınmaz & Demir, 2016).

Solid waste management is advantageous from the sustainable perspectives of Socio-economic, Environmental, health and Ecological. In many of the cities in Ethiopia the municipality administration is responsible for waste collection. Though, there is a wide variation in performance in relation to waste collection in cities of Ethiopia, it has become a common business practice to have household waste to be pre- collected by individuals who are organized through formal or informal association. The pre- collected waste is then transferred into containers which are then collected by municipalities. Nevertheless, the system is not sufficient and well-organized for the generated solid wastes.

About 20% to 30% of the waste generated in Addis Ababa remained uncollected and made the city environment aesthetically unpleasant and affected the city's public health (Mesfin & Meine Pieter, 2014).

### 2.4.1 Waste management hierarchy

Solid wastes must be managed so as to mitigate its potential negative impact on the environment and human health, sustainable and zero-waste societies should be pursued, in accordance with circular-economy principles (UNEP, Waste - Investing in energy and resource efficiency, 2011) and (VanEwijk & Stegemann, 2014).

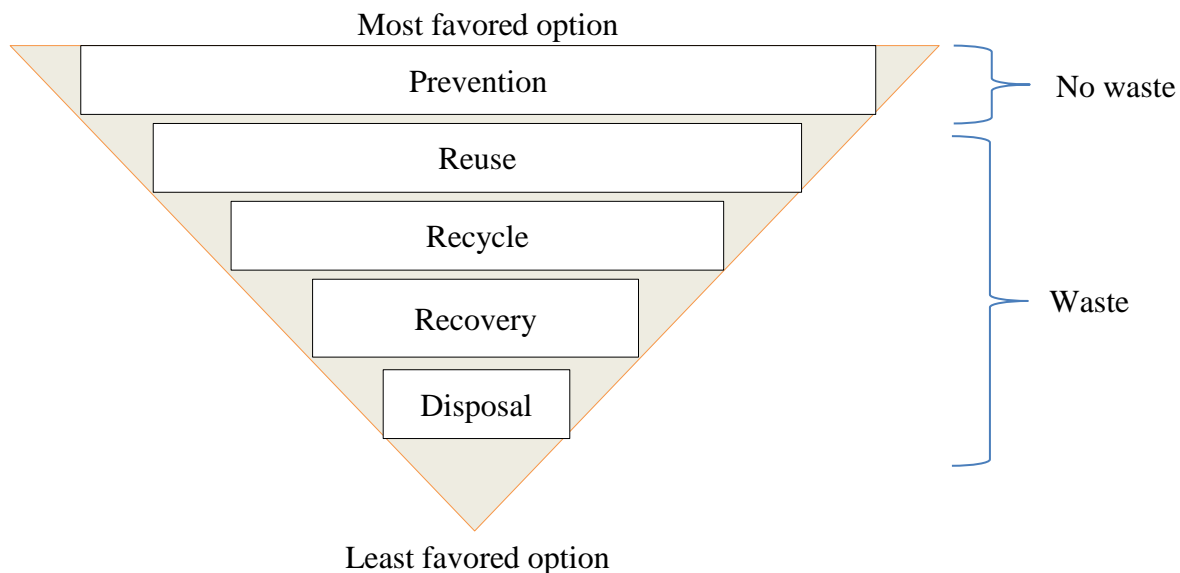


Fig. 2. 7: waste management hierarchy, source: (Katia, Rita, & Bianca, 2016)

**Prevent:** - a process of preventing production of wastes at the sources and managing the generation undesirable items at source. Waste prevention measures have the potential to raise the awareness of the community and other stakeholders, control the generation of waste, and improve the quality of recyclable resources (David, Ljiljana Rodic, & Reka, 2015).

**Reuse:** is the process of collecting used materials, products, or components from the field, and distributing or selling them as used. Thus, although the ultimate value of the product is also reduced from its original value, no additional processing is required (McKinnon, Browne, & Whiteing, 2012).

**Recycling:** is the process of collecting used products, components, and/or materials from the field, disassembling them (when necessary), separating them into categories and processing into recycled products, components, and/or materials. In this case, the identity and functionality of the original materials are lost (Thierry, Salomon, Nunen, & Wassenhove, 1995).

**Recovering:** Most of the materials thrown in the garbage can be used and processed in ways other than being destroyed. Reusing, recycling and composting are the most frequently used methods for recovering waste. Another alternative is recovering the energy stored in residual material (Inderfurth & van der Laan, 2001).

**Disposal:** includes consideration of materials and transportation requirements of materials that will be used in a product. The issues of a product's biodegradability and toxicity will play a large role in this design phase. The appropriate technological tools and equipment for incorporating design for disposal need to be determined (Sarkis, 1998).

#### 2.4.2 E-wastes Management Systems

The world is producing electrical and electronic waste more than ever before. Today, with rapid technological advancement and economic development, the manufacturing of electrical and electronic products has become one of the most rapidly developing and growing industries (Goosey, 2014). This growth has significantly altered the lifestyle and consumption pattern of human beings (Achillas, Vlachokostas, & Baniyas, Optimizing reverse logistics to support policy making in the case of EEE, 2010), (Yu & Solvang, 2016). According to a United Nation study, between 2009 and 2014, the global annual production of electronic waste has been approximately fixed at 42 million tones.

E-wastes – wastes from waste electrical and electronic equipment is characterized as electronic equipment that is considered to all segments or sub-assemblies that are old, outdated, non-working, broken, end-of-life (Managing E-waste in Victoria, Starting the Conversation, 2015), (E-waste Guide, 2016). Over the most recent two decades, the universal development of electronic and electrical equipment creation and consumption has been exponential. This is to a countless magnitude because of escalating market infiltration of items in developing nations and improvement of a substitution platform in advanced nations (UNEP, E-Waste: Inventory Assessment Manual. United Nations Environment Protection, 2007).

### 2.4.3 E-Waste growth

E-waste is growing at a rapid pace and will likely continue to grow. Although e-waste is a small portion of the total world waste, about .01 to 3 percent of the total. A report entitled “E-Waste Recycling and Reuse Services Worldwide” found that the market for recycle and reuse services jumped from 6.2 to 6.8 billion from 2009 to 2010 and is expected to grow to more than triple by 2020. In the United States, Americans dispose of 47.4 million computers, 27.2 million televisions, and 141 million mobile devices annually, according to the latest figures from the Environmental Protection Agency’s report on Electronics Waste Management in the United States, and surprisingly, only a quarter of all those devices are collected for recycling. (Dagan, Dubey, Bitton, & Townsend, 2017), (Karn, Kuiken, & Otto, 2013)

In the United States, recyclers sent 70 to 80 percent of e-waste to developing countries in Africa and Asia. Developing countries are likely facing the ramifications of the lack of proper recycling due to the flow of e-waste to them from more developed countries. They are also suffering from the lack of technology for discarding e-waste properly, a lack of legislation, and lack of proper enforcement of legislation that does exist. The world’s e-waste reached a staggering 44.7 million metric tons in 2016 -- up 3.3 Mt or 8 percent from 2014.

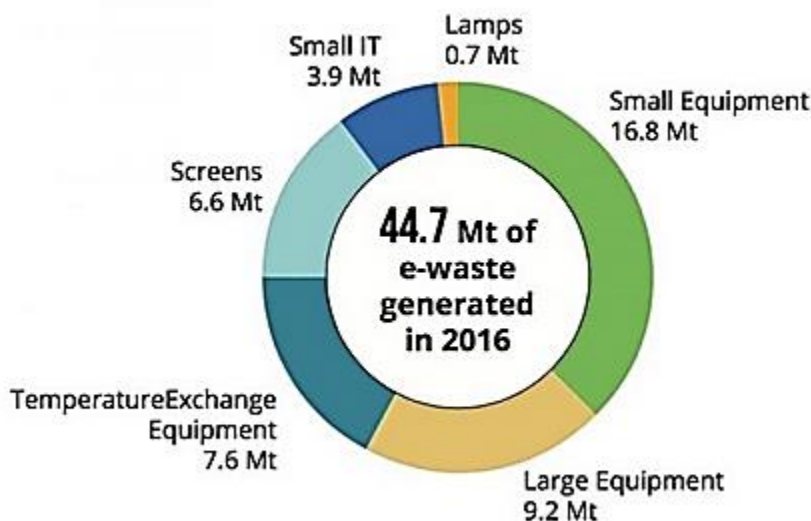


Fig. 2. 8: Global E-waste Monitor 2017, source: (Baldé, Forti, Gray, Kuehr, & Stegmann, The Global E-waste Monitor, 2017)

The global quantity of electronic waste in 2014 was mainly comprised of 12.8 million metric tons of small equipment, 11.8 million metric tons of large equipment and 7 million metric tons of temperature exchange equipment. The amount of e-waste is expected to grow to almost 50 million metric tons in total by 2018, with a growth rate of 4 to 5 percent year-to-year according to world’s statistics.

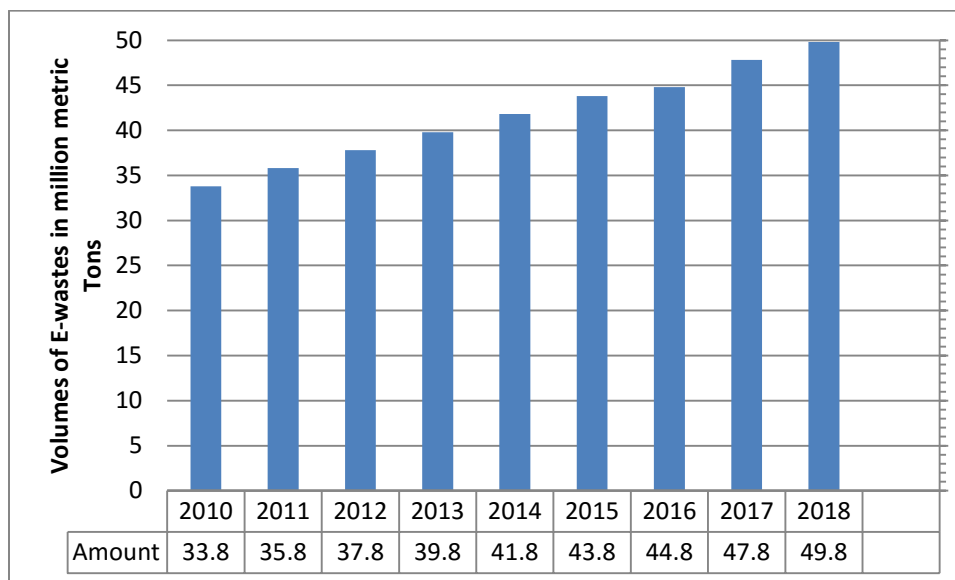


Fig. 2. 9: Globally generated e-wastes from 2010 – 2018

The difference of e-waste generated in developed versus developing countries is quite large. The richest country in the world in 2016 generated an average of 19.6 kg/inh, whereas the poorest generated only 0.6 kg/inh.

Table 2. 2: E-waste generation and collection per continent

Indicators	Africa	America	Asia	Europe	Oceania	Ethiopia
Countries in region	53	35	49	40	13	---
Population (million)	1,174	977	4,364	738	39	19116
WG (Kg/inh)	1.9	11.6	4.2	16.6	17.3	
Indication WG (Mt)	2.2	11.3	18.2	12.3	0.7	49 Kt
Documented to be collected and recycled (Mt)	0.004	1.9	2.7	4.3	0.04	---
Collection rate (in region)	---	17%	15%	35%	6%	---

Source: (Baldé, Forti, Gray, Kuehr, & Stegmann, The Global E-waste Monitor, 2017)

### 2.4.4 Categories of e-wastes

Table 2. 3: Categories of e-wastes Source: (E-waste Items that will be collected)

Types of E-waste	Examples of Equipment
ICT and Telecommunications equipment	Mainframes, Printers, Personal computers (CPU, mouse, screen and keyboard included), Laptop computer, Networking equipment, Scanners, Mobile phones, CD/ DVDs / Floppy Disks, UPSs, Radio sets, Television sets, Video cameras, Video recorders, Hi-fi recorders, Audio amplifiers and Musical instruments, LCD/ TFT screens
Office electronics and Photocopying equipment	Electrical and electronic typewriters, Pocket and desk calculators, Facsimile and Telephones
Large Household Appliances	Refrigerators, Freezers, Washing machines, Dish washing machines, Cooking equipment, Microwaves, Electric heating appliances, Electric hot plates, Electric radiators, Electric fans, Air conditioner appliances, exhaust ventilation and conditioning equipment, large appliances for heating beds, rooms and seating furniture, Televisions
Small Household Appliances	Vacuum cleaners, Carpet sweepers, Water dispensers, Toasters, Fryers, Appliances for hair-cutting, hair drying, brushing teeth, shaving and massage; Electric knives, Clocks, Appliances used for sewing, knitting and weaving
Consumer Equipment	Equipment for turning, milling, sanding, grinding, sawing, cutting, shearing, drilling, punching, folding, bending or processing wood, Metal and other materials. Tools for riveting, nailing or screwing or removing rivets, nails, screws or similar uses, Tools for welding, Soldering or similar use. Tools for mowing or other gardening activities
Toys, leisure and sports equipment	Electric trains or car racing sets, Hand-held video game, Video games, Computers for biking, diving, running, rowing, etc., Sports equipment With electric or electronic components.
Medical equipment	Scanners, Operating equipment, Stethoscopes, Radiotherapy equipment, Cardiology, Dialysis, Pulmonary ventilators, Nuclear medicine equipment, Laboratory equipment for in-vitro diagnosis, Analyzers, Freezers, Fertilization tests. Other appliances for detecting, preventing, monitoring, treating, alleviating illness, injury or disability

Monitoring and Smoke Detectors	Heating regulators, Thermostats, Measuring, control instruments weighing or adjusting appliances for household or as laboratory equipment and other monitoring and control instruments used in industrial installations (e.g. in control panels)
Batteries	Lead Batteries, telecommunication & server batteries, telephone & Laptop Batteries
Wires and Cables	All Type of Plastic insulated Wires and Cables

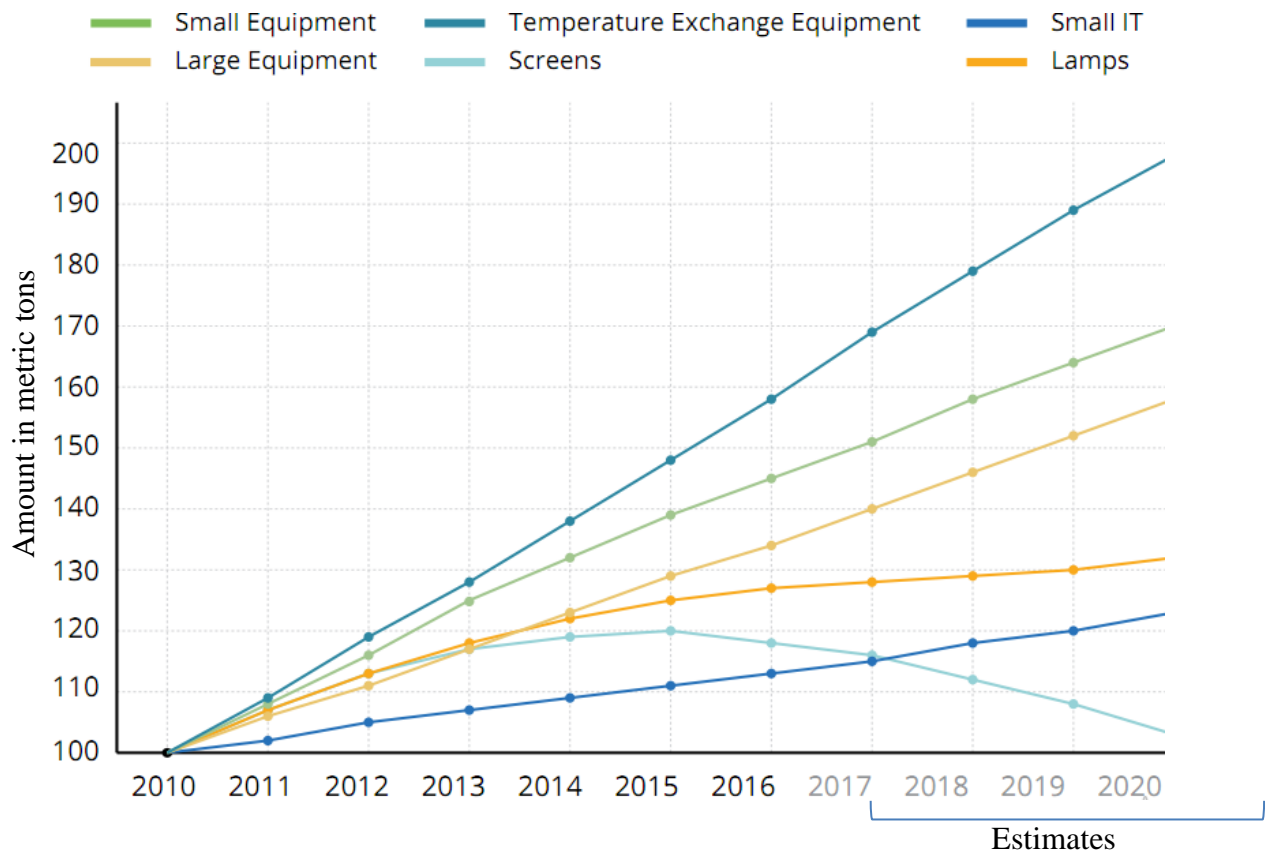


Fig. 2. 10: E-waste growth rates per category, source: (Baldé, Forti, Gray, Kuehr, & Stegmann, The Global E-waste Monitor, 2017)

#### 2.4.4.1 E-waste Category – Desktop computer

The lifespan of many electronic goods has been substantially shortened due to advancements in electronics, attractive consumer designs, marketing, and compatibility issues. For example, the average lifespan of a new computer has decreased from four and half years in 1992 to an estimated two years in 2005 and is further decreasing (Widmer, Oswald-Krapf, Sinha-Khetriwal, Schnellmann, & Böni, 2005) resulting in much greater volume of computers for either disposal or export to developing countries. Desktop computer cases and monitors are some of the most recyclable pieces of electronics in the waste stream today. As more consumers move toward mobile computing with laptops, tablets and other mobile devices, many desktop computer models are becoming obsolete (Takanori, Ryuichi, Youichi, Minoru, Yasuhiro, & Takao, 2009). The United States Environmental Protection Agency (USEPA) reported that about 0.423 million tons of waste computers, 0.595 million tons of waste monitors, 0.29 million tons of waste hard drives, 0.067 million tons of waste keyboards and mice were generated in 2010 in the USA, of which approximately 40 wt.% of computers, 33 wt.% of monitors, 33 wt.% of hard drives, 10 wt.% of keyboards and mice were recycled.

Most of the waste computers in the USA are sent to landfills or incineration process, which releases materials such as lead, mercury, or cadmium into the soil, groundwater, and atmosphere, thus having a negative impact on the environment. (USEPA, 2011). Computer parts contain many toxic substances like dioxins, polychlorinated biphenyls, cadmium, chromium, radioactive isotopes and mercury. A typical monochrome computer monitor may contain more than 6 wt.% lead, much of which is in the lead glass of the cathode ray tube (CRT). A typical 15 inch computer monitor may contain 1.5 pounds (1 kg) of lead. PCBs contain considerable quantities of lead-tin solders that are more likely to leach into groundwater or create air pollution due to incineration (Leung, Duzgoren-Aydin, & Cheung, 2008).

Table 2. 4: Material composition of dismantled DCs (Razi, Khandakar, & Habib, 2016)

Name of the components	Weight (g)	Weight (%)
Metals (outframes)	6571	49.8
Plastic	306	2.3
Screws	44	0.3
Mother board	817	6.2
Graphics card	109	0.8
Memory Modules	2595	19.7
CPU	251	1.9
CD drive	338	2.6
Floppy and hard drive	924	7.0
Wires	104	0.8
Power boards	1146	8.7
Total	13,205	100

#### 2.4.5. E-Waste Generation Forecasting

There are quite a few studies that aimed to estimate the e-waste generation rate or specifically the return stream. (Yu, Williams, Ju, & Yang, 2010) used material flow analysis to estimate and compare the return stream of obsolete computers in developed and developing countries. (Wang, Huisman, Stevels, & Bald, 2013) studied the impact of input data on the estimation of return stream. (Ara ujo, Magrini, Mahler, & Bilitewski, 2012) claimed that the dominant factor that should be used to estimate the e-waste stream is the product life span. In a recent study, (Petridis, Stiakakis, Petridis, & Dey, 2015) used several forecasting techniques to estimate the e-waste stream quantities in different regions. Their study reveals that a drastic increase will be observed in the e-waste generation rate in the U.S. and UK. Similar efforts have been made on case studies in Czech Republic (Polak & Drapalova, 2012), China (Zhang, Yuan, & Bi, 2011), the United States (Yang & Williams, 2009), , and India (Dwivedy & Mittal, 2010).

## 2.5. Reverse logistic concepts

### 2.5.1. Definitions of Reverse Logistics

Reverse Logistics Association (RLA) defines RL as "all activities associated with a product/service after the point of sale, the ultimate goal to optimize or make more efficient after market activities, thus saving money and environmental resources". RL is defined by The Council of Logistics Management as: The process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal. More precisely, reverse logistics is the process of moving goods from their typical final destination for the purpose of capturing value, or proper disposal (Güldem & Fevzi, 2011), (Richard & Tarin Jenelle, 2012).

While the forward supply chain concerns the flow from raw materials to end products and from manufacturer to consumer (Govindan K. H., 2015), reverse logistics (RL) concerns the reverse flow, from consumer to manufacturer. RL is 'the process of moving goods from their typical final destination for the purpose of recapturing value, or proper disposal' (Rogers D. S.-L., 2001). Definition by the Reverse Logistics Executive Council (RLEC) is used which states "Reverse logistics is a movement of materials from a typical final consumption in an opposite direction in order to regain value or to dispose of wastes. This reverse activity includes take back of damaged products, renewal and enlargement of inventories through product take back remanufacturing of packaging materials, reuse of containers, and renovation of products, and handling of obsolete appliances. (Hansen, Larsen, Groth, & Ghosh, 2018), (Jefferson, Robert, & Edward, 2009), (Nouri, Cory, & Mohamad, 2014).

Reverse logistics consists of all activities such as management, process, reduction and disposal of hazardous and non-hazardous wastes, packaging and product usage (Elif, Nevin, & Adil, 2012). Due to the diversity of products in the reverse flow, there are various alternatives of reverse logistics activities namely as; reutilization, repair, renovation, reprocessing, cannibalization or recycling (M.Şükrü & Aysen, 2012). RL has been defined in numerous ways by various authors.

### 2.5.2. Types of Reverse Logistic System

Generally, there are two types of RL systems, which is confidential based on the degree of the openness and in its nature of the network type.

1. Closed loop RL system
2. Open loop RL system

#### 2.5.2.1. Closed loop system

According to (Bupe, Charles, & Arnesh, 2017) reviews, closed loop system is a process in which the waste or by product of one process or product is used to returned for other products in order to making another product or derived component in its theory.

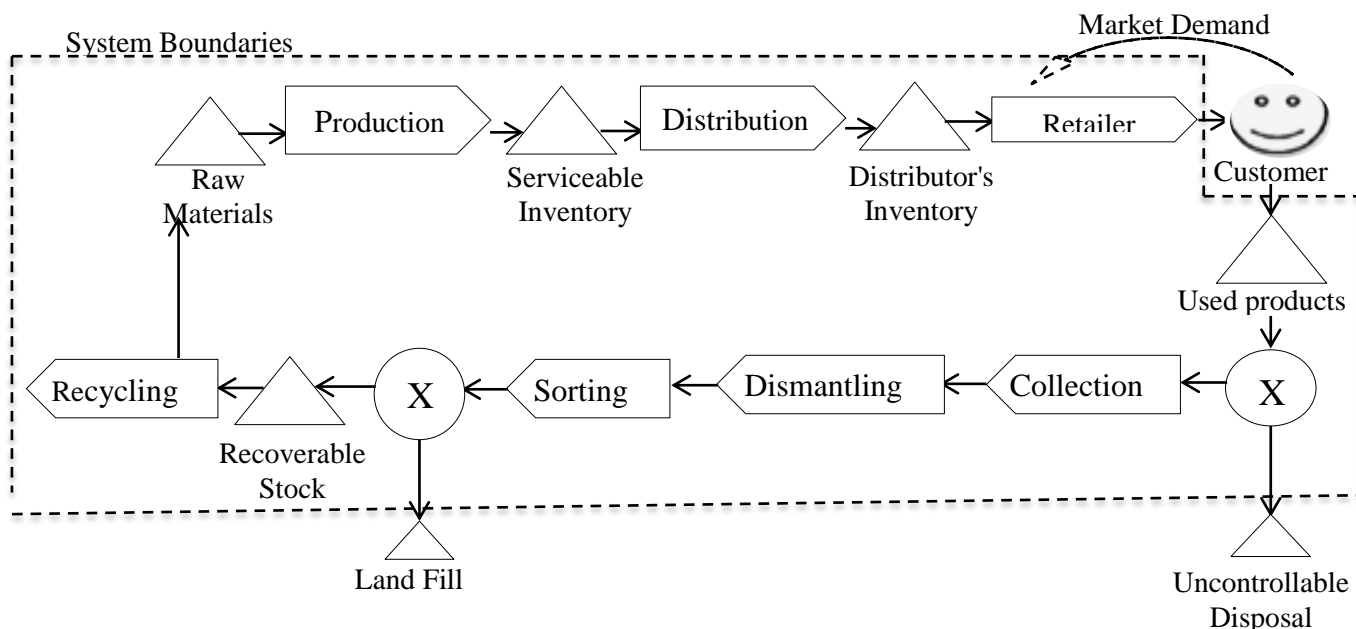


Fig. 2. 11: Closed loop reverse logistic system, source: (Samir & Rajiv, 2006) and (Getu, 2018)

#### 2.5.2.2. Open loop system

In this case, it is a process in which recycling system for the product made from one type of material is recycled into a different type of product. This occurs normally in postconsumer materials. In this process, different products and manufacturers may be involved.

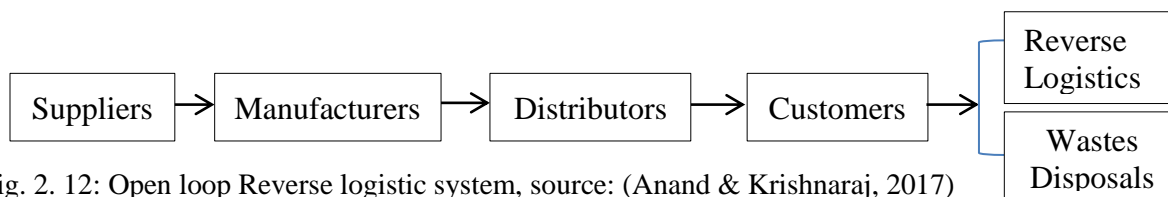


Fig. 2. 12: Open loop Reverse logistic system, source: (Anand & Krishnaraj, 2017)

### 2.5.3. Reverse Logistics Activities

(Ilyas, Thomy, Genial, & Ferry, October 2018) Divided RL activities into two parties which are involved in the process of moving products back from a supply chain namely the returner and receiver. The returner party is involved with product recall or value recovery, which are actively related to the consumers of a product, while the purpose of the receiver party is to make a profit and social pressure. The activities of the returner party include reselling, redistributing, reusing, reprocessing and recovering value (Marcelo, 2013).

According to (Tibben & Rogers, 2003) differentiated between reverse logistics activities for products and packaging. For products, the common reverse logistics activities are: refurbishing, re-manufacturing, recycling, reclaiming materials, returning to supplier, salvaging and disposing in landfills (Zailani, Suhaiza, & Hanim, 2001) and (Christensen, 2002).

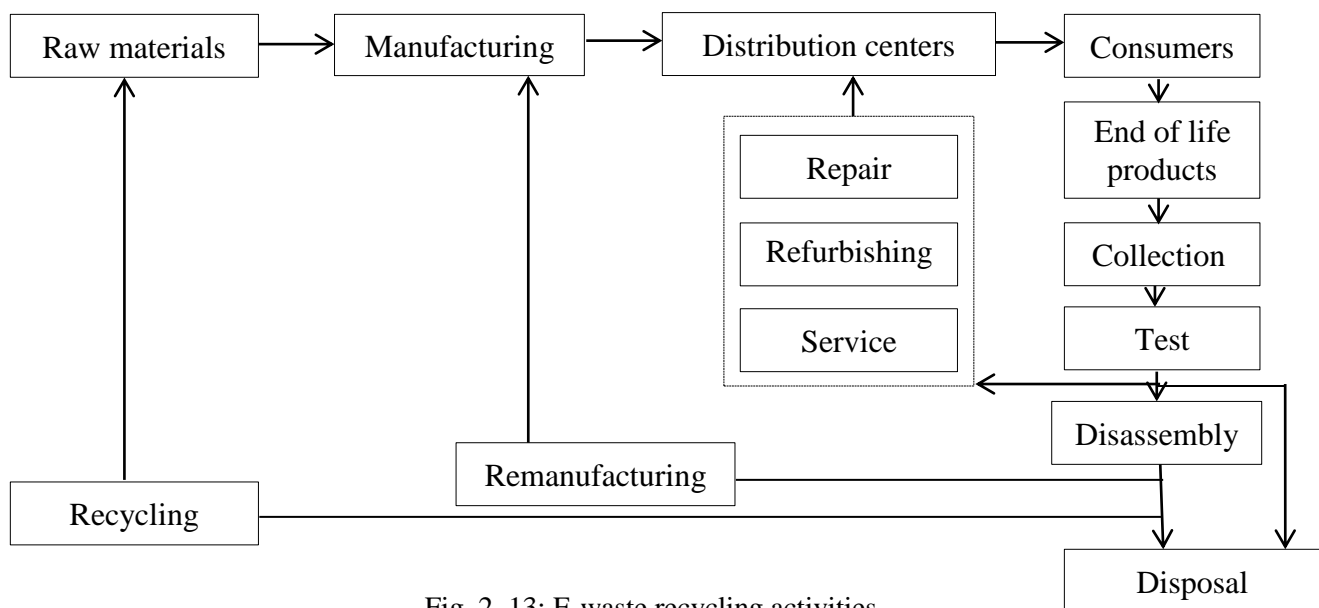


Fig. 2. 13: E-waste recycling activities

source: (Ramazan, İpek, & Ali Ekber, 2014).; (Ilyas, Thomy, Genial, & Ferry, October 2018)

### 2.5.4. Drivers of Reverse Logistics

Organizations generally become involved in reverse logistics because they can profit from it or they do not have a choice because of environmental legislation and laws, or they feel socially impelled (De Brito, Dekker, & Flapper, 2005). Evolving financial, competitive and customer pressures as well as increasingly complex environmental regulations compel organizations to engage in reverse logistics processes (Partida, 2011).

Reverse logistic always starts with the movement of products from the user to the producer (Arnesh, 2017)). The sustainable supply chain management (SSCM) concerns the management of material, information and data, capital flows and collaboration and integration among companies along the supply chain, working towards achieving the three drivers of sustainable transport namely: economic, environmental and social factors for ensuring that both customer and stakeholder requirements are met (Sebonkile, 2017).

#### **2.5.4.1. Internal drivers**

##### **2.5.4.1.1. Economic drivers**

Internal drivers of RL practices relate to the factors that motivate the organization to have an RL operation, by increasing revenue and profit through cost-saving initiatives (Hsu, Tan, & Mohamad Zailani, 2016). Recapturing the value of returned products through reuse and recycling serves as a revenue enhancement opportunity for organizations (Govindan, Soleimani, & Kannan, Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future, 2015), (Huang, Song, Lee, & Ching, 2013), (Marchi, Maria, & Micelli, 2013) and (Larsen & Jacobsen, 2016). The second-hand market also offers cost-saving opportunities, as product returns can be sold to consumers at lower prices after being returned, reducing those products' potential lost cost (Rogers, Melamed, & Lembke, Modelling and analysis of reverse logistics, 2012).

##### **2.5.4.1.2. Competitive drivers**

RL practices allow the organization to remain competitive by reducing inventory levels through product recovery, thus reducing the organizations' inventory carrying costs (Barcos, Barroso, Surroca, & Tribó, 2013). In a highly commoditized industry, using recycled inputs will allow the organizations to lower the cost of products and remain competitive in the industry, while satisfying customers through lower prices (Mafakheri & Nasiri, 2013). RL practices such as reuse, remanufacturing and recycling allow organizations to improve their image among customers, by maintaining an environmentally sustainable image (Chan, Chan, & Jain, 2012). According to (Zhou, Wen-hui, Dian-yan, & Yu-ying, 2011), customers may show an

organization preference when they have environmentally sustainable practices over the organizations that do not perform such RL practices.

#### **2.5.4.1.3. Operational performance drivers**

By effectively managing RL practices, organizations can reduce transportation, waste disposal as well as inventory carrying costs. Returned products that are reinserted into the forward flow can allow the organization to generate additional revenue, reduce operating costs and minimize the opportunity costs of disposing defective or obsolete products (Sobral, Sousa Jabbour, & Chiappetta Jabbour, 2013). The above-mentioned RL practices allow the organizations to conserve resources and lower their resource investment, thus allowing for the conservation of inputs and an overall increase in the organizations' operational efficiency (Lai & Wong, Green logistics management and performance: Some empirical evidence from Chinese manufacturing exporters, 2012). The increase in operational performance may enable organizations to gain a competitive advantage over their rivals (Lai, Wu, & Wong, Did reverse logistics practices hit the triple bottom line of Chinese manufacturers?, 2013).

#### **2.5.4.2. External drivers**

External drivers of RL focus on the triple bottom line, and typically enable the organization to enhance customer value perceptions (Stoyanov, 2012).

##### **2.5.4.2.1. Legal drivers**

It has become increasingly common for countries to enforce extended producer responsibility laws that pertain to the manufacturer's responsibility for handling the cost of disposal, collection and reuse of end-of-life products (Lamsali, Selection of return channels and recovery options for used products: doctoral thesis, 2013). Strict environmental legislation on hazardous substances, packaging waste and the recovery of packaging material are enforced to hold producers responsible for the product during the entire product life cycle (Nikolaou, Evangelinos, & Allan, 2013). Proper product disposal is essential for reducing any customer-related health issues (Aung & Chang, 2014). Defective products may harm consumers; therefore, it is critical to enforce high-quality product standards (Kapetanopoulou & Tagaras, 2011).

#### **2.5.4.2.2. Environmental drivers**

Environmental management is a key strategic issue that has the potential of impacting organizational performance (Dey, LaGuardia, & Srinivasan, 2011). Recently, a culture of consumerism ideology has contributed to a large amount of waste, thus putting stress on resource sustainability. Product recovery may reduce the effect of this ideology, by recycling or reusing products, in order to reduce the amount of packaging and waste (Arrieta, Reverse logistics as alleviation to ecological issues: Theory and implementation: doctoral thesis , 2015). Using recycled or recovered materials for inputs allows the organization to reduce polluted environment and save on energy costs (Diabat, 2011). Furthermore, reuse, recovery and effective waste management may enable the organization to improve their image, as customers are more sensitive towards environmental issues and sustainability (Zhu & Geng, 2013).

#### **2.5.4.2.3. Social responsibility and corporate citizenship drivers**

Corporate social responsibility is a professional code of conduct that is enforced because of customer pressure or stakeholder demands (Pishvae, Razmi, & Torabi, 2012). A sustainable image is essential when producing or marketing a product; thus, enforcing RL practices enables organizations to maintain a favorable public image and increase customer loyalty. Increases in governmental and societal demands for sustainability present a need for green principles to be present in every aspect of an organization (Lamsali, Selection of return channels and recovery options for used products: doctoral thesis , 2013).

### **2.5.5. Barriers to reverse logistics**

#### **2.5.5.1. Internal barriers**

An internal barrier relates to a hindrance within the organization that affects the performance of RL practices (Abdulrahman, Gunasekaran, & Subramanian, 2014).

##### **2.5.5.1.1. Lack of functional integration**

RL practices often suffer from a lack of functional communication and cooperation (Abdulrahman, Gunasekaran, & Subramanian, 2014). Internal integration builds on the premise that various functions in the organization should work collaboratively as a single entity, ensuring

that mutually acceptable outcomes are achieved and contribute to the continued success of the RL practices (Hazen, Cegielski, & Hanna, 2011). Differing views on the importance of RL are, however, shared; resulting in poor functional integration, as well as higher product return rates (Ye, Zhao, Prahinski, & Li, The impact of institutional pressures, top managers' posture and reverse logistics on performance: Evidence from China, 2013). If the functions that are involved in RL practices do not understand the end goal of RL, competing goals and objectives will be set across departments (Badenhorst, 2013).

#### **2.5.5.1.2. Top managements posture on Reverse logistics**

Top managements posture and role in the decisions ensure congruent views on RL, allowing for the appropriate resources to be dedicated to the effective performance of RL practices (Creutz & Larsson, 2012). In order to gain organizational benefits from RL practices, RL experts who are personally committed and responsible for the creation and implementation of RL strategies should be placed in the organization. (Vijayan, Kamarulzaman, Mohamed, & Abdullah, Sustainability in food retail industry through reverse logistics, 2014)

#### **2.5.5.1.3. Financial barriers**

Lack of initial capital and funds for returns monitoring systems, storage and in-house handling of returns are a major barrier to RL practices (Sharma, Panda, Mahapatra, & Sahu, Analysis of barriers for reverse logistics: An Indian perspective, 2011). Conducting RL practices are a precarious endeavor for top management, as they involve financial aspects that may impact the organization's long-term (Ganjali, Shirouyehzad, & Shahin, 2014). The information systems that are critical to track and trace product returns and recoveries are critical to the success of RL operations, but require large amounts of capital and resources to implement and maintain (Ho, Choy, Lam, & Wong, 2012). Education and training are major requirements for success in an organization; therefore, the more well-trained staff available, the greater the efficiency of the RL operation.

#### **2.5.5.1.4. Lack of sufficient information systems**

Implementing and maintaining a product return system requires strategic planning and investment in additional facilities, personnel and operating activities, which is ultimately viewed as a costly sideshow, especially if the products are not saleable afterwards. The lack of or incompatibility of information technology systems to effectively transfer product return information between the involved parties acts as a major barrier to RL practices, as the data quality and responsiveness of partners are compromised when returns have to be handled manually (Madaan, Kumar, & Chan, 2012). To ensure integrity and consistency of the RL process, an easily accessible, shared platform where supply chain partners can share information on customers, inventory and logistics is necessary (Shi, Li, Yang, Li, & Choi, 2012).

#### **2.5.5.2. External barriers**

An external barrier refers to an outside influence effecting the organizations RL practices, such as a government policy (Abdulrahman, Gunasekaran, & Subramanian, 2014).

##### **2.5.5.2.1. Supply chain partner integration**

Supply chain partners are said to be the motivators of RL practices, thus emphasizing the need for close, integrative supply chain relationships among partners (Ho, Choy, Lam, & Wong, 2012). External integration refers to the integration between a focal company and its external environment, and may take place at different levels of the supply chain (Cardoso, Barbosa-Póvoa, & Relvas, Design and planning of supply chains with integration of reverse logistics activities under demand uncertainty, 2013). Non-cooperation of supply chain partners to RL practices and organizational policies are one of the main barriers to RL, and if removed, the chances of effective RL practices will be much greater (Sharma, Panda, Mahapatra, & Sahu, Analysis of barriers for reverse logistics: An Indian perspective, 2011). Considerable time, money and effort are spent on developing a complex product return system that relies on supply chain collaboration and integration to perform effectively; however, poor integration between supply chain partners can result in the return system being a key cost driver (Bernon, Upperton, Bastl, & Cullen, 2013).

#### **2.5.5.2.2. Lack of accurate forecasting**

The lack of accurate forecasting between supply chain partners acts as a major barrier for RL because of the difficulties in planning for the quantities and diversity of products that need to flow through the reverse chain (Cardoso, Barbosa-Póvoa, & Relvas, Design and planning of supply chains with integration of reverse logistics activities under demand uncertainty, 2013). Product returns are the most common aspect of RL; however, they introduce uncertainty into the organization, as the timing, disposition, condition, quality and quantity of the returns are unknown. Infrequent and erratic timing patterns create organizational uncertainty, as to what will arrive daily at the facility (Shaharudin, Zailani, & Tan, 2014).

Decisions that are accompanied by accurate information play an effective role in the management and improvement of product flows, and enable a more efficient and profitable RL operation (Govindan, Soleimani, & Kannan, Reverse logistics and closed-loop supply chain: A comprehensive review to explore the future, 2015). Efficient information systems are capable of providing the end-to-end visibility that is needed to reduce forecasting uncertainty (Vijayan, Kamarulzaman, Mohamed, & Abdullah, Sustainability in food retail industry through reverse logistics, 2014).

#### **2.5.5.2.3. Government support and policy**

Government policy and financial support can play a major role in an organization's RL practices, as the lack of enforceable environmental laws established by the government reduces the incentive and motivation for organizations to perform RL practices (Ganjali, Shirouyehzad, & Shahin, 2014). A lack of tax policies and financial support from government to subsidizes RL has acted as a disincentive for organizations to invest and or collaborate in RL practices, as the products brought back into the reverse chain create high degrees of tax complexity and exposure (Abdulrahman, Gunasekaran, & Subramanian, 2014). It is therefore government policy that has the greatest external influence on an organization's RL practices (Ye, Zhao, Prahinski, & Li, The impact of institutional pressures, top managers' posture and reverse logistics on performance: Evidence from China, 2013).

RL implementation in developed nations had seen due to enforced laws and regulations on producers to take back products to recover value or dispose them after end of life (Strivastava, 2006). However it is an initial stage in developing countries and adoption is because of lack of communal pressure, less focus on environmental issues, and price sensitive market. Reverse management practices are often considered as a cost centers and are mostly performed by the un-organized segment (Jindal & Sangwan, 2011). The effective RL adoption could be done if these practices have economic and financial viability and support along with coordination and cooperation from supply chain partners and government. Due to change in current business scenario, competitive priority, technological advancement, behaviors of customers and suppliers management has to made policies and strategic planning about RL (Chandra, Mukesh, & Kaushik, 2015).

## 2.6. RL Modeling Approaches

Reverse logistics is considered as one of the most effective solutions for value recovery from end-of-life and end-of-use products (Yu & Solvang, A general reverse logistics network design model for product reuse and recycling with environmental considerations., 2016).

Compared with other used products, the reverse logistics design for e-waste management is more complicated, because waste of EEE contains not only renewable materials and components (Cao, et al., 2016), which need to be reused and recycled, but also hazardous substances (Oguchi, Sakanakura, & Terazono, 2013), which have to be properly treated or disposed of in order to minimize the risk to people's health and the environment. Therefore, the development of advanced tools for complex decision-making problems related to the design and planning of a sustainable reverse logistics system for WEEE is of paramount importance.

The generic model is used to configure regular flows in supply chain and to arrange components that realize reverse flow for product reuses including a set of elements of collectors, remanufacturers and recycler which are a generic supply chain model with a reverse logistics (Mostafa, 2016).

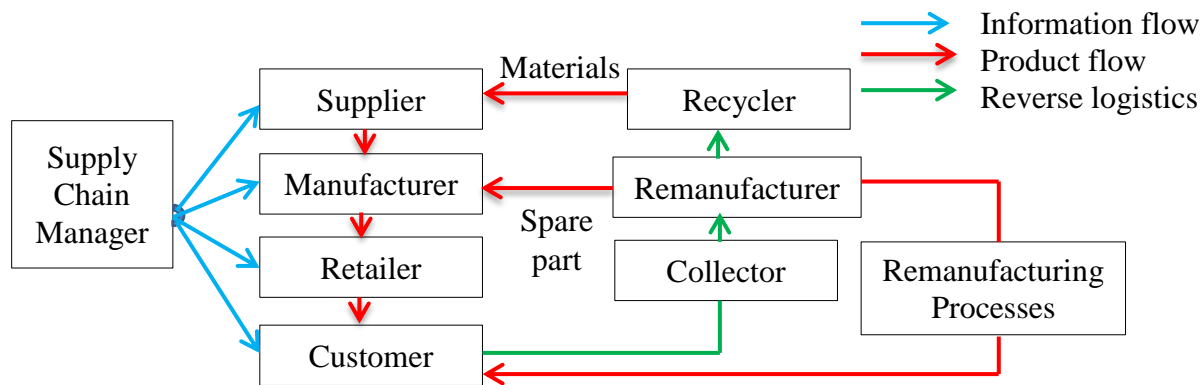


Fig. 2. 14: Generic supply chain model with reverse logistics

Basically, RLND is normally documented as a strategic supply chain issue of major importance. The location of production facilities, storage concepts, and transportation strategies are major determinants of supply chain performance (Moritz, 2001). Design of product recovery network is one of the important and challenging problems in the field of reverse logistics. The design and management of a reverse logistics network is more complex than that of forward logistics networks with direct flows (Zhongfeng, 2009). The main two factors two factors that cause these difficulties are:

- The simultaneous existence and mutual impact of the two types of flow: the possible coordination / integration and interfering constraints between forward and reverse flows must be considered
- The existence of numerous uncertainties about the return flows such as choice of recovery options, quality of return objects, quantity and reprocessing time ( Jayaraman, 2003).

According to (Ronald, 2000), product recovery is acquiring more attention recently due to sustainability and growing of environmental concerns. Therefore, due to all this fact, efficient implementation requires appropriate reverse logistic structures to be set up for the arising goods from users to producers. Reverse logistic network can be visualized indifferent perspective. Based on (Fleischmann, 2000) reviews based on the characteristics of product recovery networks by dividing them into three types (bulk recycling, assembly product re-manufacturing, and reusable items) and then classifying network characteristics within each type (e.g. dedicated

facilities, reuse in original market, mandatory recovery). So, network types depending on the disposition types of products.

(Dekker, 2004) Categorized the network types depending on the disposition types, namely re-manufacturing, recycling, and direct reuse networks. Based on (Fleischmann e. a., 1997) study, reverse logistics systems can be classified into four major categories considering types of return items. These four classes are directly reusable network (DRN), re-manufacturing network (RMN), and repair service network (RSN) and recycling network (RN).

- **Direct reuse networks (DRN):** it is design for items like pallets, container. Nothing to be done here. Just it is collect and send to the market directly for cleaning and minor maintenance if needed.it is a closed loop supply chain due to the interrelation of the forward and reverse flow.
- **Re-manufacturing networks (RMN):** which is similar with discussed above and it is also a closed-loop network. Since the re-manufacturing process implemented by original producer.
- **Recycling Networks (RN):** this process is different from the above discussed network types. Its characteristics is an open-loop network due to the operation is carried by third party specialized in the recycling process.
- **Repair service network (RSN):** defective products, such as durable goods or electronics equipment, are returned and repaired in service centers. There are few links between forward logistic and reverse logistic, so it is considered an opened-loop system.

## 2.7. Common Optimization Tools of Reverse Logistic

### 2.7.1. Stochastic Programming

Mathematical programming studies the theory and methods using random parameters with incomplete information (Ehsan, Hesamaddin, Ghomi-Avili, & Mostafa, 2015). The mathematical problems may be either descriptive problem or optimization problem. The descriptive problems help to investigate the events by processing the given information using mathematical methods. The optimization problems also help to choose an optimal solution from the set of feasible solutions. The optimization problems may be classified as deterministic problem or stochastic problems (Mostafa, 2016).

### **2.7.2. Heuristic /Approximate/ Algorithm**

Heuristic algorithm used to obtain good near optimal solution using low computation. The heuristic it is constructive algorithm method or local search algorithm method (Mostafa, 2016). Constructive algorithms are used to generate solutions by iteration process by choosing the beginning event randomly until the solution is completed. The constructive algorithms are faster but low-quality solution is obtained comparing to local search algorithms.

The local search algorithm also begins with complete solution and improves the current solution by local change continuously (Sanya, 2009).

### **2.7.3. Meta-heuristic Algorithm**

Meta-heuristic algorithm is a general purpose heuristic algorithm method designed to guide the core specific heuristic problems to search a high quality solutions (Mostafa, 2016). Meta-heuristic is a general algorithm framework which used for different optimization problem using few modifications to adapt the specific problems (Sanya, 2009).

### **2.7.4. Ant Colony Algorithm**

Ant colony algorithm is a population based-stochastic search algorithm which used to solve specific types of combination optimization problems (Mostafa, 2016). These problems are generally characterized by A set of constraints, cost function and finite sequence of components from which solution are constructed. A solution is comprised of an ordered sequence of components and a finite set of possible transition among the components (Sanya, 2009).

### **2.7.5. Genetic Algorithm**

Genetic algorithm is stochastic searching method based on the natural selection and natural genetics behavior. This is used to solve problems when there is large space search with a little knowledge. This genetic heuristic optimization method which includes tabular search simulated annealing and evolutionary strategies to obtain optimal or near-optimal solution for difficult problems (Mostafa, 2016). Genetic algorithm gives a better solution comparing to heuristic methods by selecting randomly based on natural selection process for solving both constrained and unconstrained optimization problems. Genetic algorithm and mixed integer programming algorithm can help to solve the reverse logistics problems related to location and allocation of facility for third part logistic system (Muthusamy & Ramasamy, 2014)

### 2.7.6. Fuzzy TOPSIS Method

Technique for order preference by similarity to ideal solution (TOPSIS) allows the decision maker to incorporate unquantifiable information, non-obtainable information and incomplete information (Hasan & Irem, 2014). Using TOPSIS, the best opportunity will be a value that is nearest to the positive ideal solution (maximizing benefit criteria and minimizing cost criteria) and farthest away from the negative ideal solution (Mst. Nazma, Md. Habibur, & Abdullah, 2016)The TOPSIS method uses a weight a criterion which is known precisely and that reflects values used in the evaluation procedure (Senthil, Srirangacharyulub, & Ramesh, 2012).

### 2.7.7. LINGO

LINGO is a tool that can be used to solve linear nonlinear optimization large problems in order to analyses the solution. This helps to use resources efficiently mostly inventory, time, money, machinery, staff and more (Fitsum, 2016). The LINGO solver displays the result including the model class, state, and objective, number of iterations, total variables and constraints (Alok, Sagar, Srikar, & Tiwari, 2015). LINGO solver analysis the problems to group the modeling class of the stated problem. The LINGO *Model Class* field summarizes the properties of the stated model. The main modeling class of LINGO 17 solver is shown in the table (LINGO, 2017)

Table 2. 5: Modeling class of LINGO

Model Class	Abbreviation	Description
Linear Program	LP	The model contains no integer restrictions on the variables and all expressions are linear.
Nonlinear Program	NLP	At least one of the relationships in the model is nonlinear with respect to the variables
Mixed Integer Linear Program	MILP	The subset of the variables is restricted to integer values and All expressions are linear
Quadratic Program	QP	There are no integer restrictions and all expressions are linear or quadratic
Mixed Integer Quadratic Program	MIQ	The subset of the variables has integer restrictions and all expressions are either linear or quadratic
Mixed Integer Nonlinear Program	MINLP	The subset of the variables has integer restrictions and at least one of the expressions in the model is nonlinear. Generally, this class of model is very difficult to solve for all but the smallest

		cases
Pure Integer Linear Program	PILP	All variables are restricted to integer values and all expressions are linear
Pure Integer Nonlinear Program	PINLP	All variables have integer restrictions and at least one of the expressions in the model is nonlinear. Generally, this class of model is very difficult to solve for all but the smallest cases
Pure Integer Quadratic Program	PIQP	All variables have integer restrictions and at least one of the expressions in the model is nonlinear. Generally, this class of model is very difficult to solve for all but the smallest cases
Pure Integer Quadratic Program	PIQP	All variables are restricted to integer values and all expressions are linear or quadratic
Conic Program	CP	All variables are continuous and the model is a conic (second-order cone) program
Mixed Integer Conic Program	MICO NE	A subset of the variables is restricted to integer values and the model is a conic (second-order cone) program
Pure Integer Conic (Second-Order Cone) Program	PICON E	All the variables are restricted to integer values and the model is a conic (second-order cone) program

### 2.7.8. SPSS

SPSS is a statistics tool that helps to interactive or batched statistical analysis. It has multi-layer perceptron and radial basis function neural network algorithms. The factor analysis and neural network in the SPSS are used to predict and analysis the relationship between the variables (AMJAD & RASHID, 2102). The SPSS neural network are used to provide an alternative predictive and to analysis the impact of each variable (Mark & Patrick, 2013). The correlation in SPSS shows how strongly how two or more variables are related to each other or the degree of association between them (Eriksson & Sundh, 2010).

Generally, we can summarize the difference between the Algorithms, Optimization and multi-criteria decision-making Tools as shown in table below. The SPSS and LINGO tools are used for this study due to their flexibility and multi-functionality as described in table below.

Table 2. 6: Advantage and disadvantage of reverse logistic optimization tools

Algorithms, Optimization and multi-criteria decision making Tools	Advantage	Disadvantage
Fuzzy TOPSIS	Used to rank weighted criteria to choose a best result from the given alternatives	It Deals with reasoning that is approximate rather than fixed and exact
IBM SPSS	Multi-functional and flexible to analyses a set of variables	It is difficult to interpret when it produces extremely complex models with multiple layers
LINGO	It used to solve linear nonlinear optimization large problems and possible to set declare variables as character format	Constraint limited, a maximum of 150 constraints
LINDO	Solves linear and non-linear optimization large problems and solve integer variables up to 50	Constraint limited, a maximum of 150 constraints and impossible to set the variables as character format
Genetic Algorithms	It simulates processes in natural systems necessary for evolution; especially those follow the principles by Charles Darwin of 'survival of the fittest'	A random search used to solve optimization problems.
Heuristic /Approximate/ Algorithm	It used to obtain good near optimal solution using low computation	Difficult to achieve an optimal solution
Ant Colony Algorithm	It used to solve specific types of combination optimization problems.	Difficult to solve more complex and generalized problems

Lingo version software is simple and flexible tool for utilizing the power of linear and non-linear optimization to formulate problems concisely. For this study of reverse logistics network, LINGO 18.0 software package as linear programming problem is used. LINGO 18.0 contains a set of built-in solvers to solve a variety of operation research problems, unlike many modeling packages LIGO solvers are directly linked to the modeling environment.

## 2.8. Reverse logistics as a competitive advantage

In a highly commoditized industry where costs are one of the most important factors to customers, lower prices may increase the organizations market share and customers repurchase behaviour (Cuneo, Lopez, & Yague, 2012). RL practices allow organizations to benefit from additional cost-saving opportunities by recovering the costs of product materials and reusing them at a later stage (Arrieta, Reverse logistics as alleviation to ecological issues: Theory and implementation: doctoral thesis , 2015). Cost savings can be transferred into the price of the

products, thus allowing the organization to remain price competitive (Akdoğan & Coşkun, 2012). Conducting backhaul activities can also generate revenue streams and allow the organization to improve the efficiency of their fleet utilization, ultimately reducing the cost of transportation and the end product (Hsu, Tan, & Mohamad Zailani, 2016). The ability of the organization to develop a competitive advantage from RL practices may stem from the organizations effectiveness and efficiency in conducting RL practices on a day-to-day basis (Akdoğan & Coşkun, 2012).

## **2.9. Practices of e-waste management systems in Ethiopia**

Ethiopia is the 2nd largest population from Africa and many populations are in its capital city, Addis Ababa. In Ethiopia, the growing population and the increasing number of people led to a strong movement in causing inflation of waste's problems as Ethiopia does not have a good e-waste recycling network. The Ethiopian government has legislations related to the waste issues (Solid Waste Proclamation: No. 513/2007), but implementation of these regulations does not take place, and accordingly most of the electronic manufacturers and importers don't follow any guidelines to manage their wastes.

Addis Ababa is characterized by rapid population growth caused by natural increase and migration from rural area for it was largest business center of Ethiopia. These increase the city's population to be around 6.8 million in 2017 which account about 6.6 percent of the total population of the country. In addition to individual household, there are different governmental and non-governmental organizations in the city. Such rapid increase in population together with rapid development of the city has produced increasing volumes of wastes which is generated from the population's daily life activities both directly and indirectly.

The disposal method that the city used is less systematic which has hazardous effect on health and the environment. The environmental and sanitary conditions of the city have become more serious from time to time, and people are suffering from living in such conditions. Irresponsiveness and reckless practices of these wastes apart from polluting the air, water, soil and causing severe threat to public health, it also distorts beautification of the city. Most of the wastes that are generated in the city remain uncollected and simply dumped in open areas, road sides, river courses, gullies and unintentionally left at use's hand. Among these wastes, the new

emerging wastes with the advancement of science and technology are e-wastes which are highly growing waste stream.

Computers, mobile phones, tablets, laptops, and other electronic devices are sold by the millions, but when today’s electronics break, become obsolete, or just go out of fashion, most consumers send them to the dump. When e-wastes are improperly recycled or end up in landfills, it ultimately causes negative effects to living organisms and environment due to their harmful toxins constituents (Doolan, 2014). Challenges of e-wastes management systems in Addis Ababa city raised from: lack of strategic plan from the government in facilitating the facilities and policies for proper waste management, un awareness of users to collect the e-wastes due to absence of subjective collectors, lack of e-waste management practices, lack of understanding of e-waste effects from health, environment and economic perspectives and absence of reverse logistics stakeholders (Kassahun, 2016).

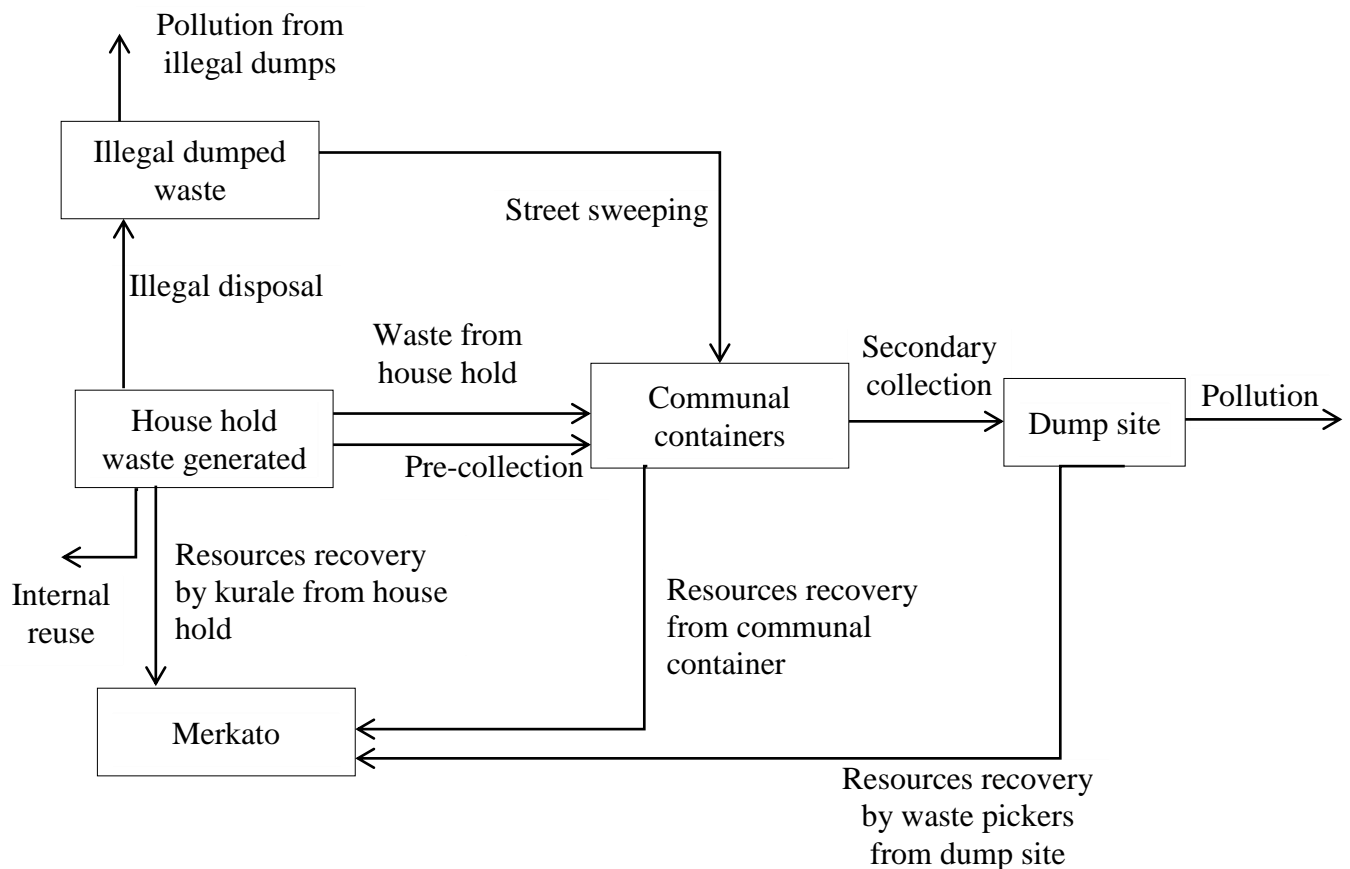


Fig. 2. 15: Material wastes flow in Addis Ababa, source: Addis Ababa Solid Waste Management Agency

A variety of electronics and electrical equipment (EEE) were identified through its channel of importation to consumers via different means, and analysis based on data from Ethiopia custom authority showed that a total of 123,039 tons gross and 119,699 tons net EEE are imported from different industrialized countries per year. Despite the increment of E-waste generation in cities of developing countries, still it managed together with municipal solid waste and mainly by the informal sectors where the case of Ethiopia also shares the same challenge (Massreshaw, 2017).

In the case of Ethiopia there are ongoing efforts by governments together with international development organization like UNDO to develop legislations, regulation for electronic waste management's at national level, in line with that a pilot project to improve Akaki Computer Refurbishment and Training Center facility considering as initial pilot E- waste treatment center. Currently collection of E-wastes in Ethiopia, especially in Addis Ababa is done mainly by informal sectors together with valuable recyclable materials rather than governmental organizations restrict by ministry of science and technology innovation along with environmental protection agency to give their e-wastes to Akaki Computer Refurbishment and Training Center facility without disposing to the environment.

In Addis Ababa, most of repairing and refurbishment shops purchasing used electronic materials through auction, they maintains and resell to the user or dismantle the components for replacement of similar electronic devices and sales the scraps of metals components to the middle men. The rest of the components that does not have function for replacement or not recycled are dump together with municipal waste into environment or transported to the dam site where notoriously it can cause nuisance to the environment.

According to the study by IGNIS (Mapping of formal and informal sector in Addis Ababa solid waste management, 2011), hundreds of scavengers and around 3200 informal waste pickers “Korales” purchase valuable solid waste included electronic waste and deliver to Middle men(around 800) and hundreds of recyclers settled in Merkatos. According to the custom's Authority record new and second hand electrical equipment are imported to Addis Ababa city through different directions. These electrical materials are distributed to different regions of the country. It is estimated that about 30% of the equipment are remain to the city (Ethiopian Custom Authority, 2019). These EEE will join the waste stream after their average life span.

Table 2. 7: Summary of reviewed literatures and gap analysis

Author, year	Title	Methods	Gap
Devin N. Perkins, M.-N. B., 2014	E-Waste: A Global Hazard, Annals of Global Health	Review where e-waste is generated and recycled and adverse environmental exposures, health consequences, and the policy frame-works	The Policy frameworks didn't explicitly explain the collection and reprocessing system: an overview of global aspects
Ramachand -ra V., Saira Varghese K., 2016	Environmentally sound options for e-waste management	Defined the responsibilities of agents involved in e-waste generations	It is only about responsibilities (governments, citizens and industries) but methods of involvements of those agents are not properly explained. Not about RLND or reprocessing system
Chandra Prakash, Mukesh Kumar, 2015	Barriers Analysis for reverse Logistics	Fuzzy fryamework that handle impreciseness and uncertainty	The study identified RL barriers (Lack coordination with providers, customer perceptions about reverse logstics and lack of system to monitor returns) without solving it.
Geogiadis, 2004	Introduce a new approach on the study of reverse logistics.	System Dynamics (SD)	Illustrative how SD modeling can be used to produce a powerful long-term decision-making
Vaidy Jayaraman, 2001	Design of Reverse Distrib-ution Networks:model s and Sol-ution Procedures	Heuristic concentration Procedure	"Heuristic expansion" was also performed using the solution found with a greedy Heuristic to provide a short-list of potential facility sites
Vlachos, 2003	Approaches on the study of reverse logistics	System Dynamics (SD)	Shows how SD modeling can be used to produce a powerful long-term decision-making tool
Pumpino, 2014	Investigating the current practices in the RL systems	qualitative and quantitative methods was employed	Analysis shows waste managed by a Cooperative like franchise of SCs perceived that their practices were more efficient than non-franchise practices
Kaeberrick and Jessica Hanafi, 2008	Solid waste Collection Strategy considering cost and environmental impact simultaneously	Integrated collection strategy which combines a Fuzzy Colored Petri Net forecasting method and collection network model to collect EOL products	Providing demographic data and historical sales of a relevant product in a certain location, the best strategy to collect EOL products in that location can determined
Masakazu,	Status of recyc-	Comparison of Energy	Recycling of plastic bottles is a waste

2014	ling plastic bottles in Japan and recycling methods	Consumption Required for Different Recycling Methods	of energy. It is better to combust used plastic bottles, rather than recycle them, to produce and utilize heat.
Bupe Mwanza and Charles Mbohwa, 2017	Recycling and RL: significance of sustainable resource utilization and waste management	Used Scenario study approach	Merits in implementing reverse logistics systems and these can benefit the developing economies
Joao Menezes, 2009	Elements of customer service and their importance in RL for recycling.	Applying multivariate statistical methods	Suggest important guidelines to improve such a complex logistics service.
Ochieng, A. S., 2013	Cell phone disposal and strategic evaluation of electronic waste management in kenya	Both the published and unpublished documents were gotten from the government's achieves	Strong relationship between effective strategic evaluation management and cell phone disposal. It about proper disposal, no RLND
Rupesh Kumar Pati, P. V., 2017	Cost optimisation model in recycled waste reverse logistics system	Linear analytical model	It is only about reprocessing system: making strategic inventory management decisions. Not about RLND
Rehaballah Elbadrawy, 2015	E-waste Reverse Logistic Optimization in Egypt	Considers collection cost, installation cost of sorting, repairing and recycling facilities, processing capacity and transportation between different facilities	Model of optimal centralized collection facility location and the material flows which is less optimal than decentralized collection facility and no state about forecasts of e-waste future generation

## 2.10. Literature summary and Gap

Some of the points that indicate the existence of gap from the literature related to the research study are:

- In previous literatures, most of the reverse logistics network design models are mainly focused on minimizing total costs. However, environmental impact is becoming critical issues and economic advantages from the reverse logistic are the most important especially for thus developing countries such as Ethiopia
- But some research tries to recommend that, Recycling is well-known for its environmental benefits, which include resource conservation, energy conservation and reductions in air pollution, including reductions in greenhouse gas generation, as many researchers are often overlooked.
- The developed models don't consider how to reduce the transportation cost and the advantage of developing a collection center to return products from the end user customers to the origin of producers in the reverse logistic process. The missing proper network design is from the lack of optimization technique. The other limitation of the researchers is they didn't pay an attention the impact of drivers and barriers of reverse logistic and relationships of the stakeholders involved in the RL.
- Most, , European countries such as Germany, Turkey, Holland, Greece and other Asian Country's such as China, Indian, and USA are the leading contributors through the implementation of e-waste management system. However, the design and analysis of the e-waste RL system from African countries including Ethiopia has not been still well impressed.

Therefore, the study identified less studies on e-waste reverse logistics and recycling in Africa and none in Ethiopia and recommended that more researches are needed on this topic and it was serious issues for environmental aspects and becoming economic advantageous through recycling of e-wastes. Thus, this study identified that very few studies addressed on e-waste, no study tried to quantitatively evaluate and select the initial location of the RL facilities, absence of e-waste RLND explicitly through DCC, past researches forecast e-waste by MFA or consumption rate than methods of sales marketing system and absence of well-developed e-waste reprocessing technique related to the case facility.

## CHAPTER THREE

### RESEARCH DESIGN AND METHODOLOGY

This section describes in detail the general intention of the research and the methods used for data collection and analysis. In order to achieve the stated objectives of the study, research methodology tool was carryout to develop a reverse logistics network model for e-waste management in Addis Ababa city.

#### 3.1. Research Design

The objective of this research is to design a generic and optimized reverse logistic network model for EWMS particularly computer waste in Addis Ababa city. The result of this model is used as an input for Computer Refurbishing and Training Center (CRTC) through the development of optimized collection system. This study is focused on the identified literature gaps and the existing problems of the company by using the data collection techniques. Qualitative data on the level of existence of RL barriers is collected from CRTC to identify the root cause of RL problems. These collected data is mainly focused on the three major parts of Reverse Logistics Supply Chain Management (RLSCM) – Suppliers’, the target Company, CRTC and Customer sides to know the major area of problems for the further study of the research. For this study, the following procedures are addressed to come up with the final output.

- The reverses logistic of CRTC problems from point of view of suppliers’ the CRTC and customers’ sides are studied
- Qualitative data collected from CRTC is analyzed by Microsoft excel and SPSS Statistics 20 software, the major problem of RL system is identified from suppliers’ side depending on the results of total score and percentage level of existence of the barriers and Pearson Correlation (PC) of the most significant barrier with other barriers by testing its reliability,  $\alpha$
- Designing solution for problems identified
  - waste justification and category selection
  - Identifying potential Desktop Computer (DC) waste generating sites and accessing their locations by Google Earth Pro software

- Forecasting sales capacity and waste generation from potential generating sites
- Systems of collecting DC wastes from sources/ end users are analyzed by comparing decentralized and centralized collection system
- For the quantitative model of collection centers and transportation their optimality is checked using LINGO17
- Based on the analyses a reverse logistics network is developed

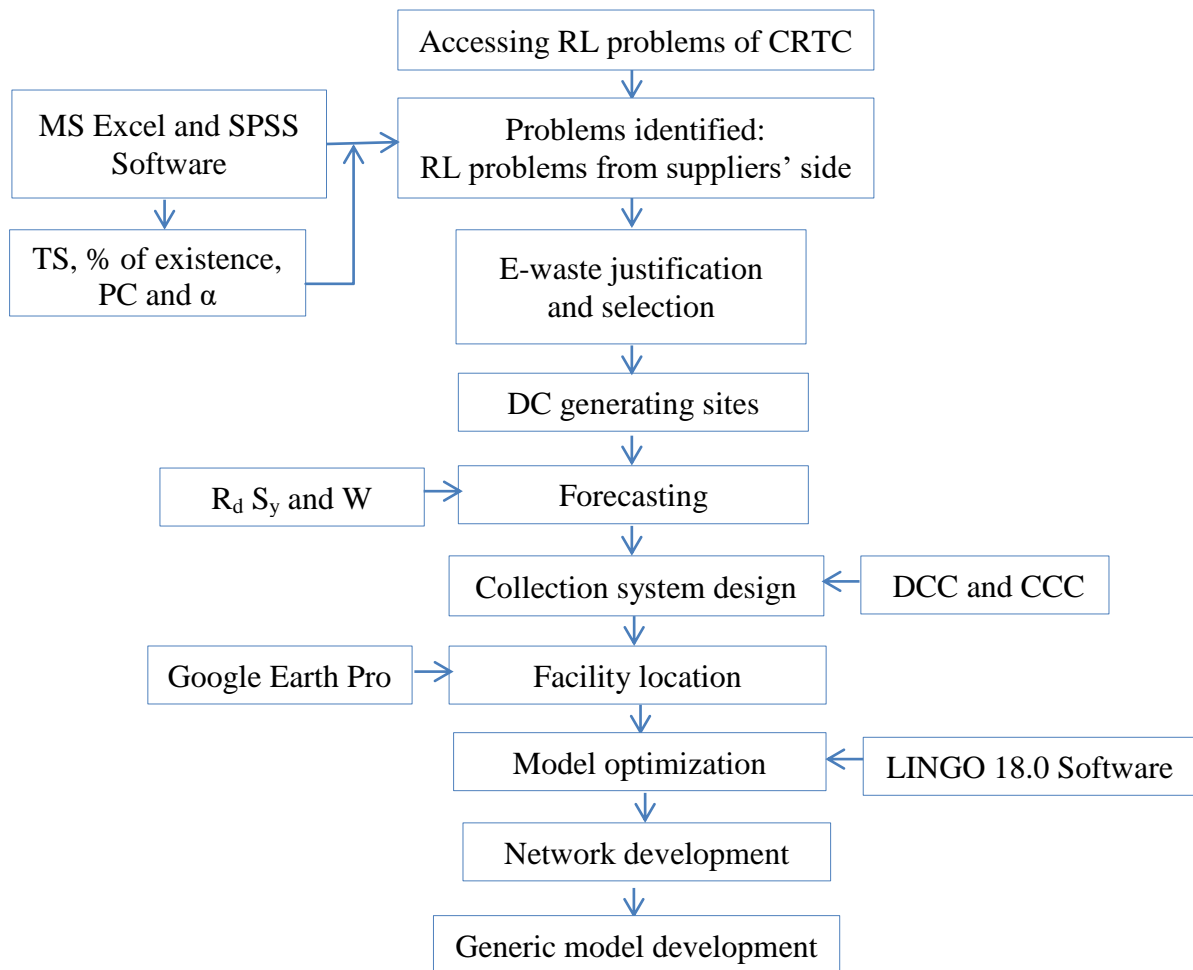


Fig. 3. 1: A procedure to develop reverse logistics model

## 3.2. Research Methodology

As described in the objective of the research, design and analysis of a reverse logistics network for e-waste management system is the main intent of this research. To accomplish this objective, research methodology that can duly ensure its outcome to the desired objective is formulated. Data required for the formulation of the model, was collected from different sources through various data collection methods. The research plan and procedure are presented and described below to pursue the work of the study.

### 3.2.1. Types of data

The data collected for this study contains both primary and secondary data as well as qualitative and quantitative data. Each category explicitly described in the following section.

#### 3.2.1.1. Primary data

- Qualitative primary data of RL barriers from the case facility (ACRTF) were collected through Observation, questionnaire, semi-structured and structured interview. A total of 30 questions were prepared and grouped as 1 – 11 for collection center related, 12 – 22 for case facility related and 23 – 30 for distribution center related. Those questionnaires were distributed for 25 participants of the company basically for top management, refurbishing, de-manufacturing, property management and cost controlling department of the company. The questionnaires were filled by 21 respondents; however, 4 participants have not returned the questionnaires.
- Methods of e-waste management system from Addis Ababa Solid Waste Management Agency (ASWMA): questionnaire and interview and the researcher informed that no e-waste collection network in the city
- Situation and collection system of e-waste from Potential Generating Sites (PGS) through observation: questionnaire and interview, (PGS: Addis Ababa University – main compass, Faculty of Business Education, Entoto Polytechnic College, Addis Ababa Institute of Technology , College of Natural Science, School of Commerce and Tegebareid Polytechnic college)
- From Google Earth Pro for location of collection centers facility and generating sites and

### 3.2.1.2. Secondary data

- Quantitative data of EEE sales from 2010 – 2019 and accumulated e-waste in 2019 from PGS

Sales: to forecast future (2025) sales and waste generate

Accumulated e-waste: to design capacitated collection network

- Literature review: Electronic books, journals, proceedings, published researches, organizational periodic performance reports and others are reviewed.
- Historical data of case facility on the annual reprocessing capacity from manual of e-waste reprocessing system
- ASWMA: existing waste collection system in Addis Ababa city

### 3.2.2. Tools and methods of data analysis

The questionnaire consisted of both open and closed form to exhaust the research question and objectives. As a result, the study addressed existing e-waste dealer and some major governmental organizations in the city, where e-waste is mostly generated and serve as a supplier for the case facility. The respondents of the interview were experts and higher officials of CRTTC. This type of interview helps to compare and contrast the information obtained from different respondents, and to add some other relevant points at the time of the interview.

Microsoft Excel and IBM SPSS Statistics 20 software are used to analyze the quantitative data collected from CRTTC concerning the barriers of RL and validity of the data analyzed were checked. Gravitational location and optimization model was formulated for the reverse logistics network; the model was solved for case of computer waste with LINGO 18.0 software package as linear programming problem. Lingo is simple and flexible tool for utilizing the power of linear and non-linear optimization to formulate problems concisely. LINGO 18.0 contains a set of built-in solvers to solve a variety of operation research problems, unlike many modeling packages LIGO solvers are directly linked to the modeling environment.

### 3.2.3. Study area

Addis Ababa is capital and largest city of Ethiopia. It is located on a well-watered plateau surrounded by hills and mountains, in the geographic center of the country, geographically, it is located at 9° 38' North between 38° 42' East, with the lowest elevation of 2000m above sea level, in the southern periphery, and the highest over 3000m above sea level, north of the city and average daily temperature is about 10 to 20 °c.

In Ethiopia, Addis Ababa is the highest waste generator. However, About 20% to 30% of the waste generated in Addis Ababa remained uncollected and made the city environment aesthetically unpleasant and affected the city's public health (Mesfin & Meine Pieter, 2014). The remaining amount of waste is illegally disposed on unauthorized place such as in drainage lines, open spaces, street sides. The other technical element of solid waste management such as sorting, transfer and transportation, treatment and disposal hold a lesser attention from the city municipality. The study of (Hailu, 2014) confirmed that the distribution of communal container is inequitable, the containers are not periodically picked and emptied, land filled managed poorly, recycling is neglected, and the participation of stakeholders is insignificant.

Therefore, this research is more emphasized on RLND for ACRTC based on the major e-waste generating sites in Addis Ababa city. Because, in Addis Ababa, Several international organizations have their headquarters in the city; the most important are the African Union and the United Nations Economic Commission for Africa, both located in Africa Hall and other educational and administrative centers. The bulk of the export and import trade of Ethiopia is channeled through Addis Ababa on its way to or from the ports of Djibouti, on the Gulf of Aden, or Asseb, Eritrea, on the Red Sea. The city is also the collection and distribution center for much of the country's internal trade.

Akaki Computer Refurbishment and Training Center Facility (ACRTCF) considered as initial pilot EW treatment center. Currently collection of EWs in Addis Ababa is done mainly by informal sectors together with valuable recyclable materials rather than governmental organizations restricted by ministry of science and technology innovation along with environmental protection agency to give their e-wastes to ACRTCF without disposing to the environment.

### 3.2.4. Sampling Techniques

Based on the RL barriers identified from the case facility, major suppliers and product of the case facility, PGS of e-waste were selected. The major suppliers of the case facility were governmental organizations mainly located in Addis Ababa city and sample of organizations that generate large quantity of EWs for the case selected based on the results of preliminary survey of the study. In the other side; electronic waste profile was developed by taking primary and secondary data from relevant organizations. For taking the sample of this study, governmental organizations are selected because of the availability e-wastes and stated above reasons.

From the governmental organizations, Higher Educational Institute (HEI) and Educational Training Colleges (ETC) are where large quantities of EWs are generated and they are the major suppliers of the case facility. In HEI and ETC, electronic equipment like computers, printers, photo copies, laptops and other electronic equipment which used for teaching aids are highly available relative to other institutions. From these electronics equipment, DC is the dominant in quantity as well as its effects to environment and health which need to be managed properly, that is the aim of this study. From HEI and ETC in Addis Ababa city, Addis Ababa University (AAU) and Vocational and Educational Training Colleges (VETC) are randomly selected respectively. From AAU, AAU Main Campus, Faculty of Business and Economics (FBE), Addis Ababa Institute of Technology (AAIT), College of Natural Science (CNS) and School of Commerce (SC) and from VETC Teferi Mokonnen Polytechnic College (TTMPC) and Tegebareid Polytechnic College (TPC) from VETC were selected based on the RL barriers identified from the case facility, major suppliers and product of the case facility and PGS of e-waste.

### 3.2.5. Reverse Logistics Network Model Formulation

Decentralized or centralized RL network is used as a tool for system of collecting wastes from end users and designing collection facilities. A Decentralized Reverse Logistics Network (DRLN) is composed of independent entities that fulfill the functions of collectors, processors, or recyclers and who often compete with one another. Network in terms of tiers, where each tier represents one typical function, or operation, in the recycling network are conceptualized. The study considered a general model of decentralized reverse production systems comprised of

potential generating sites, decentralized collection centers and reprocessing facility or facilities. Each tier is populated by multiple independent entities and each tier is connected to its upstream and downstream neighbors by material flows. A methodology is developed to determine material flow allocation mechanisms between tiers. The individual entity behavior is to maximize its own profit functions subject to its own constraints.

### 3.2.5.1. Formulations and methods of analyzing collected data

From the analysis of questionnaire results, the study identified that the major problems of the company's RL are from the suppliers sides due to lack of collection network facilities to collect e-wastes from the end users. To solve these problems, this study further investigated the issues by designing optimal collection system and facilities through identifying potential e-wastes sources. The amount of e-waste available from potential generating sites are gathered and analyzed for the collection network design.

Total score, TS weight of each of the barriers,  $Q_n$  that rated by the respondents can be calculated by adding each score with its coefficient of degree of existence. The total score, TS of RL barriers,  $Q_n$  is calculated as:

$TSQ_n = (0*VL) + (1*L) + (3*M) + (5*H) + (7*VH)$ . Where: 0 = the value assigned for Very Low (VL), 1 = the value assigned for Low (L), 3 = the value assigned for Medium (M), 5 = the value assigned for High (H) and 7 = the value assigned for Very High (VH). Using the same procedure, the total score of each barrier is calculated using Microsoft excel.

The percentage, P of level of existence of the barriers,  $Q_n$  is calculated using:

$PQ_n = \frac{TSQ_n}{\Sigma_{total\ score}} \times 100$  %. Then using the same procedure percentage of level existence of the barriers is calculated using Microsoft excel. Therefore, the rank of the barriers can be determined either based on the total score or percentage of the existence using descending order. By using SPSS software, the reliability of the collected data result and PC of the most significant barrier with other barriers are determined. The potential generating sites are accessed and yearly sales amounts of DCs are collected from historical data to estimate the future growing sales and the amounts of waste generated each year.

$$R_d = \frac{S_y - S_{y-1}}{S_y}$$

$$S_{y+1} = S_y * R_d + S_y$$

Where:  $R_d$  = annual decreasing rate at life span,  $S_y$  = sales amount in  $y$  year,  $S_{y+1}$  = sales amount in  $y+1$  year and  $ls$  = life span of the DC.  $W_{ls} = inflow * P = (S * P)$ , Where:  $W$  = Outflow/ waste generated,  $S$  = sales/ inflow and  $P$  = percentage amount when product reaches at its end of life.

The considered quantitative model for locating collection and recycling facilities DC was described in the paper and formulated mathematically as transportation problem using gravitational location method.

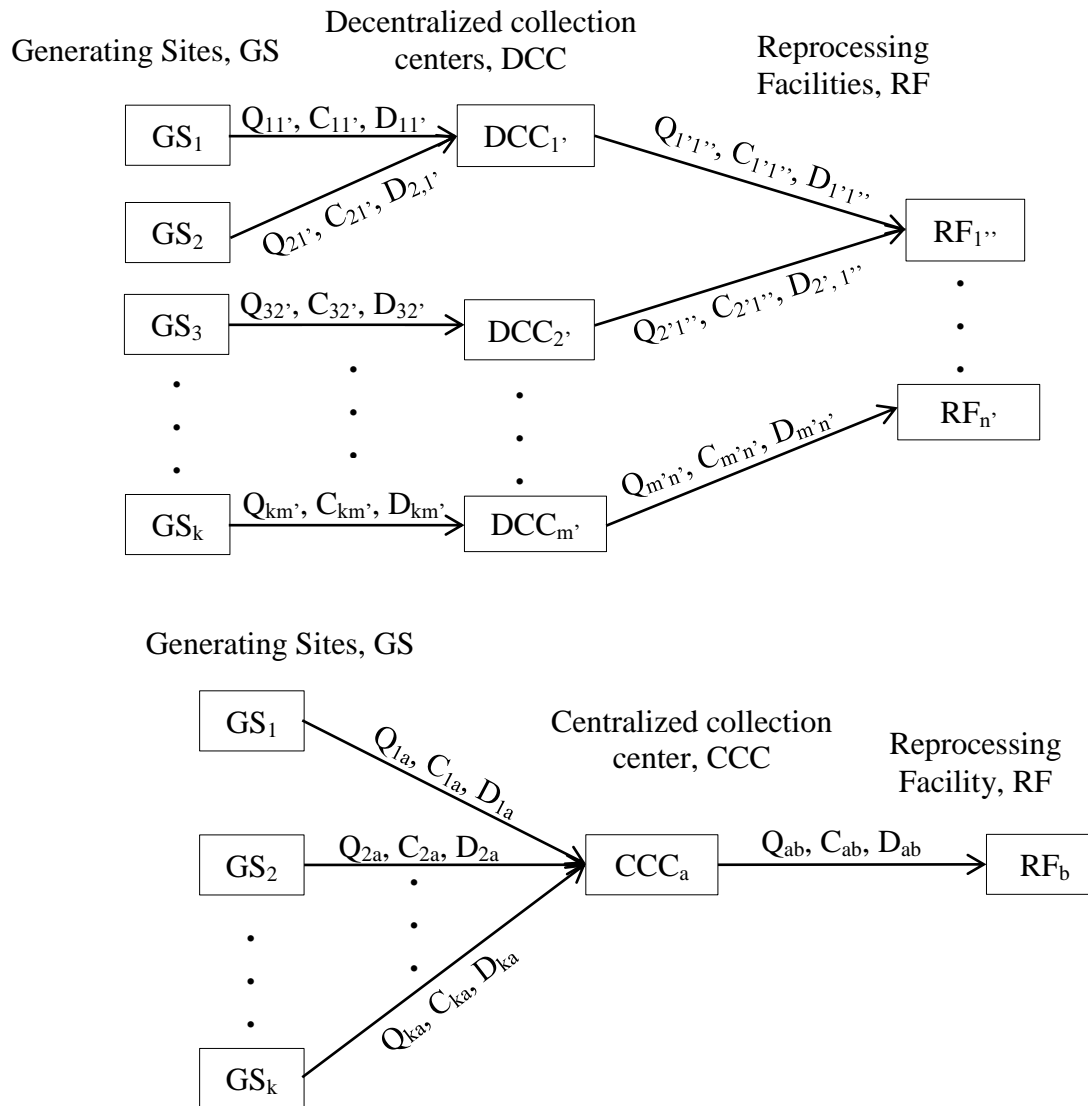


Fig. 3. 2: Generalized decentralized and centralized collection system

Where:  $Q$  = quantity in tons of DC generated at generating sites

GS = generating sites, DCC = decentralized collection centers, RF = reprocessing facilities, CCC = centralized collection center, C and D are the cost and distance between each stations respectively. To reduce transportation cost the study formulated linear transportation model.

The objective function is to minimize:

$Z = \sum_{i=1}^k \sum_{j=k+1}^m C_{ij}Q_{ij} + \sum_{i=1}^m \sum_{j=m+1}^n g_{ij}Q_{ij} + A_{fc}$ . Where,  $m = k + r_1$ ,  $n = m + r_2$ ,  $k$  = number of sources where waste is generated,  $r_1$  = number of collection site,  $r_2$  = number of reprocessing units,  $C_{ij}$  = unit transport cost between source  $i$  and collection site  $j$ ,  $g_{ij}$  = unit transport cost from source  $i$  or collection site  $j$  to reprocessing unit  $j$ ,  $Q_{ij}$  = quantity of waste transported from source  $i$  or collection site  $j$  to reprocessing unit  $j$ .  $A_{fc}$  = Annual operational cost.

Subject to constraints:

$$\sum_{i=1}^k x_{ij} \leq Q_j, \quad j = k+1, \dots, n$$

$$\sum_{j=k+1}^m x_{ij} = Q_i, \quad i = 1, \dots, k,$$

$$\sum_{i=1}^k x_{ij} - \sum_{j=m+1}^n x_{ij} = 0, \quad j = k+1, \dots, n$$

Generally, for the fomulated collection model of the studt in the above diagrams:

objective function: minimize

$$Z = \sum_{i=1}^2 \sum_{j=1'} C_{ij}Q_{ij} + \sum_{i=1'} \sum_{j=1''} g_{ij}Q_{ij} + A_{fc} \quad \dots \dots \dots \text{for DCC}$$

$$+ \sum_{i=3}^3 \sum_{j=2'} C_{ij}Q_{ij} + \sum_{i=2'} \sum_{j=1''} g_{ij}Q_{ij}$$

$$\vdots \quad \vdots$$

$$+ \sum_{i=k}^k \sum_{j=m'} C_{ij}Q_{ij} + \sum_{i=m'} \sum_{j=n'} g_{ij}Q_{ij}$$

Subject to:

$$Q_{km'} = Q_{m'n'}$$

$$Q_{1'1''} = Q_{11'} + Q_{21'}$$

$$Q_{32'} = Q_{2'1''}$$

objective function: minimize

$$Z = \sum_{i=1}^k \sum_{j=a}^a C_{ij}Q_{ij} + \sum_{i=a}^a \sum_{j=b}^b g_{ij}Q_{ij} + A_{fc} \quad \dots \dots \dots \text{for DCC}$$

Subject to:

$$= \sum_{i=1}^k Q_i = Q_a = Q_b, \quad i = 1, 2, \dots, k \quad Q, C, D > 0$$

After the DC waste is identified and collected from its generating sites and transported to its reprocessing facility through its collection center(s), the waste passes through certain

reprocessing activities like refurbish, disassembly and assembly and de-manufacturing in reprocessing facility.

### 3.2.5.2. Model Assumptions

In designing the reverse logistics network for Desktop Computer (DC) waste management, the model formulated considers the following assumptions:

- I. The locations of the places that generate DC waste are known. The generating sites are considered as the initial (pre) collection points.
- II. The amount of generated DC waste annually is known.
- III. A decentralized or centralized collection centers and recycling plant facilities was proposed with a capacity constraint for handling DC waste.
- IV. The collected DC waste contains several computer models (types) which must be classified at the collection center then transported to the recycling plant according to some proportion. But, for the model formulation the computer waste collected are treated as homogeneous or the same model
- V. The transportation costs are proportional to the quantity computer waste and the distance between the two locations.
- VI. Fixed cost and variable cost for the facilities is estimated.
- VII. There is market available for DC waste collected at only reprocessing facility
- VIII. DC waste collected is maintained and/ or refurbished at only reprocessing facility

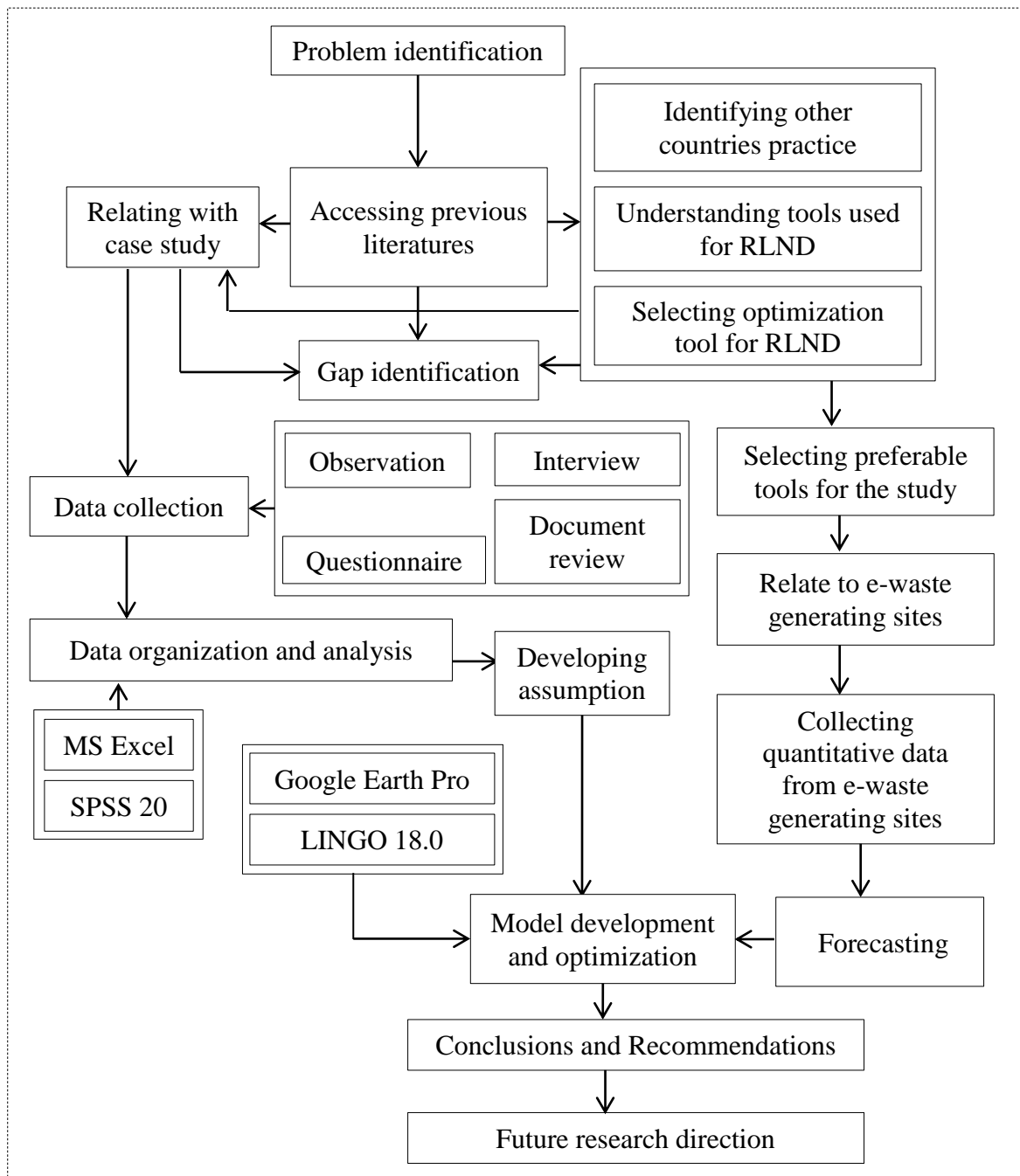


Fig. 3. 3: Research methodology flow diagram

## CHAPTER FOUR

### DATA ANALYSIS AND DISCUSSIONS

#### 4.1. Introduction

This research study deals with the analysis and development of e-wastes- specifically computer waste management system in Addis Ababa city by designing RL network. The designed network is used as a system for Akaki computer refurbishment and training center for collecting e-wastes from end users and reprocessing systems by studying the nature of e-wastes in both the city and the company. For gathering data, a questionnaire was formed in order to gate more information about reverse logistics of Akaki computer refurbishment and training center.

The questionnaires consists of three parts: the first part were about Personal Information, second part were about Suppliers, the Company and Customers' Logistics Related Issues and the third part were to get high lights of general information about the company' s view towards RL concepts. Those questionnaires were distributed for 25 participants of the company basically for top management, refurbishing, de-manufacturing, property management and cost controlling department of the company. The questionnaires were filled by 21 respondents; however, 4 participants have not returned the questionnaires.

From the analysis of this questionnaire results, the study identified that the major problems of the company's RL are from the suppliers sides due to lack of collection network facilities to collect e-wastes from the end users. To solve these problems, this study further investigated the issues by designing optimal collection system and facilities through identifying potential e-wastes sources. The amount of e-waste available from potential generating sites are gathered and analyzed for the collection network design.

## 4.2. Existing RL systems of CRTC

This company receives any types of e-wastes from local governmental organizations, and imported e-wastes from North America, Europe and Sweden ICT Company to refurbish, de-manufacture and also give training services in and outside the company. As a summary, the company's yearly capacity and process flow activities of collected computer waste are illustrated in the blow table and diagram respectively.

Table 4. 1: used computer bought and processed per year in ACRTC

Year	From Local	From Import	No. of refurbished and sold computer		De-manufactured amount
			To Export	To Local	
2014	3,681	8,852	8,022	3,134	6,768
2015	5,149	6,379	7,378	2,882	6,225
2016	4,028	4,697	5,619	2,192	4,714
2017	8283	4,358	8,090	7,964	6,826
2018	10,147			8,379	4, 70
2019	9,533			7,681	2,853
Yearly Average	6,804	4,048	4,852	5,372	4,565

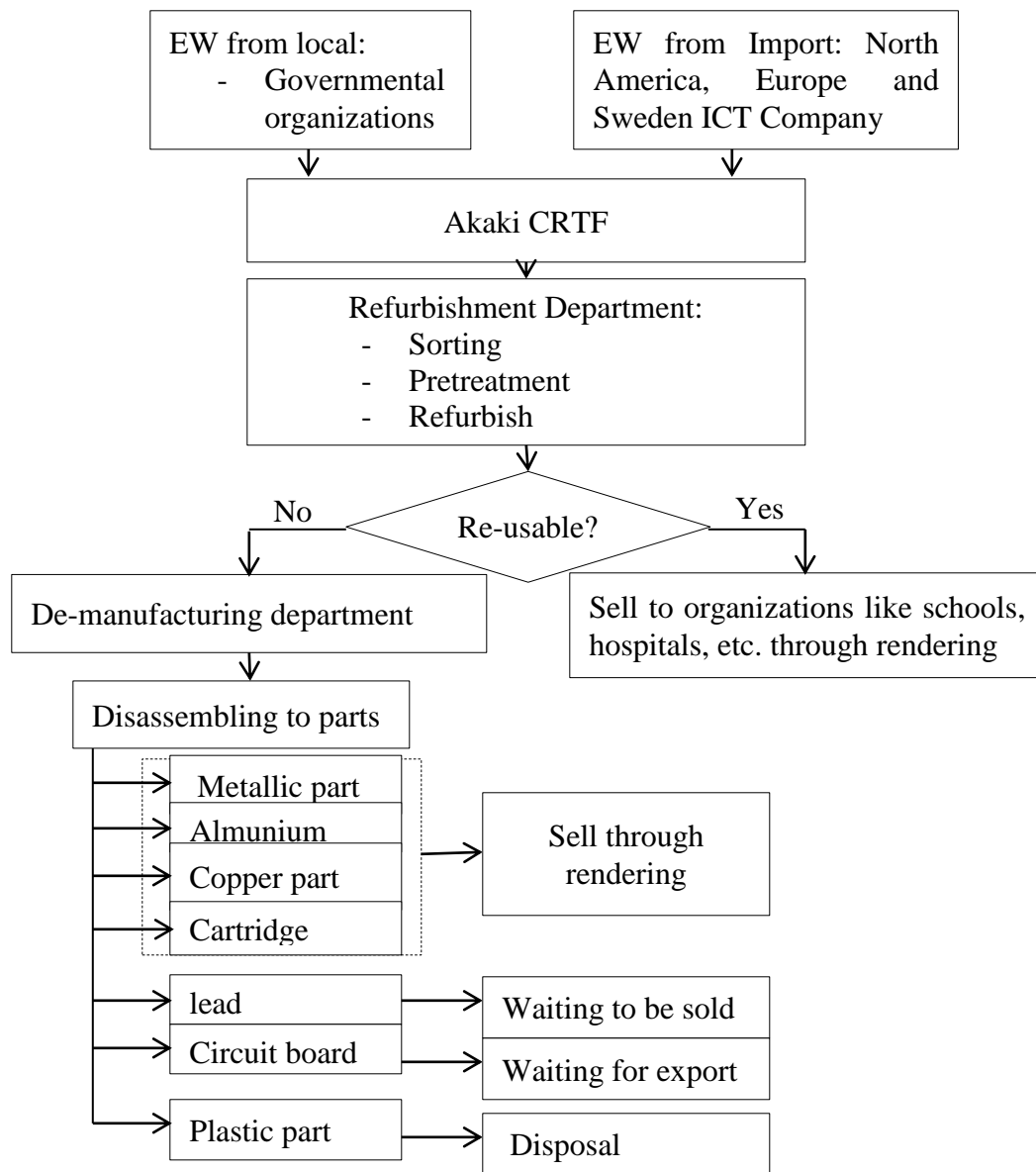


Fig. 4. 1: ACRTC process flow chart

### 4.3. Analyzing Existing Logistics Problems of ACRTC

This section is intending to present, analysis and interpretation of data which has been gained from both primary and secondary source of information and background analysis. Therefore, the general objective of this chapter is to assess the existing practice and challenges of e-waste management, develop and RL network model and drawing conclusions from the collect data from discovered e-waste generating sites and the target company.

Data are collected from the target company – Akaki Computer Refurbishment and Training Center to access the existing systems of RL management of EW including suppliers’ side (collection networks), system inside the company and demand/ customer side (distribution/ selling networks) to find out the problem of the company in managements of EWs especially from Addis Ababa city. In Analyzing existing logistics systems of CRTC, questionnaire is distributed to employees of CRTC consisting of managers, supervisors and workers.

A proper and an efficient reverse logistics system help to increase competitiveness in the market and also return on investment. Analyzing the barriers and drivers hindering the successful implementation of reverse logistics is an important issue. Most of time the barriers and drivers of reverse logistics not only affect the system but also affects each other’s (Badenshorts, 2013). In the CRTC, there are barriers of effective RLs management system. To access those barriers, the researcher collected data from the company mainly focusing the supply barriers, the company itself and the demand/ customer barriers by distributing those barriers to the respondents in the form of semi structured and structured questionnaire.

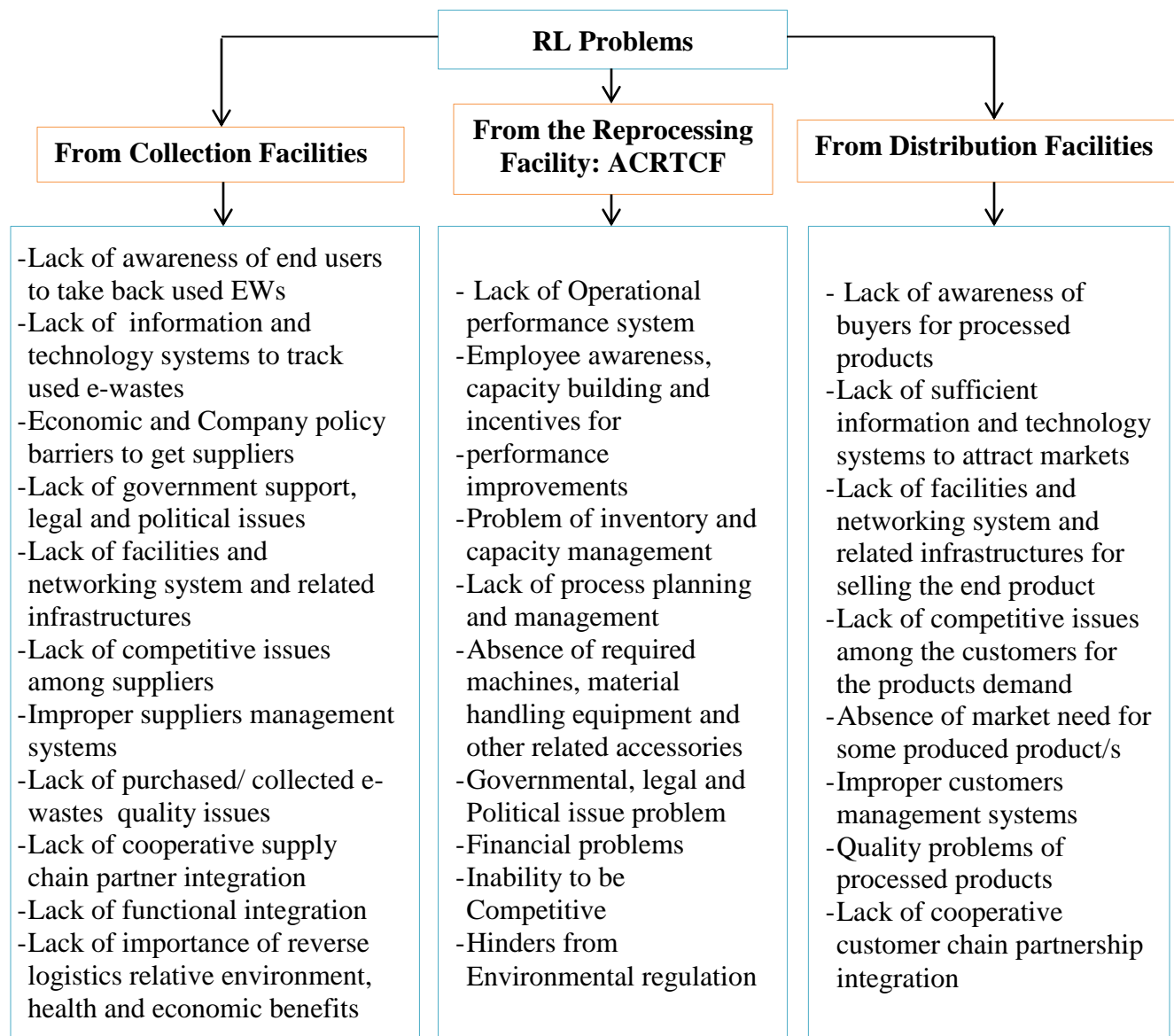


Fig. 4. 2: Reverse Logistic barriers: Source: Questionnaire distribute to ACRTC

#### 4.4. Socio Economic characteristics of respondents

The socio-economic structure of a given society is the most relevant issue to understand the practice of e-wastes management and adopted the appropriate management system. Because consumption pattern, waste composition and generation, and disposal system could be conditioned to an important degree on the behavior, attitude, income, and awareness level of the

society. As a result, assessing the socio economic and demographic variation is very crucial to point out baseline inform.

Table 4. 2: Socio Economic and Demographic characteristics of respondents

No.	Variables	Category	Frequency	Percentage (%)
1	Gender	Male	18	85.71
		Female	3	14.29
		Total	21	100
2	Educational Level	Level	11	52.38
		Diploma	6	28.57
		Degree	3	14.29
		Masters	1	4.76
		Total	21	100
3	Position	Worker	18	85.71
		Manager	3	14.29
		Total	21	100
4	Work Experience	≤ 1 year	7	33.33
		2 - 5 years	11	52.38
		Above 5 years	3	14.29
		Total	21	100

As shown on the above Social Economic and Demographic characteristics of respondents, the sex composition of respondents indicates that, the significant numbers respondents (85.71%) were male which six fold of female counterparts is. Only 14.29% of the respondents were female respondents. This was due to almost of the workers in the company were males. The educational level of Most of the workers in the target company is levels and diploma holders due to the work of refurbishment and de-manufacturing section (main sections in the company) less technical and requires experience than profession.

#### 4.5. ACRTC RL barriers Analyzes and discussions

The reverse logistics of CRTTC are affected by different logistics barriers. In this study the main barriers of reverse logistics that affect the company are considered from the three points of view: suppliers' side, the company and the customers' side. From the results of data collected, reverse logistic problems are revealed from each side which mainly affects the reverse logistics system.

The major problems observed from suppliers' perspectives are: Lack of facilities and networking system and related infrastructures which includes reverse logistics facilities like collection, sorting, processing and distribution facilities of reverse logistics and other supporting facilities. For making those facilities capable and effective, purposefully designed network should be needed through which the wasted e-wastes are reversed from end users. From the analyzed results of the collected data from the respondents, the facilities and networking problems are the most revealed problem in which 42.86% of the respondents indicated that level off existence of these problems is very high and respondents' Percentage of Weight Score is 4.97%.

The Lack of government support, legal and political issues, Lack of awareness of end users to take back used e-wastes and Lack of sufficient information, technology systems to track used e-wastes and Lack of importance of reverse logistics relative environment, health and economic benefits are the major problems observed from gathered data results of the respondents. From the target company, the major RL problems are Problem of inventory and capacity management, Lack of process planning and management, Absence of required machines, material handling equipment and other related accessories and being Competitive problems. The other effective way of implementing the RL systems is creating how to sell the reprocessed products which requires proper design of distribution network, marketing system and customer attraction.

From the results of the data collected, the target company is facing the problems of Lack of facilities and networking system and related infrastructures for selling the end product, Lack of awareness of buyers for processed products, Lack of sufficient information and technology systems to attract markets, Lack of competitive issues among the customers for the products demand and Absence of market need for some produced product/s for the effective managements of effective RL of e-wastes. Generally, the results of the data collected are analyzed in the tables below which indicate the major company's RL problems which direct the next work of the study.

These data is analyzed by Microsoft excel to rate and categorize the results and IBM SPSS Statistics 20 to check the validity of the data results and to relate the variables within each other.

Table 4. 3: Barriers of Reverse Logistics Activities

<b><i>Collection Facilities Related Barriers</i></b>		Design -ations	Level of Existence (%)				
			0 = VL	1 = L	3 = M	5 = H	7 = VH
1	Lack of awareness of end users to take back used e-wastes	Q1	4.76	9.52	38.1	28.57	19.05
2	Lack of sufficient information and technology systems to track used EWs	Q2	4.76	9.52	23.81	33.33	28.57
3	Economic and Company policy barriers to get suppliers	Q3	9.52	14.29	33.33	19.05	23.81
4	Lack of government support, legal and political issues	Q4	4.76	9.52	38.1	28.57	19.05
5	Lack of facilities and networking system and related infrastructures	Q5	0	9.52	14.29	33.33	42.86
6	Lack of competitive issues among suppliers	Q6	47.62	38.1	9.52	4.76	0
7	Improper suppliers management systems	Q7	23.81	19.05	28.57	14.29	14.29
8	Lack of purchased/ collected e-wastes quality issues	Q8	9.52	19.05	52.38	19.05	0
9	Lack of cooperative supply chain partner integration	Q9	14.29	28.57	23.81	14.29	19.05
10	Lack of functional integration	Q10	14.29	33.33	42.86	9.52	0
11	Lack of importance of reverse logistics relative environment, health and economic benefits	Q11	9.52	14.29	38.1	14.29	23.81
<b><i>Reprocessing Facility Related Barriers</i></b>							
12	Performance management problems	Q12	14.29	47.62	19.05	14.29	4.76
13	Lack of interdepartmental integration	Q13	28.57	52.38	14.29	4.76	0
14	Lack of Operational performance system	Q14	14.29	38.1	28.57	14.29	4.76
15	Employee awareness, capacity building and incentives for performance improvements	Q15	9.52	14.29	42.86	19.05	14.29
16	Problem of inventory and capacity management	Q16	4.76	14.29	28.57	28.57	23.81
17	Lack of process planning and management	Q17	9.52	14.29	33.33	28.57	14.29

18	Absence of required machines, material handling equipment and other related accessories	Q18	14.29	19.05	28.57	23.81	14.29
19	Governmental, legal and Political issue problem	Q19	19.05	19.05	42.86	14.29	4.79
20	Financial problems	Q20	9.52	23.81	47.62	14.29	4.76
21	being Competitive problem	Q21	4.76	14.29	38.1	28.57	14.29
22	Hinders from Environmental regulation	Q22	14.29	33.33	23.81	19.05	9.52
	<b><u>Distribution facilities Related Barriers</u></b>						
23	Lack of awareness of buyers for processed products	Q23	4.76	19.05	33.33	23.81	19.05
24	Lack of sufficient information and technology systems to attract markets	Q24	4.76	14.29	33.1	28.57	14.29
25	Lack of facilities and networking system and related infrastructures for selling the end product	Q25	4.76	14.29	23.81	38.1	19.05
26	Lack of competitive issues among the customers for the products demand	Q26	14.29	19.05	19.05	33.33	14.29
27	Absence of market need for some produced product/s	Q27	9.52	19.05	28.57	28.57	14.29
28	Improper customers management systems	Q28	9.52	23.81	52.38	14.29	4.76
29	Quality problems of processed products	Q29	38.1	52.38	9.52	0	0
30	Lack of cooperative customer chain partnership integration	Q30	14.29	23.81	38.1	19.05	4.76

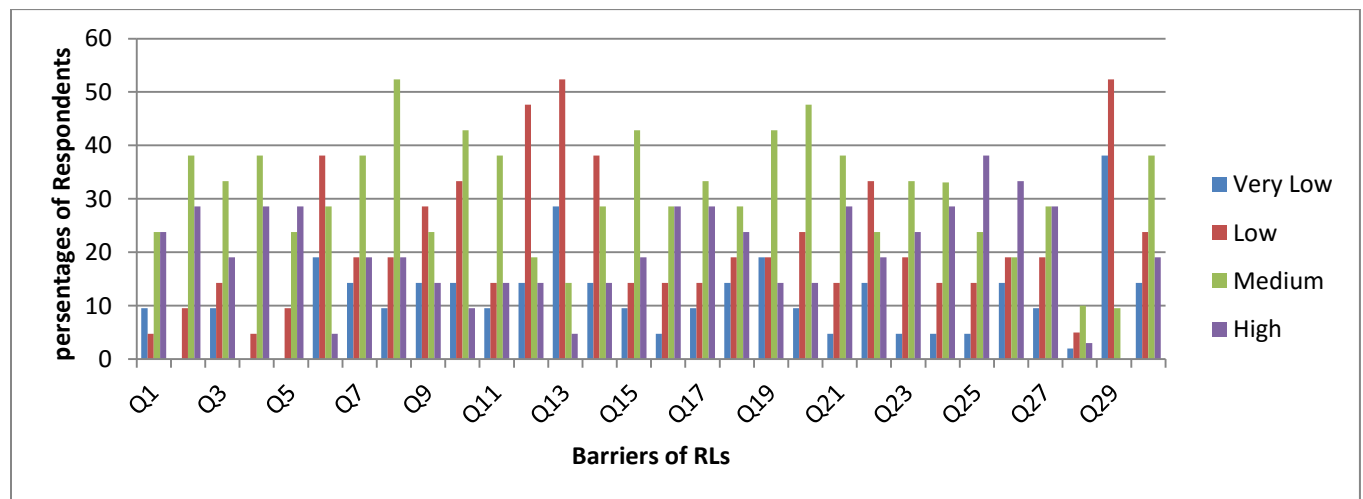


Fig. 4. 3: Barriers of reverse logistics

Total score, TS weight of each of the barriers, Qn that rated by the respondents can be calculated by adding each score with its coefficient of degree of existence. The total score is calculated as:

$TSQ_n = (0 \cdot VL) + (1 \cdot L) + (3 \cdot M) + (5 \cdot H) + (7 \cdot VH)$  Then the total score for Q1 can be calculated as:  $TSQ_1 = (0 \cdot 2) + (1 \cdot 1) + (3 \cdot 5) + (5 \cdot 5) + (7 \cdot 8) = 97$

For  $TSQ_2 = (0 \cdot 0) + (1 \cdot 2) + (3 \cdot 8) + (5 \cdot 6) + (7 \cdot 5) = 91$ .

Using the same procedure, the total score of each barrier is calculated using Microsoft excel as shown in the below table. The percentage, P of level of existence of the barriers (PQn) also can be calculated using:

$PQ_n = \frac{TSQ_n}{\sum_{total\ score}} \times 100$  %. Then for Q1,  $PQ_1 = \frac{TSQ_1}{2044} \times 100$  % =  $\frac{97}{2071} \times 100$  % = 4.68%.

For Q2,  $PQ_2 = \frac{TSQ_2}{907} \times 100$  % =  $\frac{91}{2071} \times 100$  % = 4.39%. Then using the same procedure percentage of level existence of the barriers is calculated as shown in the below table using Microsoft excel. Therefore, the rank of the barriers can be determined either based on the total score or percentage of the existence using descending order.

Table 4. 4: Percentage and total score of Barriers of Reverse Logistics

Barriers of RLs Activities (Qn)	Scores of Number of respondents					Total Score	Percentage of Weight Score	Rank
	0 = VL	1 = L	3 = M	5 = H	7 = VH			
Q1	2	1	5	5	8	97	4.68	2
Q2	0	2	8	6	5	91	4.39	4
Q3	2	3	7	4	5	79	3.81	7
Q4	0	1	8	6	6	97	4.68	2
Q5	0	2	5	6	8	103	4.97	1
Q6	4	8	6	1	2	45	2.17	27
Q7	3	4	8	4	2	62	2.99	19
Q8	2	4	11	4		57	2.75	20
Q9	3	6	5	3	4	64	3.09	18
Q10	3	7	9	2		44	2.12	28
Q11	2	3	8	3	5	77	3.72	11
Q12	3	10	4	3	1	44	2.12	28
Q13	6	11	3	1		25	1.21	30
Q14	3	8	6	3	1	48	2.32	26
Q15	2	3	9	4	3	71	3.43	16
Q16	1	3	6	6	5	86	4.15	5

Q17	2	3	7	6	3	75	3.62	13	
Q18	3	4	6	5	3	68	3.28	17	
Q19	4	4	9	3	1	53	2.56	25	
Q20	2	5	10	3	1	57	2.75	20	
Q21	1	3	8	6	3	78	3.77	8	
Q22	3	7	5	4	2	56	2.70	23	
Q23	1	4	7	5	4	78	3.77	8	
Q24	1	3	8	6	3	78	3.77	8	
Q25	1	3	5	8	4	86	4.15	5	
Q26	3	4	4	7	3	72	3.48	15	
Q27	2	4	6	6	3	73	3.52	14	
Q28	2	5	10	3	1	57	2.75	20	
Q29	8	11	2			17	0.82	31	
Q30	3	5	8	4	1	56	2.70	23	
Total						2071			

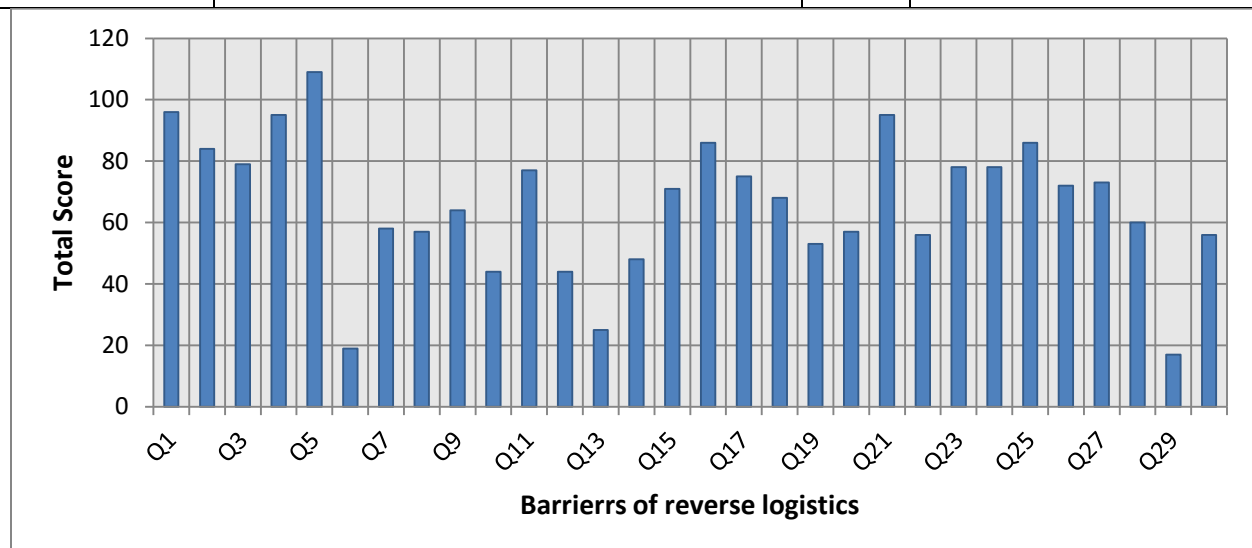


Fig. 4. 4: Barriers of reverse logistic

As the results of the surveyed data from the respondents indicate, most of the company’s e-waste RL problems are from the absence of the facilities and networking system and related infrastructures which affects other variables as the researcher summarized from IBM SPSS Statistics 20 software by Pearson correlation. The correlations of Q5, Lack of facilities and networking system and related infrastructures with other many variables are positive and significant at level of 2-tailed. This indicates that Lack of facilities and networking system and related infrastructures is independent variable which highly affects many other dependent

variables. Solving this independent variable majorly solves other dependent variables. Therefore this study mainly focused on the RL network design for managing e-wastes in Addis Ababa city.

Table 4. 5: Correlation of Q5, Lack of facilities and networking system and related infrastructures with relative to other variables

		Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15
Q5	PC	.502*	.067	.016	.115	1	.166	.139	.117	.232	.357	.316	.047	.235	-.193	.215
	Sig. (2t)	.021	.772	.946	.619		.473	.549	.614	.312	.112	.163	.839	.305	.402	.350

		Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23	Q24	Q25	Q26	Q27	Q28	Q29	Q30
Q5	PC	-.151	.192	.088	.492*	.112	.296	.116	.249	.151	.066	.032	.294	.161	-.037	.441*
	Sig. (2t)	.514	.404	.703	.024	.629	.193	.616	.277	.512	.775	.891	.196	.485	.872	.045

\*. Correlation is significant at the 0.05 level (2-tailed). PC = Pearson Correlation

\*\*. Correlation is significant at the 0.01 level (2-tailed). Sig. (2t) = significant level (2-tailed)

Table 4. 6: Reliability Statistics of the variables

Reliability Statistics		
Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	Number of Items
0.631	0.613	30

According to the Alpha standard, Cronbach's Alpha is accepted within the range of  $0.5 \leq \alpha \leq 1$ . Based on Standardized items it is in acceptable range to proceed with the study since it is 0.631.

#### 4.6. Characteristics and Justification of E-waste

Over the recent decades, the global market of Electric and Electronic Equipment (EEE) continues to grow exponentially, while the life span of those products becomes shorter and shorter. Predictably, the number of electrical devices will continue to increase on the global scale, and microprocessors will be used in ever increasing numbers in daily objects. The production of EEE is one of the fastest growing global manufacturing activities. Rapid economic growth, coupled with urbanization and a growing demand for consumer goods, has increased both the consumption and the production of EEE (Balabanic, Rupnik, & Klemencic, 2011).

This new kind of waste is posing a serious challenge in disposal and recycling to both developed and developing countries. Electronic waste has raised concerns because many components in these products are toxic and are not biodegradable. The dumping of e-waste, particularly

computer waste, has made e-waste management an issue of environment and health concern. Compared to conventional municipal wastes, certain components of electronic products contain toxic substances, which can generate a threat to the environment as well as to human health (Bhutta, Adnam, & Xia Ozhe, 2016).

Unlike the conventional waste (municipal solid waste) e-waste has a different end points for the same good and also the varied discarding patterns. Therefore it is difficult to assess what is the waste generation rate from any particular item of electronic gadgets. For instance, a Personal Computer (PC) bought would have an average life span of 3 to 5 years. However, user of PCs would show varying patterns of discarding it after its life span is over. Some may continue to use it beyond its life time; others may donate it where it is used further for some years. Some may keep in store and others may pass it on to informal recyclers where they would use the useful part for refurbished PCs and other may be subjected to material recovery and final disposal. This invariably compels researchers to adopt material flow analysis in a life cycle framework in order to estimate the generation of EW.

No clear guidelines are there for the unorganized sector to handle EWs and also no encouragement from governments to lure people engaged to adopt formal path for handling EWs. Limited reach out and awareness regarding disposal, after determining end of useful life and unawareness of end users to think of the impact on environment while disposing off their old EEE. Therefore, to solve these critical issues, this study engaged in RLND and analysis of EWs specifically, personal computer – desk top waste from certain generating sites which will be collected, sorted, reprocessed and sold at each stage or final stage or properly disposed.

For instance, PC monitors normally contain hazardous materials such as lead, mercury, and cadmium, while nickel, beryllium, and zinc can often be found in circuit boards. Due to the presence of these substances, recycling and disposal of personal computers specifically DCs becomes an important issue. Relative to other solid waste management in ethiopia, there no sufficient recycling and collection facilities relative to quantum of EW that is being generated. No collection and take back mechanisms are in place due to lack of recycling facilities.

#### 4.7. E-Waste Generating Sites

As the study over viewed from literature, the consumption rate and demand for DC is nowadays increasing in developing countries. Developing countries are now in the transformation phase, they are struggling for growth and development. At present, Addis Ababa, capital city of Ethiopia is showing a rapid development in different sectors. For the success of the transformation plan, different stakeholders, government and non-government office, educational institutes and other service giving industries are involved. DC is one of the key common resources that are utilized by these stakeholders; most of the operations, study and work are done through Desktop Computer.

This may be due to the advancements of science and technology to make complex and difficulty tasks more simpler through the use of electronic devices like desktop computers. In order to fulfill this large demand for desktop computers, the electronic manufacturers and recyclers play a key role. Computer refurbish, de-manufacturing and training center facility located in Addis Ababa at Akaki Kality sub-city refurbish and de-manufacture e-wastes mainly desktop computers. However, large proportions DCs are discarding by different stakeholders instead of being recycled and reused. Though, there are wide potential areas of DCs waste location in Addis Ababa, a priority analysis must be computed to focus on vital few from trivial many.

Key potential areas for waste desktop computers exist where there is many organization especially that of governmental, which is directly proportional high demand for desktop computers and its high rate of waste. This area includes education institutes, government and non-government office, enterprise and commercial areas. Based on a preliminary survey of the above potential areas, this research paper gives focus on educational institutes as a priority generating sites. Specifically, from educational institutes a random selection was made where selected Addis Ababa University campuses and TVET (Technical vocational education and training) institutes considered as a potential generating sites for the model validation of this research paper.

The preliminary survey has assessed the potential areas and selected educational institutes as sample generating sites for model validation based on the following criteria.

**Number of organizations:** An assumption was made, where the organization size in potential area is directly proportional to the amount of desktop computer utilized. This measures the availability of desktop computers.

**Pre-collection space:** These assess the availability of enough space for pre, initial collection center facility in the organizations.

**Related Activities:** The potential areas, locations were assessed on the involvement of organizations activities, tasks dealing with desktop computers, this leads to a high amount of desktop computers production.

**Variety and condition of desktop computers:** All e-wastes do not equally possess the harmful constituents; desktop computer contains the most harmful chemicals like lead. The survey indicates areas with types and availability of variety of desktop computers.

In addition, the condition of the desktop computers, that is easily refurbishable, repairable and de-manufacturable are should be considered.

#### **4.8. Forecasting the sales capacity and waste generated from potential generating sites**

The potential generating sites are accessed and yearly sales amounts of DCs are collected from historical data to estimate the future growing sales and the amounts of waste generated each year. From the concepts of literatures reviewed, the average life span of DCs is five years with 75% of purchased amounts are reached at its end of life for developing countries. Taking these considerations into account, the study estimates the future sales and waste generated amounts of the potential generating sites.

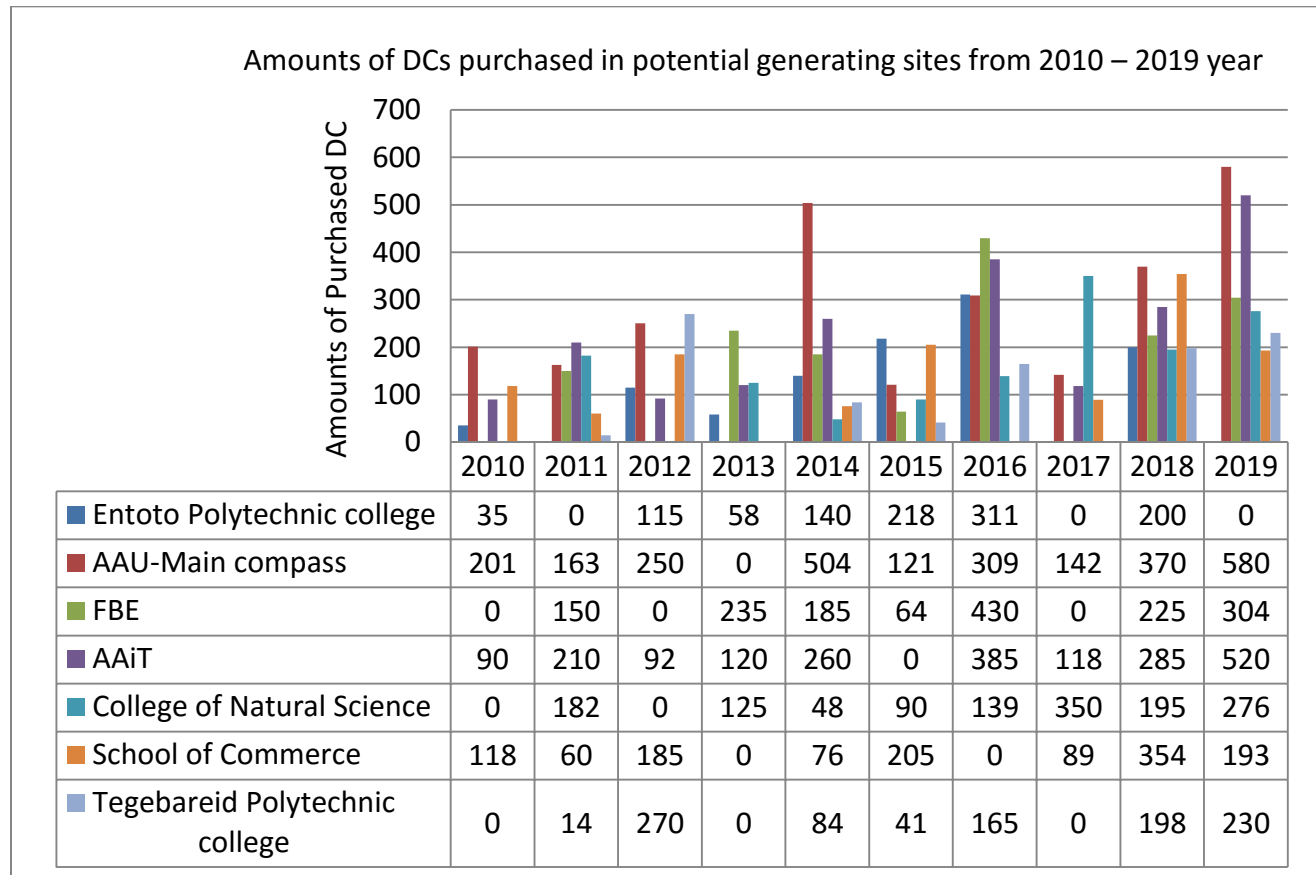


Fig. 4. 5: Amounts (in number) of DCs purchased in potential generating sites from 2010 – 2019 year

EEE is usable until its life span and no need of sale and waste generated in the life span duration. Therefore, if the potential generating sites buy certain amounts of DC at certain year, they may not buy or buy less amounts of DC in the next year. The waste generated is also depending on the sales amount and lifespan of the product. Thus why the above diagram indicating the variable amounts of sales and waste from year to year.

It is important to know the amount of the DC waste that will be generated and when it will be generated in order to establish appropriate collection infrastructures. The authors performed a material flow analysis model in this study to calculate the future e-waste amount from the potential generating sites. The model was based on the assumptions of the life span and historical and future sales data. The recycled and disposed amount to be generated in the future was calculated based on the end of life quantity with assumptions in their percentages, which is depend on the average life span. Estimation of the future amount of products to be collected for end of life management required forecasting the future sales.

In order to calculate the future sales amount, the study constructed two methods: The first method was annual decreasing rate concept to estimate the future sales amount and the second method was calculation of outflow/ waste generated from inflow/ sales data with percentages of products when reach its end of life. The two methods are depending on life span of the product.

$$R_d = \frac{S_y - S_{y-ls}}{S_y} \quad S_{y+1} = S_y * R_d + S_y$$

Where:  $R_d$  = annual decreasing rate at life span,  $S_y$  = sales amount in  $y$  year,  $S_{y+1}$  = sales amount in  $y+1$  year and  $ls$  = life span of the DC.

$$W_{ls} = \text{inflow} * P = (S * P),$$

Where:  $W$  = Outflow/ waste generated,  $S$  = sales/ inflow and  $P$  = percentage amount when product reaches at its end of life. For this study,  $P = 75\%$ .

Table 4. 7: DC annual decreasing rate, Sales and Waste of Potential generating sites

Year	R <sub>d</sub> and S of Potential generating sites													
	EPC		AAU-MC		FBE		AAiT		CNS		SC		TPT	
	R <sub>d</sub>	S	R <sub>d</sub>	S	R <sub>d</sub>	S	R <sub>d</sub>	S	R <sub>d</sub>	S	R <sub>d</sub>	S	R <sub>d</sub>	S
2015	0.825		0.661		0.250		0.200		0.171		0.424		0.122	
2016	0.730	365	0.472	201	0.651	80	0.455	90	0.309	96	1.500	292	0.915	46
2017	0.386	538	0.761	455	0.239	710	0.220	560	0.849	182	1.079	60	2.600	316
2018	0.710	115	0.757	250	0.044	114	0.579	144	0.359	647	0.921	185	0.970	270
2019	0.383	342	0.131	650	0.391	235	0.500	450	0.826	265	0.606	680	0.635	390
2020	0.363	314	0.816	656	0.849	423	0.904	780	0.837	504	0.339	310	0.891	376
2021	0.273	428	0.741	1191	0.450	782	0.741	1485	0.850	926	0.942	415	0.768	711
2022	0.848	545	0.932	2073	0.919	1134	0.954	2585	0.796	1713	0.890	806	0.940	1257
2023	0.801	1007	0.908	4004	0.897	2176	0.944	5052	0.937	3076	0.768	1523	0.919	2439
2024	0.875	1814	0.924	7638	0.926	4127	0.947	9819	0.954	5957	0.928	2692	0.951	4680
2025	0.908	3401	0.955	14696	0.947	7950	0.959	19118	0.957	11638	0.940	5191	0.959	9130
Total = 71,124														
Year	S and W from Potential generating sites													
	EPC		AAU-MC		FBE		AAiT		CNS		SC		TPT	
	S	W	S	W	S	W	S	W	S	W	S	W	S	W
2016	365	273.75	201	150.75	80	60	90	67.5	96	72	292	219	46	34.5
2017	538	403.5	455	341.25	710	532.5	560	420	182	136.5	60	45	316	237
2018	115	86.25	250	187.5	114	85.5	144	108	647	485.25	185	138.75	270	202.5
2019	342	256.5	650	487.5	235	176.2	450	337.5	265	198.	680	510	390	292.5

						5				75				
2020	314	235.5	656	492	423	317.25	780	585	504	378	310	232.5	376	282
2021	428	321	1191	893.25	782	586.5	1485	1113.75	926	694.5	415	311.25	711	533.25
2022	545	408.75	2073	1554.75	1134	850.5	2585	1938.75	1713	1284.75	806	604.5	1257	942.75
2023	1007	755.25	4004	3003	2176	1632	5052	3789	3076	2307	1523	1142.25	2439	1829.25
2024	1814	1360.5	7638	5728.5	4127	3095.25	9819	7364.25	5957	4467.75	2692	2019	4680	3510
2025	3401	2550.8	14696	11022	7950	5962.5	1918	14338.5	11638	8728.5	5191	3893.25	9130	6847.5
Total = 53,343.05														

DC is one of fixed property type which serves at least three to five years depending on the situations before its end of use. Therefore the sales techniques of this device depend on its annual decreasing rate or depreciation rate. There may be sales or not at certain years and accumulations of the device from previous year’s sales will exist in the potential generating organizations. This analysis took these concepts into consideration to forecast and estimate the future sales and waste generated amount from the potential generating sites until the year of 2025.

From the results of the above analyzes of sales and waste forecast, the potential generating sites accumulates a total sales of 71,124 and waste of 53,344 amounts in number of DCs at the end of 2025. Specifically each potential generating sites accumulates (x, y) of sales and wastes of DCs respectively. Where: x = sales accumulated and y = accumulation of waste generated. Accordingly, EPC (3401, 2551), AAU – MC (14696, 11022), FBE (7950, 5963), AAiT (19118, 14339), CNS (11638, 8729), SC (5191, 3894) and TPC (9130, 6848) accumulate sales and wastes amount in number of DCs at the end of 2025.

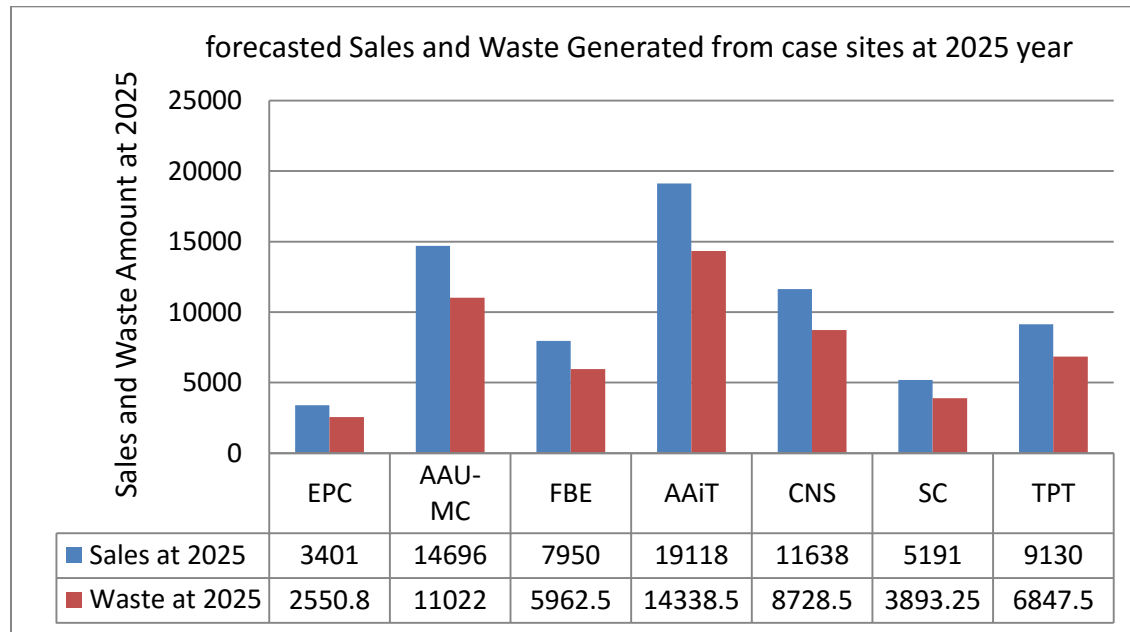


Fig. 4. 6: Sales and Waste Generated from case sites at 2025 year

#### 4.9. Selection and Locating RL Network Facilities

The considered quantitative model for locating collection and recycling facilities DC was earlier described in the paper and formulated mathematically as transportation problem using gravitational location method. As discussed on previous section desktop computers waste are considered as recyclable e-waste streams and potential generating sites are educational institutes and universities. The validation of the model is done with an assumption of a third party; Akaki-Kality computer refurbish and de-manufacture facility, which is the only e-waste dealer in Ethiopia. Five campus of Addis Ababa University and two polytechnic colleges have been selected as desktop computers waste generating sites and the amounts of waste generate is gathered from these sites through data collection tools.

The location of waste generating sites and collecting centers are indicated from Google Earth Pro software. The final actor in the network is the recycling plant, for this case study already established desktop computers waste recycling company located in Akaki-Kality sub-city is selected. In locating the collection facilities, two approaches were used. The first is where the collection sites are decentralized and second is when one centralized collection center is established for all generating sites and the method is chosen based on the results of the analysis.

For this case study, the decentralized collection center is preferred: as briefly described in previous, Gravitational location model is used for locating the facilities.

Three alternative collection centers were considered. In locating the three collection centers, the generating sites were clustered according to their proximity distance or closeness. Accordingly, generating sites,  $GS_1$ ,  $GS_2$  and  $GS_3$  are cluster 1,  $GS_4$  and  $GS_5$  are cluster 2 and lastly  $GS_6$  and  $GS_7$  are cluster 3. From the three clustered generating sites, three locations were identified as potential locations for collection center. The decentralized collection centers for each cluster are: for cluster 1, collection center 1 ( $CC_1$ ), for cluster 2: Collection center 2 ( $CC_2$ ) and for cluster 3: collection center 3 ( $CC_3$ ). In the other case one centralized collection center ( $CC$ ) is identified for all generating sites.

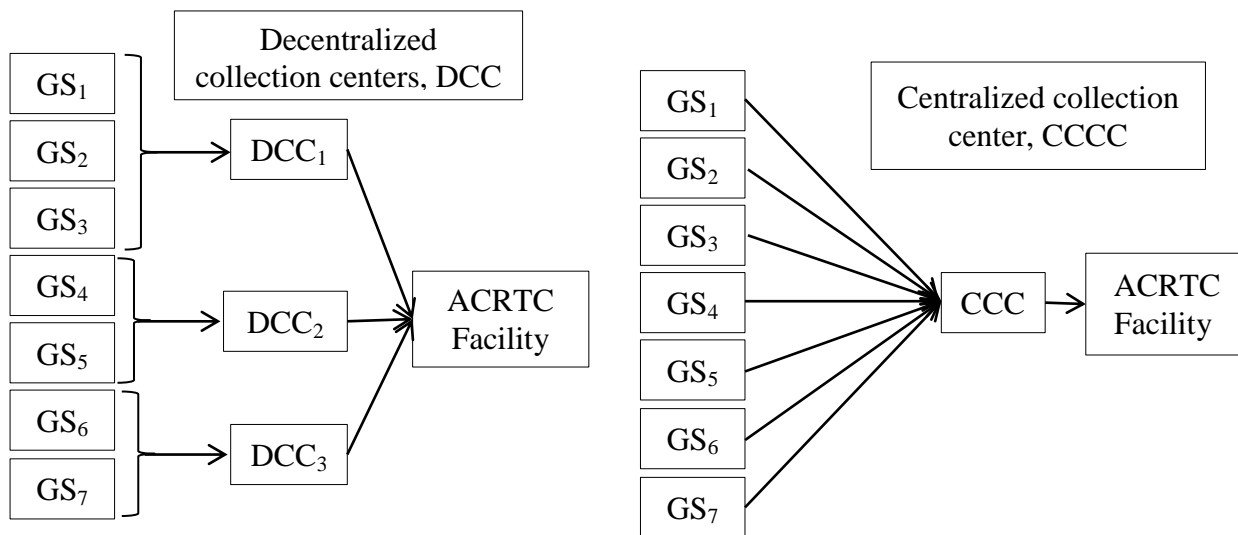


Fig. 4. 7: Candidate collection facilities for generating sites

The locations are computed with gravitational model, minimizing the transportation cost of waste desk top computer (DTC) from generating sites to collection center. All distance is calculated as Euclidian distance between two points. Finally, the model is solved using LINGO 18.0 x64.

Table 4. 8: Selection of collection centers

I	Generating Sites, $GS_i$	Longitude N°	Latitude E°	Amount of DTC in Kg	$L_x$	$L_y$	Center of Gravity
1	Teferi Mokonnen Polytechnic college	38.763	9.052	3,270	126,755.01	29,600.04	$C_{x1} = 38.761$ $C_{y1} = 9.049$
2	AAU-Main compass	38.760	9.048	12,410	481,011.60	112,285.68	
3	FBE	38.763	9.048	6,930	268,627.59	62,702.64	

4	AAiT	38.763	9.040	7,490	290,334.87	67,709.60	$C_{Y2} = 9.0373$ $C_{x2} = 38.7635$
5	College of Natural Science	38.764	9.035	7,280	282,201.92	65,774.80	
6	School of Commerce	38.750	9.013	4,630	179,412.50	41,730.19	$C_{Y3} = 9.0121$ $C_{x3} = 38.748$
7	Tegebareid Polytechnic college	38.744	9.010	2,130	82,524.72	19,191.30	
Total				44,140.000	1,710,868.21	398,994.25	$C_x = 38.760$ $C_Y = 9.0393$
$C_x = \frac{\sum Lxi}{\sum Amounti}$ $C_Y = \frac{\sum Lyi}{\sum Amounti}$ $i = 1,2,\dots,7$							





Fig. 4. 8: Assigned collection facilities locations

#### 4.9.1. Decentralized collection Centers facility model

The e-wastes generated can be collected in its generating sites which is called pre or initial collection center. But in this study this pre-collection centers are considered as generating sites assuming that each generating sites have their own storage facility of e-wastes generated. The collected waste DTC from its generating sites are transported to the decentralized collection centers and then to the processing facility, ACRTC by truck.

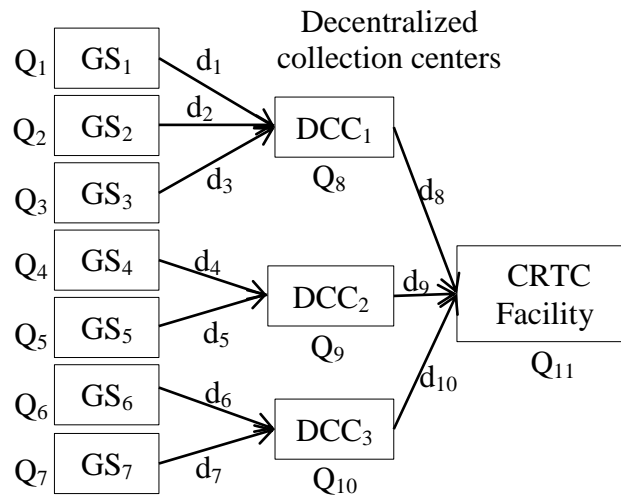


Fig. 4. 9: Decentralized collection center facilities diagram

Taking the specific designed load carrying capacity of truck with two axles as 450 Kg (0.45ton), the total turns or total path transorted to ship the waste DTC between the facilities following the paths are known. The paths between generating sites, decentralized collection centers and the target facility are obtained from the Google Earth. As a sample calculations, the amount of waste DTC generated at generating site two, Addis Ababa University – main compass, GS<sub>2</sub> to decentralized collection center one, DCC<sub>1</sub> is 12,410 Kg/ 12.410 ton. Taking 450 Kg of capacity of truck, number of turns =  $\frac{12,410 \text{ Kg}}{450 \text{ Kg}} = 28$  turns.

Table 4. 9: Facility capacity and shipment quantity

Generating Sites Gsi or Quantity, Q <sub>i</sub>	quantity of waste, Q <sub>i</sub> in Kg	Turns/450 Kg of Truck	Decentralized collection centers, DCC or Q <sub>j</sub>	Capacity of DDC	Turns per 450 Kg of Truck
Q <sub>1</sub>	3,270	8	DCC <sub>1</sub> , Q <sub>8</sub>	22,610	51
Q <sub>2</sub>	12,410	28			
Q <sub>3</sub>	6,930	16			
Q <sub>4</sub>	7,490	17	DCC <sub>2</sub> , Q <sub>9</sub>	14,770	33
Q <sub>5</sub>	7,280	17			
Q <sub>6</sub>	4,630	11	DCC <sub>3</sub> , Q <sub>10</sub>	6,760	15
Q <sub>7</sub>	2,130	5			
Total		99	ACRTCF, Q <sub>11</sub>	44,140	99

For a single turn the path between GS<sub>2</sub> and DCC<sub>1</sub> is obtained from Google Earth as 0.84 Km. Therefore, the total path GS<sub>2</sub> and DCC<sub>1</sub> 0.84 Km x 28 = 23.52 Km. From the transportation standards of Addis Ababa city as  $\frac{0.6 \text{ birr}}{\text{Km}}$ , the total transportation cost to ship the waste amount

between  $GS_2$  and  $DCC_1$ , is calculated as  $\frac{0.6 \text{ birr}}{\text{Km}} * 23.52 \text{ Km} = 14.112 \text{ birr}$ . This transportation cost in birr per ton of the waste amount will be:  $\frac{14.112 \text{ birr}}{12.410 \text{ ton}} = \frac{1.137 \text{ birr}}{\text{ton}}$ .

Table 4. 10: Input parameters obtained from Google Earth and analysis

Transportation path, $d_{ij}$	Transportation path, Km		Transportation cost, $C_{ij}$	Transportation cost/ton, $C_{ij}$
	Single path	Total path		
d18	0.63	5.04	C18	0.925
d28	0.84	23.52	C28	1.137
d38	0.59	9.44	C38	0.817
d49	0.46	7.82	C49	0.626
d59	0.47	7.99	C59	0.659
d610	0.31	3.41	C610	0.442
d710	0.54	2.70	C710	0.760
d811	22.67	1156.17	C811	30.681
d911	21.70	716.10	C911	29.10
d1011	18.85	282.75	C1011	25.10

To reduce transportation cost the study formulate linear transportation model which is expressed below. The objective function is defined as:

$$\text{Minimize } Z = \sum_{i=1}^k \sum_{j=k+1}^m C_{ij}x_{ij} + \sum_{i=1}^m \sum_{j=m+1}^n g_{ij}x_{ij} + A_{fc}$$

Where,  $m = k + r_1$ ,  $n = m + r_2$ ,  $k$  = number of sources where waste is generated,  $r_1$  = number of collection site,  $r_2$  = number of reprocessing units,  $C_{ij}$  = unit transport cost between source  $i$  and collection site  $j$ ,  $g_{ij}$  = unit transport cost from source  $i$  or collection site  $j$  to reprocessing unit  $j$ ,  $x_{ij}$  = quantity of waste transported from source  $i$  or collection site  $j$  to reprocessing unit  $j$ .

$A_{fc}$  = Annual operational costs which includes: material cost, labor costs, truck rent, collection centers with its accessory facilities costs, other unexpected costs (costs for contingency activities) and etc.

Subject to constraints:

$$\sum_{j=k+1}^m x_{ij} = Q_i, i = 1, \dots, k,$$

$$\sum_{i=1}^k x_{ij} \leq Q_j, j = m+1, \dots, n$$

$$\sum_{i=1}^k x_{ij} - \sum_{j=m+1}^n x_{ij} = 0, j = k+1, \dots, m$$

Table 4. 11: Estimated annual operational costs (birr)

Estimated annual operational costs			
Costs	Quantity	Unit cost	Total cost
Material cost	44,410Kg	3.5	154,490
Labor cost	6*12	2,000	144,000
Truck rent	1	40,000	40,000
collection centers with its accessory facilities costs	3	60,000	180,000
other unexpected costs (costs for contingency activities)			30,000
Total			548,490

Then, from the data input of above tables and decentralized collection center facilities diagram:

$$\begin{aligned} \text{Min } Z &= \sum_{i=1}^3 \sum_{j=8}^8 C_{ij}x_{ij} + \sum_{i=8}^8 \sum_{j=11}^{11} g_{ij}x_{ij} + \sum_{i=4}^5 \sum_{j=9}^9 C_{ij}x_{ij} + \sum_{i=9}^9 \sum_{j=11}^{11} g_{ij}x_{ij} \\ &+ \sum_{i=6}^7 \sum_{j=10}^{10} C_{ij}x_{ij} + \sum_{i=10}^{10} \sum_{j=11}^{11} g_{ij}x_{ij} \\ &= 0.925x_{18} + 1.137x_{28} + 0.817x_{38} + 0.626x_{49} + 0.659x_{59} + 0.442x_{610} \\ &+ 0.760x_{710} + 30.681x_{811} + 29.100x_{911} + 25.100x_{1011} \end{aligned}$$

Subject to:

$$\begin{aligned} X_{59} &= 7.280 \\ X_{811} &= X_{18} + X_{28} + X_{38} & X_{610} &= 4.630 \\ X_{911} &= X_{49} + X_{59} & X_{710} &= 2.130 \\ X_{1011} &= X_{610} + X_{710} & X_{811} &\leq 22.610 \\ X_{18} &= 3.270 & X_{911} &\leq 14.770 \\ X_{28} &= 12.410 & X_{1011} &\leq 6.760 \\ X_{38} &= 6.930 & X_{ij} &\Rightarrow 0, g_{ij} \Rightarrow 0 \\ X_{49} &= 7.490 \end{aligned}$$

#### 4.9.2. Centralized collection Center facility model

The collected waste DTC from its generating sites are transported to the centralized collection centers and then to the processing facility. The same pcedues are followed to analyze the system as that of decentralized collection centers.

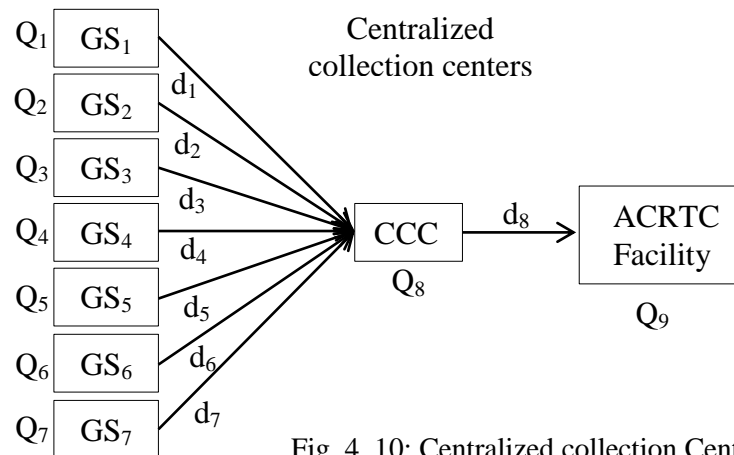


Fig. 4. 10: Centralized collection Centers facility model

Table 4. 12: Capacity of Centralized collection Centers

Generating Sites Gsi or Quantity, Q <sub>i</sub>	quantity of waste, Q <sub>i</sub> in Kg	Turns/450 Kg of Truck	Centralized collection centers, CCC or Q <sub>j</sub>	Capacity of DDC	Turns per 450 Kg of Truck
Q <sub>1</sub>	3,270	8	CCC, Q <sub>8</sub>	44,140	99
Q <sub>2</sub>	12,410	28			
Q <sub>3</sub>	6,930	16			
Q <sub>4</sub>	7,490	17			
Q <sub>5</sub>	7,280	17			
Q <sub>6</sub>	4,630	11			
Q <sub>7</sub>	2,130	5			
Total		99	ACRTCF, Q <sub>9</sub>	44,140	99

Transportation path, d <sub>ij</sub>	Transportation path, Km		Transportation cost, C <sub>ij</sub>	Transportation cost, C <sub>ij</sub> (birr/ton)
	Single path	Total path		
d18	1.65	13.20	C18	2.422
d28	1.61	45.08	C28	2.180
d38	1.29	20.64	C38	1.787
d48	0.74	12.58	C49	1.008
d58	1.06	18.02	C59	1.485
d68	4.31	47.41	C610	6.144
d78	4.77	23.85	C710	6.718
d89	22.14	2191.86	C811	29.794

$$\begin{aligned} \text{Min } Z &= \sum_{i=1}^7 \sum_{j=8}^8 C_{ij}x_{ij} + \sum_{i=8}^8 \sum_{j=9}^9 g_{ij}x_{ij} \\ &= 2.422x_{18} + 2.180x_{28} + 1.787x_{38} + 1.008x_{48} + 1.485x_{58} + 6.144x_{68} + 6.718x_{78} \\ &\quad + 29.7941x_{89} \end{aligned}$$

$$\begin{aligned} \text{Subject to:} & & X_{58} &= 7.280 \\ X_{89} &= \sum_{i=1}^7 \sum_{j=8}^8 x_{ij} & X_{68} &= 4.630 \\ X_{18} &= 3.270 & X_{78} &= 2.130 \\ X_{28} &= 12.410 & X_{89} &\leq 44.140 \\ X_{38} &= 6.930 & X_{ij} &\Rightarrow 0, Q_{ij} \Rightarrow 0 \\ X_{48} &= 7.490 \end{aligned}$$

From the analyzed results of the two collection facilities/ centers (decentralized and centralized collection center), the decentralized collection center is optimal because, it incurred a total transportation cost of 35.948 birr compared to a total transportation cost of 101.93 birr for centralized collection center. Assuming that the total annual operational cost of the two collection facilities is the same and to be 548,490 birr, the centralized collection center incurred a total system cost of  $101.93 + 548,490 = 548,591.93$  birr and that of decentralized collection center will be  $35.948 + 548,490 = 548,525.48$  birr.

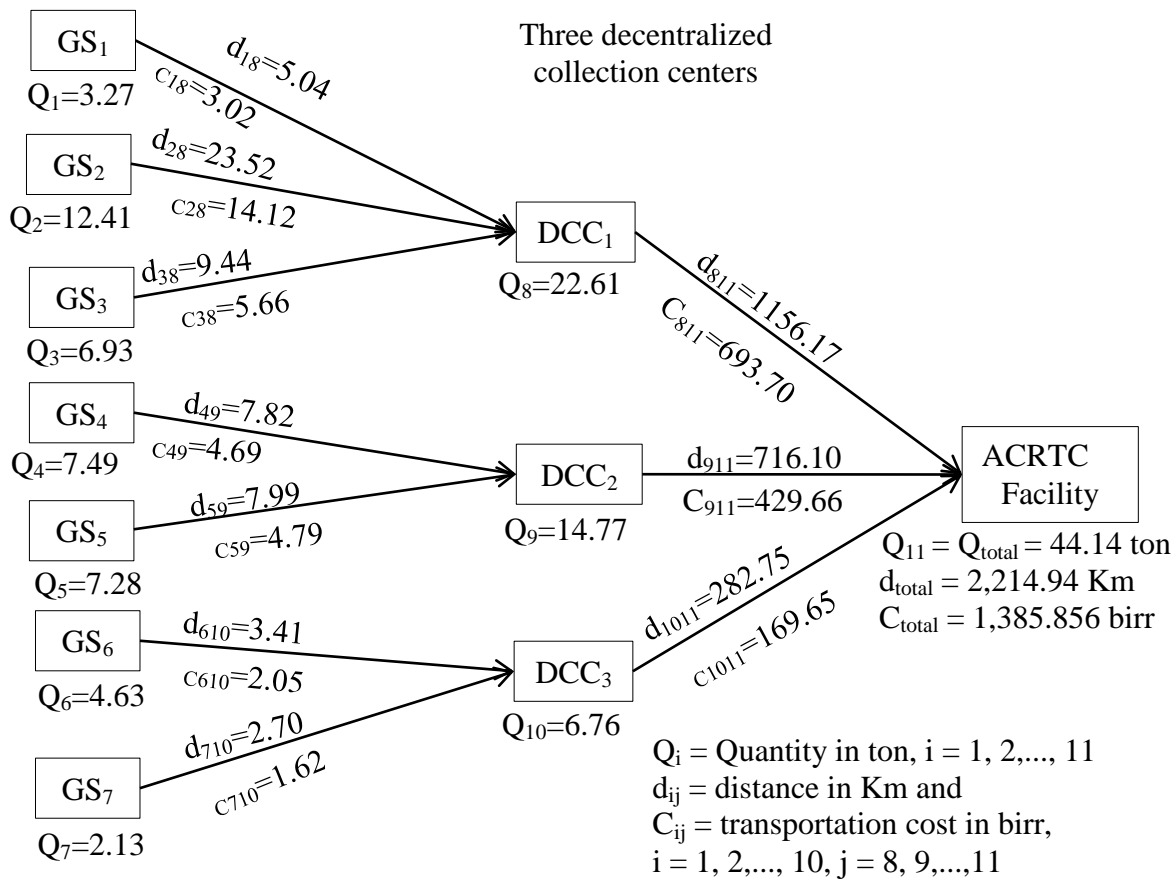


Fig. 4. 11: Decentralized collection center with its capacity

As concluded from the literatures, 95% of e-wastes can be recycled. To roughly estimate the profit obtained from the collected waste, 95% of 44,140 Kg = 41,933 Kg. After processed, As the results of survey questionnaire, ACRTCF is selling its products at about 25birr/Kg. This will be 25birr/Kg\*41,933Kg = 1,048,325 birr. Depending on the results of the research analysis, the total profit = selling price – total cost = 1,048,325 – 548,525.48 = 499,799.52 birr. This is a huge profit that obtained from a single type of e-waste. If the analysis is done on all categories of e-waste, more profit can be obtained. Accordingly, after e-waste is systematically collected and its collection systems and collection facilities are analyzed and evaluated, the next step is reprocessing activities like refurbish, de-manufacture and etc. in reprocessing facility. These analyzed and evaluated results of this study are used as a system input for the case study company which is ACRTC facility. This facility is the only e-waste dealing facility in Ethiopia. This facility refurbishes and de-manufactures e-waste and gives training service for government and non-government organizations.

#### 4.10. E-waste re-processing system

ACRTCF is the only EW dealing facility in Ethiopia located in Akaki-Kality sub-city of Addis Ababa. This facility collects varieties of EW especially from governmental organizations to refurbish and de-manufacture for selling to second market and also give skill development training on how to maintain electronic equipment. The major EW category this reprocessing facility dealing with is PC especially DC. Due to this reason, the study mainly focused on waste management of DC.

Electronic waste is delivered to the reprocessing facility from generating sites; stored to its warehouse; taken to the refurbishing department and then sorted and categorized depending on expected quality. According to their relative quality, the products are graded as grade 'A', 'B' or 'C'. Grade 'A' product can easily refurbished and ready for selling. Grade B needs more refurbishment processes. If it is reusable, it can be sold, otherwise taken to the de-manufacturing department with grade C product. In de-manufacturing department, the product is disassembled to its constituent parts or sub-parts and collected according to their types. Large component of disassembled part is compacted by pressing machine to save place and easy of transportation.

This processing facility is not selling all the disassembled parts EW. The facility has market link of some EW parts like metallic part, aluminum, copper and cartridge. Other parts like lead, circuit board, plastics, glass and other parts are stored and waiting for market or disposal. From the disassembled sub-parts circuit board needs especial techniques because of its integrated constituents which are precious metals like silver, gold, copper and platinum which can't be disassembled easily. It requires extra reprocessing methods like crushing, pulverization, separation and etc. Generally, the method of dealing with EW in the reprocessing facility, ACRTCF, is illustrated as follows.

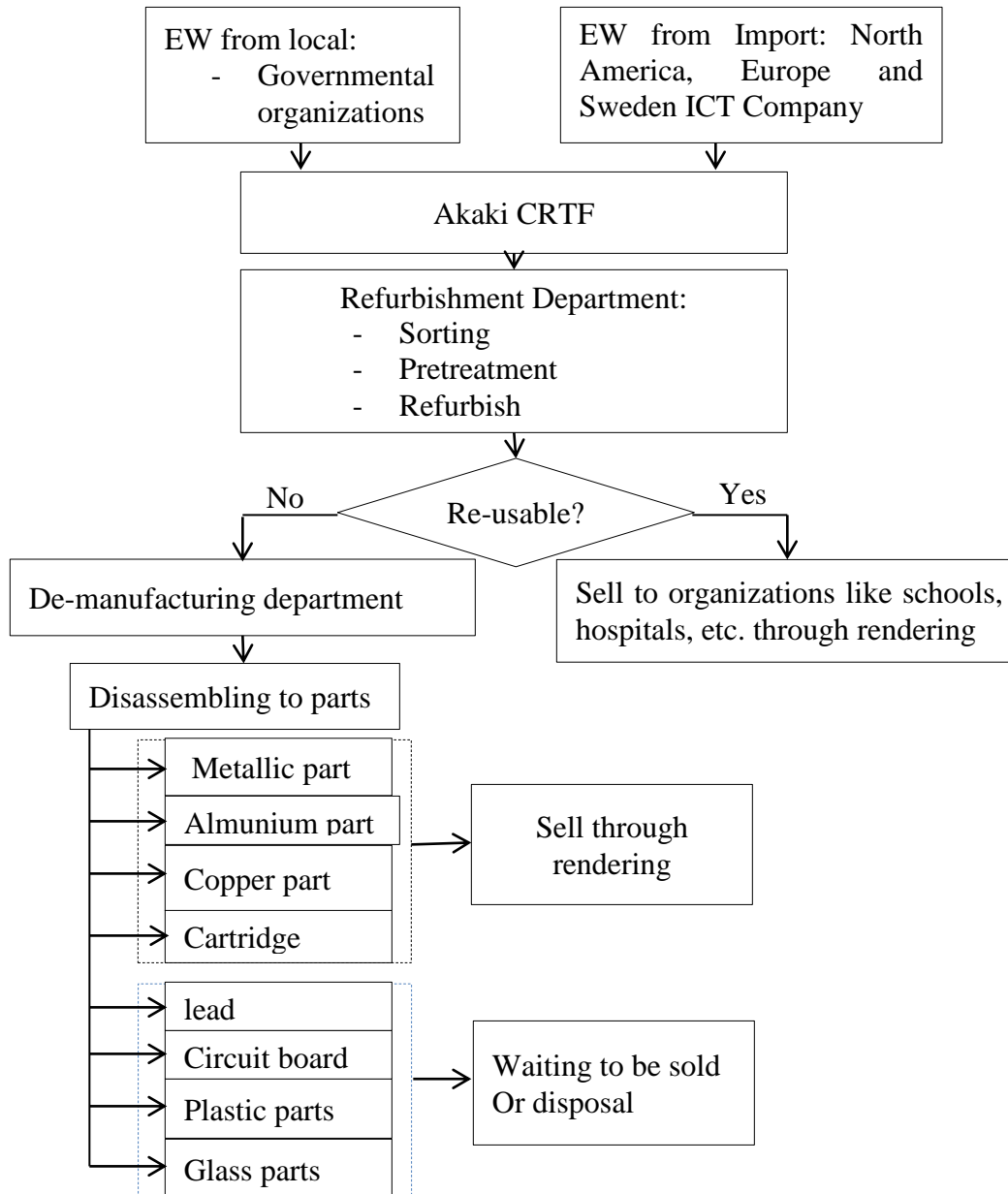


Fig. 4. 12: ACRTF process flow chart

The methods of reprocessing EW in ACRTC are not fully effective due to some disassembled parts are simply stored for the shortage of market linkage and disposed to the environment as mentioned above. From disassembled parts of the DC, like circuit board, plastics, glasses and others. are dangerous to the environment and thus needs special care.

To solve these problems of reprocessing methods in the facility, this study formulated a modified EW reprocessing technique which is depicted in the following figure.

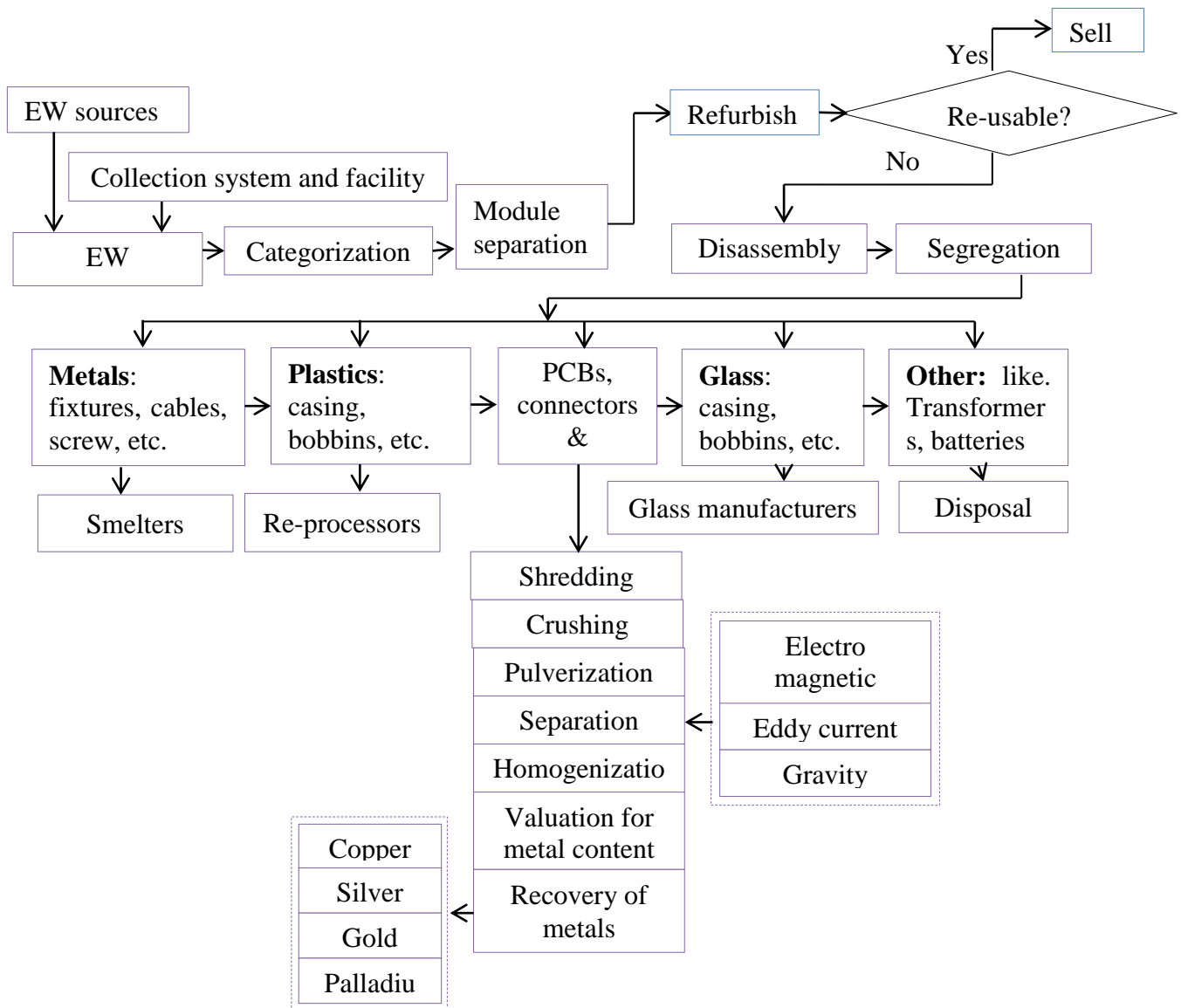


Fig. 4. 13: modified e-waste reprocessing system for ACRTF

#### 4.11. Data Analysis and Discussion Summary

The purpose of this study was to analysis and design the network of e-waste specifically DC collection system through identifying the key challenges e-waste management system of the case, identification and analysis of the potential generating sites with their future perspectives of e-waste generation, collection facility system design and methods of reprocessing systems in the reprocessing facility. This study revealed that the major problems of e-waste RL system is the problem of supply network through which e-waste is collected from its end users specifically due to the lack of facilities and networking system and related infrastructure which measures a total score of 103, percentage score weight of 4.97%, relatively positive PC than other RL barriers and reliability of Cronbach's Alpha of 0.631.

DC waste is one of the most dominant e-waste categories that available in educational organizations and constituents important and dangerous components that need proper management system. This waste is one of the fast growing e-waste category due to design change as a results of science and technology advancement dynamic users' interest. As the results of study conducted in potential generating sites DC sale reaches 71,124 and waste of 53,343 units in 2025 year. Accordingly, EPC (3401, 2551), AAU – MC (14696, 11022), FBE (7950, 5963), AAiT (19118, 14339), CNS (11638, 8729), SC (5191, 3894) and TPC (9130, 6848) accumulate sales and wastes amount in number of DCs respectively at the end of 2025 year.

To solve the problems of RL systems as this study revealed, the study designed the collection system of e-waste specifically DC waste from its potential generating sites by assessing their location by Google Earth software and amount of DC waste units accumulated in 2019. The design systems of this study compared two collection systems with their facility costs: decentralized collection system and centralized collection system.

From the analyzed results of the study's optimization by LINGO 18.0 software, the decentralized collection system is the optimal collection network system with optimal collection cost of 548,526 birr and optimal collection distance of 2,215Km compared to centralized collection network system with collection cost of 548,592 birr including fixed and operating costs. After this waste is properly collected through this designed collection network, it is

transported to the reprocessing facility where it passes through simple or complex reprocessing activities like refurbish, assembling de-manufacturing or disassembling to its specific parts and sold to the concerned customers.

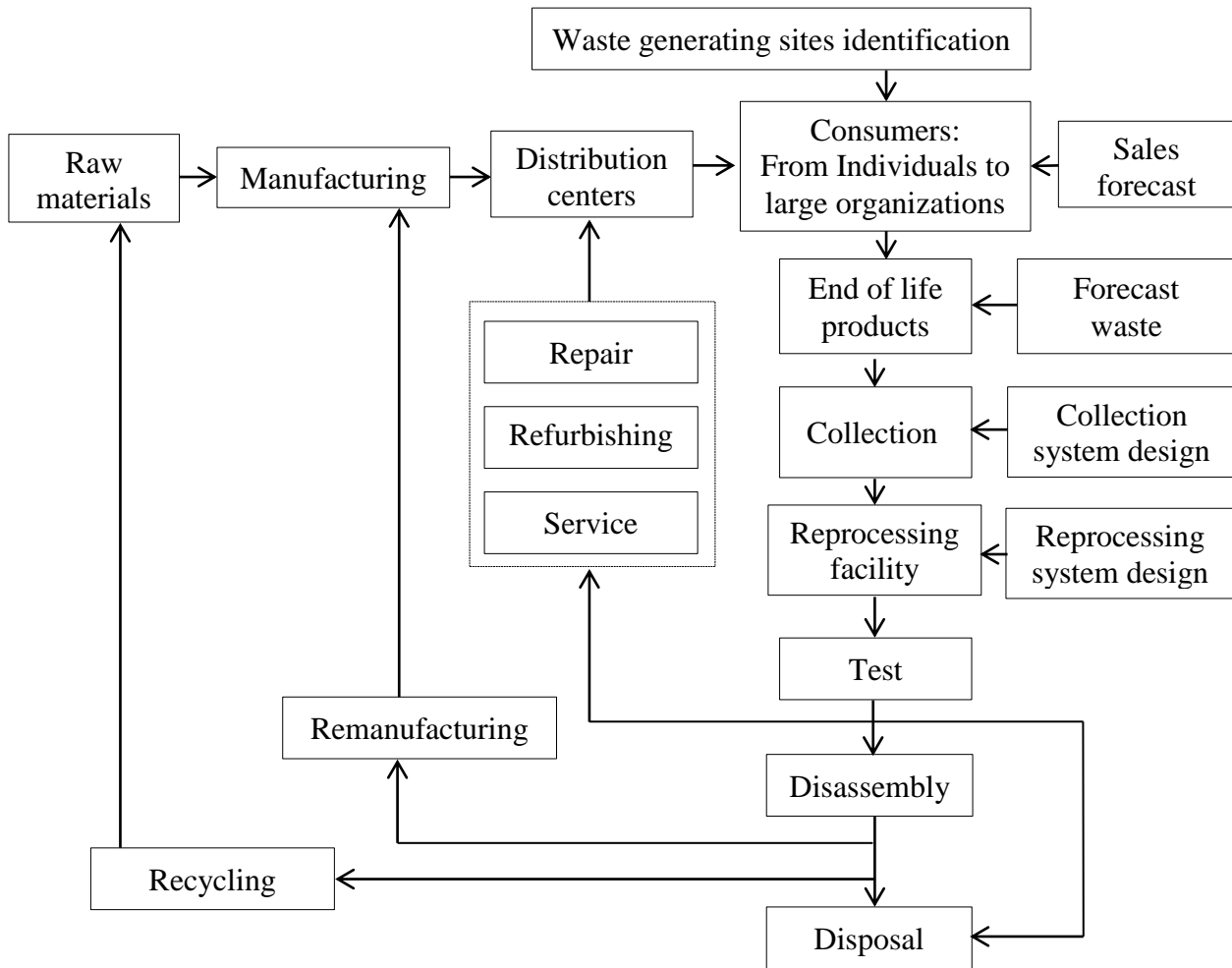


Fig. 4. 14: E-waste RLN model

## CHAPTE FIVE

### CONCLUSION AND RECOMMENDATION

#### 5.1. Conclusion

Waste of electrical and electronic equipment, or e-waste, is one of the fastest growing municipal solid waste streams due to continuous technology innovation and high demand from consumers. Managing e-waste has become a major challenge in many developing countries. The challenge faced in e-waste management is not only the growing quantities of waste but also the complexity of e-waste. E-waste is one of the most complex waste streams because of the wide variety of products ranging from mechanical devices to highly integrated systems and rapid change in the products' design. Electrical and electronic products are an integration of numerous modern technologies and are composed of many different materials and components. The composition of the electrical waste and electronic equipment depends on each item that composes it.

The purpose of this study was to analysis and design the network of e-waste specifically DC collection system through identifying the key challenges e-waste management system of the case, identification and analysis of the potential generating sites with their future perspectives of e-waste generation, collection facility system design and methods of reprocessing systems in the reprocessing facility. This study revealed that the major problems of e-waste RL system is the problem of supply network through which e-waste is collected from its end users specifically due to the lack of facilities and networking system and related infrastructure which measures a total score of 103, percentage score weight of 4.97%, relatively positive PC than other RL barriers and reliability of Cronbach's Alpha of 0.631.

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Generally, managements of e-waste is the concern of end user to take back the products at its end of life to the concerned agent, extended producers responsibility to recollect the product they produce and sold, government responsibilities to set rules and regulation for managing e-waste generated, settling infrastructures and facilities for collecting and managing e-waste to protect environment, health and implementing the reprocessing facilities with market connections of the reprocessed or de-manufactured components.

## 5.2. Recommendation

Conventionally, reverse logistics aims primarily at taking advantage of circular economy. However, reuse and recycling of used product in an improper way may lead to secondary pollution, so the environmental consideration of reverse logistics system is of great importance. The purpose of the thesis was to analyze and design effective reverse logistic system for e-waste management. To achieve the objective, researcher tried to identify practice related with computer refurbish and de-manufacture facility, explored the main barriers that affect the implementation of reverse logistic system, especially through taking the case study at ACRTC. This research forwards suggestions and recommendations which can help to solve the existing environmental problems and ensure effective recovery of used DC in order to achieve economic advantage and further protect the environment from the adverse effects. So, the researcher identified the problems and forwarded possible solutions to the problems as below: -

- E-waste management should be supported by participation and awareness of end user to take back the product at its end of life,
- The re-processing facility, ACRTF, should re design the facility layout for solving problems of space utilization, product improvement and easy material movement,
- Capacity improvement is needed for the case facility to accommodate large amounts of e-waste as this waste is produced in large amount from time to time,
- The case facility should design market networks because of that some disassembled parts and refurbished products are simply stored and waiting for market due to shortage of distribution networks,
- This model framework in this study can be extended for other different recovery strategies, this includes reusing, remanufacturing with understanding of the characteristics of the products involved,
- The model can be extended by accounting environmental constraints, minimization of the carbon emission during transportation and reprocessing,
- Government should formulate rules and regulations governing the e-waste management system to promote and sustain health and environmental protection,
- The user should be trained at individual level about the usage and proper disposal of e-wastes,

- Government bodies should work on organizing and supporting informal sectors which work on recycling of e-wastes,
- To collect e-wastes effectively and efficiently, the separation, collection, transportation and recycling processes must be given emphasis by the different stakeholders,
- Policies should be developed that encourage and promote informal sectors by taking into consideration the economic benefits gained from recycling of e-wastes, in terms of the contributions towards pollution control, and conservation of virgin resources,
- The network design can be applied for other case of solid and recyclable materials with different features and within their characteristics,
- Private sectors who are willing to plant e-waste recycling facility should be encouraged by lowering tax requirement, providing affordable space for recycling plant and marketing, allowing tax free imports of machinery etc.

### **5.3. Future Research Work**

The discrepancy in the various types of collection options makes it challenging to come up with a standard index and introduce an accessibility index for other end of life options like sell to the secondhand market that can be comparable to return accessibility.

In this study, only the accessibility of the collection programs is considered in the model. However, in reality, selling the product to the secondhand market may or may not be more accessible, depending on the geographical location or the availability of waste recovery regulations at each location. Further investigation of such factors should be a priority in the future work. More comprehensive reverse logistics system should be formulated for handling different types of used products. Appropriate treatment of uncertainties related to the quantity and quality of the reverse material flow is also suggested as one of the most promising directions for the future improvement of this study.

There are several issues that require further research with regard to e-waste RL system. Lastly, though conducting the literature review, some gaps in the area of e-waste reverse logistic network design and their major barriers that affecting implementation of reverse logistic were identified and proposed as future direction. Therefore, in linking with the summarized gaps the following future direction can be given to extend the work of this study:

- Integration of stakeholders along with value recovery from e-wastes management system,
- Process of recovering virgin components from e-waste through chemical analysis,
- Methods of creating end user awareness to take back e-equipment after their end of life,
- Policy needed to minimize effects of e-waste,
- Monitoring e-waste management at Ethiopian national level
- Determining the optimum collection periods through mathematical models so as to strength the sustainability of the network,
- Expansions of e-waste re-processing facility through Ethiopian regions and facilities location study

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## Appendix A

### A1. Questionnaire for case Company, ACRTC Facility

Addis Ababa University  
Addis Ababa University Institute of Technology  
School of Mechanical and Industrial Engineering

#### Issues: - Data Collection Questionnaire

This is an academic exercise aimed at gathering primary data towards writing a thesis work entitled “Reverse logistic network design for e-waste management in Addis Ababa City” for the partial fulfillment of M.Sc. degree program in Industrial engineering.

The objective of this questionnaire is to obtain the opinion of different experts on recycling of e-wastes for reuse and its environmental effects on stated places. Therefore, I kindly request you to share your great idea because, I believe that your experience and your cooperation in providing honest and prompt to questionnaire is valuable for the success of the study and it would be very much appreciated. The information obtained will be used for the academic research purposes only and will not be transferred to other parties for any other purpose. And also, it is confidential that no attempt will be made to identify any individual or organizational information in any of the publications. Thus, please feel free and provide your personal opinion to each question.

**Note:** the information obtained here will be held in a strictly confidential manner. Neither your name nor your business company name will be used in any document based on this survey.

For any enquiry, please contact; Researcher: - Sisay Negesse

Tel; 0923 5811 22, Email: [mengstudent740@gmail.com](mailto:mengstudent740@gmail.com)

Advisor: Dr.-Ir. Kassahun Yimer

Co- advisor: Wogene T. (PhD) candidate

Thank you very much for your cooperation!

### **Part one: - Personal Information**

The following questions refer to your personal background and experience and you are cordially invited to provide the most appropriate response (by filling the blanks and putting a thick mark in the box provided) to each of the questions per the response choices provided under each question. What is your gender?  Female  Male

1. Your age in years: - \_\_\_\_\_

2. Your profession background: - \_\_\_\_\_

3. What is your position in this company: - \_\_\_\_\_

4. Your work experience in the industry:

Less than one year  1 – 5 years  6 – 10 years  above 10 years

5. Please indicates your educational level:

Primary School  high school  certificate  diploma  Bachelor's degree

Master's Degree  PHD

6. How many persons do your company employed?

1 – 50  50 – 100  100 – 300  300 – 500  above 500

### **Part Two: Suppliers, the Company and Customers' Logistics Related Issues**

1. What barriers of Reverse Logistics related to suppliers do exist in your company? Check all that if the following barriers exist in your system and Please rate the level of existence of the barriers using, (Very low = 0, Low = 1, Medium = 3, High = 5 and Very high = 7) by putting tick mark (√) in the corresponding cell.

2. Which of Reverse Logistics problems do you think that your company is challenging? Check all that if the following Drivers are helpful and Please rate the Degree of importance for the Reverse Logistics Drivers using, (Very low = 0, Low = 1, Medium = 3, High = 5 and Very high = 7) by putting tick mark (√) mark in the corresponding cell.

Suppliers Related Issues		Level of Existence				
		0	1	3	5	7
1.	Lack of awareness of end users to take back used e-wastes					
2.	Lack of sufficient information and technology systems to track used e-wastes					
3.	Economic and Company policy barriers to get suppliers					
4.	Lack of government support, legal and political issues					
5.	Lack of facilities and networking system and related infrastructures					
6.	Lack of competitive issues among suppliers					
7.	Improper suppliers management systems					
8.	Lack of purchased/ collected e-wastes quality issues					
9.	Lack of cooperative supply chain partner integration					
10.	Lack of functional integration					
11.	Lack of importance of reverse logistics relative environment, health and economic benefits					
Within the Company Related Issues		Degree of Existence				
		0	1	3	5	7
1.	Performance management problems					
2.	Lack of interdepartmental integration					
3.	Lack of Operational performance system					
4.	Employee awareness, capacity building and incentives for performance improvements					
5.	Problem of inventory and capacity management					
6.	Lack of process planning and management					

7.	Absence of required machines, material handling equipment and other related accessories					
8.	Governmental, legal and Political issue problem					
9.	Financial problems					
10.	Inability to be Competitive					
11.	Hinders from Environmental regulation					

3. What problems of Reverse Logistics related to customers do exist in your company? Check all that if the following barriers exist in your system and Please rate the level of existence of the barriers using, (Very low = 0, Low = 1, Medium = 3, High = 5 and Very high = 7) by putting tick mark (√) in the corresponding cell.

Customers Related Issues		Degree of Existence				
		0	1	3	5	7
1.	Lack of awareness of buyers for processed products					
2.	Lack of sufficient information and technology systems to attract markets					
3.	Lack of facilities and networking system and related infrastructures for selling the end product					
4.	Lack of competitive issues among the customers for the products demand					
5.	Absence of market need for some produced product/s					
6.	Improper customers management systems					
7.	Quality problems of processed products					
8.	Lack of cooperative customer chain partnership integration					

**Part Three: general information**

1. How many used computer you bought per year? Please, fill the table below.

Year	From Local	From Import	No. of refurbished and sold computer		De-manufactured amount
			To Export	To Local	

2014					
2015					
2016					
2017					
2018					
2019					

2. From where did your company buy – Suppliers the used computer and where to sell – customers the refurbished computer?

	Suppliers		Customers	
	Name of supplies	Location	Name of customers	Location
1.				
2.				
3.				
4.				
5.				

3. Please, Try to Answer the Following Questions in Detail.

Do you have any competitors that refurbish/ recycle used computers in Ethiopia?

yes  no If 'yes, list them: \_\_\_\_\_

What are the major problems in the current reverse logistics system of your company exists?

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

4. How does your company get the used computer from the suppliers?

\_\_\_\_\_

\_\_\_\_\_

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5. Do you have a collection center in order to collect the used computer?

If yes: list them with their location \_\_\_\_\_

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6. Does your company has a distribution center to sell the refurbished computer or how do  
your company sell the refurbished computer?

If yes: list them with their location: \_\_\_\_\_

---

7. Please, list out the benefits of a good reverse logistics process from your experience in  
your company?

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8. What factors are driving you to apply the reverse logistic system?

## A2. Questionnaire for potential generating sites

**Addis Ababa University**  
**Addis Ababa University Institute of Technology**  
**School of Mechanical and Industrial Engineering**

**Issues:** - Data Collection Questionnaire

This is an academic exercise aimed at gathering primary data towards writing a thesis work entitled “Reverse logistic network design for e-waste management in Addis Ababa City” for the partial fulfillment of M.Sc. degree program in Industrial engineering.

The objective of this questionnaire is to obtain the opinion of different experts on recycling of e-wastes for reuse and its environmental effects on stated places. Therefore, I kindly request you to share your great idea because, I believe that your experience and your cooperation in providing honest and prompt to questionnaire is valuable for the success of the study and it would be very much appreciated. The information obtained will be used for the academic research purposes only and will not be transferred to other parties for any other purpose. And also, it is confidential that no attempt will be made to identify any individual or organizational information in any of the publications. Thus, please feel free and provide your personal opinion to each question.

**Note:** the information obtained here will be held in a strictly confidential manner. Neither your name nor your business company name will be used in any document based on this survey.

For any enquiry, please contact; Researcher: - Sisay Negesse

Tel; 0923 5811 22,      Email: [mengstudent740@gmail.com](mailto:mengstudent740@gmail.com)

Advisor: Dr.-Ir. Kassahun Yimer

Co- advisor: Wogene T. (PhD) candidate

Thank you very much for your cooperation!

1. What types and amounts of electronic waste/ e-waste generated in your organization from 2015 – 2019?

Types of e-waste	E-waste generated from 2015 – 2019 (amount or in Kg)				
	2015	2016	2017	2018	2019

2. What types and amounts of electronic equipment purchased in your organization from 2010 – 2019?

Types of electronic equipment purchased	Electronic equipment purchased from 2010 – 2015 (amount in number)									
	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019

## Appendix B

### B1. Results of ran software

Lingo 18.0 results: DCC

Global optimal solution found.

Objective value: 35.948  
 Infeasibilities: 0.0000  
 Total solver iterations: 0  
 Elapsed runtime seconds: 0.04

Model Class: LP

Total variables: 4  
 Nonlinear variables: 0  
 Integer variables: 0

Total constraints: 4  
 Nonlinear constraints: 0

Total non-zeros: 7  
 Nonlinear non-zeros: 0

Variable	Value	Reduced Cost	Row	Slack or Surplus	Dual Price
X18	3.2700	0.0000	1	35.948	-1.0000
X28	12.410	0.0000	2	0.0000	-0.92500
X38	6.9300	0.0000	3	0.0000	-1.1370
X49	7.4900	0.0000	4	0.0000	-0.81700
X59	7.2800	0.0000	5	0.0000	-0.62600
X610	4.6300	0.0000	6	0.0000	-0.65900
X710	2.1300	0.0000	7	0.0000	-0.44200
X811	0.0000	30.681	8	0.0000	-0.76000
X911	0.0000	29.100	9	22.610	0.0000
X1011	0.0000	25.100	10	14.770	0.0000
FAC	0.0000	1.0000	11	6.7600	0.0000

Lingo 18.0 results: CCC

Global optimal solution found.

Objective value: 101.93  
 Infeasibilities: 0.0000  
 Total solver iterations: 0  
 Elapsed runtime seconds: 0.04

Model Class: LP

Total variables: 1  
 Nonlinear variables: 0  
 Integer variables: 0

Total constraints: 2  
 Nonlinear constraints: 0

Total non-zeros: 2

Nonlinear non-zeros: 0

Variable	Value	Reduced Cost	Row	Slack or Surplus	Dual Price
X18	3.2700	0.0000	1	101.93	-1.0000
X28	12.410	0.0000	2	0.0000	-0.42200
X38	6.9300	0.0000	3	0.0000	-2.1800
X48	7.4900	0.0000	4	0.0000	-1.7870
X58	7.2800	0.0000	5	0.0000	-1.0080
X68	4.6300	0.0000	6	0.0000	-1.4850
X78	2.1300	0.0000	7	0.0000	-6.1440
X89	0.0000	29.794	8	0.0000	-6.7180
			9	44.140	0.0000