ICT Waste Handling: Regional and Global End-of-Life Treatment Scenarios for ICT Equipment

Andrew Liebmann

ROYAL INSTITUTE OF TECHNOLOGY

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Supervisor:
Xingqiang Song
Examiner:
Monika Olsson

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Abstract

Electronic waste is the fastest growing waste stream today and information and communications technology (ICT) equipment make up a significant portion of all the electronics put on market. Due to the valuable, rare, and toxic material content of ICT equipment, their disposal requires proper treatment to ensure materials are recovered and harm to the surrounding environment and nearby residents is avoided. As a tool used to identify the impacts resulting from a product, life cycle assessment (LCA) requires details around the processes performed during each stage of a product's life. LCA studies on ICT waste often assume that discarded equipment is fully recycled under formal conditions. This study investigates current ICT waste treatment practices and proposes a more reasonable end-of-life treatment scenario for use in future LCA work. The volume of ICT waste generated in each country is estimated according to reported mobile phone subscription counts, and treatment flows are investigated for the countries identified as generating the most waste in each region. National results are then aggregated to estimate regional and global end-of-life treatment scenarios.

The research indicates that developed countries properly recycle the majority of the ICT waste that is collected and treated domestically; the United States is an exception as a majority of ICT waste generated there is discarded to landfills. Developing countries tend to recycle a majority of electronic waste in informal sectors where a lack of technology and limited enforcement of regulations result in harmful waste processing activities. Waste is also exported from developed countries for treatment in developing countries. The proposed global end-of-life treatment scenario is 19% of ICT waste is recycled under formal conditions, 64% is recycled using informal methods, and the remaining 17% is discarded in landfills. Due to a lack of uncertainty, there is a clear need for more research regarding the treatment of ICT waste, especially in regards to B2B waste and export flows. A sensitivity analysis to determine the overall impact these results may have when applied to an LCA study is recommended.

Keywords: End-of-life treatment, e-waste management, ICT network waste flows

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Abbreviations

APAC	Asia Pacific
B2B	Business-to-business
B2C	Business-to-consumer
CRT	Cathode ray tube
EEE	Electrical and electronic equipment
EoL	End-of-life
EoLT	End-of-life treatment
EoU	End-of-use
EPR	Extended producer responsibility
E-waste	Electronic waste
ICT	Information and communications technology
IT	Information technology
LCA	Life cycle assessment
PCB	Printed circuit board
UEEE	Used electrical and electronic equipment
UEP	Used electronic product
WEEE	Waste electrical and electronic equipment

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2 Introduction

An estimated 45 million tons of electronic waste was generated globally in 2012, and it is now considered the fastest growing waste stream with a 4% increase each year (Seitz, 2014). The growing waste stream is problematic for a number of reasons from the physical volumes of waste to deal with to potential impacts from toxic content or loss of valuable and rare materials when proper disposal methods are not practiced (Robinson, 2009). With a growing concern over products and their potential impacts, manufacturers have started producing goods with improved environmental performance. One of the tools used to analyze the environmental performance of a product, process, or service is life cycle assessment (LCA).

Life cycle assessment offers a comprehensive framework to evaluate the environmental performance of a product or process through identifying the material and energy inputs and emissions of each life cycle stage, from resource extraction to final disposal. For disposal, it is often assumed that proper waste treatment activities are performed, unless improper disposal methods are known to be present (USEPA, 2006). Arushanyan et al. (2014) state that most research is conducted with a limited focus on energy and carbon footprints, and that many of the other impact categories are overlooked. Under the commonly used assumption that discarded equipment is treated according to the best case scenario, the environmental impacts resulting from the disposal stage may be underestimated. This scenario is used for example in a previous LCA study on mobile phone networks that assumes full recovery of recyclable materials and energy and stabilization of any remaining materials before disposal to landfill (Scharnhorst et al., 2006).

Another approach used is to assess the impacts of multiple end-of-life scenarios. As an example, a LCA study of desktop computers considers the resulting impacts from three different end-of-life treatment scenarios: 1) all waste equipment landfilled, 2) worst case recycling where waste equipment is recycled under informal conditions, and 3) best case recycling where proper treatment is performed under controlled conditions (Duan et al., 2009).

2.1 Problem definition

If the assumption of complete formal recycling of retired equipment is inaccurate, the resulting impacts of an LCA study are inaccurate. Therefore a need exists for researching current electronic waste treatment practices to support accurate LCA modeling.

Three different approaches were taken to calculate end-of-life impacts in recent mobile phone LCA studies at Ericson Research. The first study was performed under the assumption that 25% of phones discarded in Sweden are recycled under safe and environmentally sounds conditions, another 50% end up in landfills, and the remaining 25% are exported and recycled under uncontrolled and environmentally harmful conditions (Moberg et al., 2014). In a more recent study, the end-of-life stage is allocated a fixed 2% of the device’s total life cycle impact concerning global warming potential, a method which was taken from studies conducted by Apple (Ercan, 2013). No evidence is given that a thorough investigation of waste treatment flows was performed to validate the methodology used in either study. In a third LCA study conducted at Ericsson, the only end-of-life impacts considered in the decommissioning of network equipment are the carbon dioxide emissions resulting from transportation of waste for disposal (Kultur, 2012).

This thesis investigates current ICT waste flows to propose an end-of-life treatment scenario for application in future LCA studies on ICT devices and network equipment. The proposed EoLT scenario offers a more reasonable basis for assessing the impacts associated with disposal of retired equipment than the approaches otherwise used.

A copy of the initial project proposal as published by Ericsson is provided in Appendix I.

2.2 Aim and Objectives

The aim of this study is to improve life cycle assessment modeling within the ICT sector by updating the end-of-life treatment assumptions for ICT equipment. Each objective of the study is listed in Figure 1.

The following objectives are taken to achieve the goals of this study:

- Identify the countries generating the largest volume of ICT waste.
- Describe the electronic waste management system in each country.
- Identify the percentage of ICT waste directed to each form of EoLT.
- Develop a scenario of the estimated regional and global EoLT practices.

Figure 1: Study objectives

3 Methodology

This study is conducted using the research methodologies described here.

3.1 Literature review

The foundation of this study is a thorough review of recently published research on electronic waste treatment practices, mass flow assessments, and life cycle assessments. Most data are collected from publications of previous research on recycling systems and official national reports.

3.2 Country case studies

The literature review is used to investigate the electronic waste treatment practices in each country through individual case studies. Relevant countries are determined by the volume of ICT waste generated, which is estimated from the number of mobile phone subscriptions reported for each country. Mobile phone counts are considered as an indicator for the volume of ICT network waste generated because the devices are a source of waste on their own, and because the number of mobile phones in use drives the scale of network infrastructure necessary to support the phone service.

Table 1 lists the top 21 countries according to the reported number of active mobile phone subscriptions. The data is also used to determine the weight each country is given for estimating the regional and global waste treatment flows in chapter 4. No case studies are performed for Vietnam, Bangladesh, Thailand, and Turkey because it is assumed that a large enough representation is achieved based on the regional share of mobile phones subscriptions in the other countries investigated. Although not included in the list of top 21 countries, a review of the waste management practices in Ghana is considered necessary due to the level of electronic waste imported to the country for treatment. An extended list showing all countries and their corresponding mobile subscription counts is available in Appendix II.

Table 1: National mobile phone subscriptions (World Bank, 2014)

Country	Region	Mobile phone subscriptions	Global percentage
China	APAC	1,229,113 M	19%
India	APAC	886,304 M	13%
United States	North America	305,743 M	5%
Indonesia	APAC	303,695 M	5%
Brazil	Latin America	271,100 M	4%
Russian Federation	Europe	218,300 M	3%
Japan	APAC	146,455 M	2%
Pakistan	Middle East & North Africa	127,737 M	2%
Nigeria	Sub-Saharan Africa	127,246 M	2%
Vietnam	APAC	120,000 M	2%
Bangladesh	APAC	105,051 M	2%
Mexico	North America	105,006 M	2%
Philippines	APAC	102,824 M	2%
Egypt	Middle East & North Africa	99,705 M	2%
Germany	Europe	98,470 M	1%
Italy	Europe	96,904 M	1%
Thailand	APAC	92,463 M	1%
United Kingdom	Europe	78,144 M	1%
South Africa	Sub-Saharan Africa	77,826 M	1%
Turkey	Middle East & North Africa	69,661 M	1%
Argentina	Latin America	65,910 M	1%

3.3 Data Modeling

The country case studies are used to collect data on the end-of-use (EoU) and end-of-life treatment (EoLT) flows of ICT network waste generated in each country.

End-of-Use (EoU) - The first set of data identifies waste flows according to what is done with equipment once retired from use. Each flow is reported as a percentage of total volume of waste generated, and the four options are:

- Storage
- Reuse
- Export
- End-of-life treatment

All equipment passing through each of the first three flows will eventually be discarded for end-of-life treatment, but each flow is collected based on the relevance toward modeling impacts through LCA studies, such as the effect of reuse flows to operational lifetime. Data on export flows are necessary to understand the region or countries responsible for the waste generated and the corresponding impacts. The description and implications of each end-of-use option are discussed in more detail in later chapters of this study.

End-of-Life Treatment (EoLT) - The second data set is a breakdown of end-of-life treatment (the 4^{th} option listed under end-of-use flows) into the following three options:

- Formal recycling
- Informal recycling
- Landfill

All waste is assumed to eventually be either dumped or recycled. Both activities can occur under formal or informal conditions. Further explanation of each end-of-life treatment method is given in later sections of this study.

The EoLT data indicates the estimated distribution of end-of-life treatment methods performed within each country. In order to capture the eventual treatment of all waste each country is responsible for generating, the treatment of exported WEEE is also integrated when export flows exist. Export flows are assigned EoLT rates according to the assumed destination country and included with the domestic EoLT rates based on the weighted percentage of each flow.

The results for each country are then accumulated by geographic region to develop an estimated scenario for current waste treatment methods performed at a regional level. The consolidation of national data for a regional summary is done by weighting each country based on the proportion of ICT waste generated within the region. Finally, the regional scenarios are consolidated to estimate a global scenario for the end-of-life treatment of ICT waste.

3.4 Interviews

Several interviews are conducted with Ericsson employees to collect specific knowledge regarding the handling of network equipment once decommissioned. All interviews have an unstructured and open format to allow a flexible discussion.

3.5 Boundaries

The boundaries for each aspect of this study are defined here.

Temporal Frames - Considering the rate of change in the industry, data are collected from the most recent studies available. With a few exceptions, most of the research reviewed for this study was published between 2010 and 2014. When discussing waste stream flows, data is normally presented on an annual basis.

Equipment Categories - The system addressed in this study is the ICT network, and data are collected for end user devices as well as network infrastructure equipment. When data for these specific product categories are not available, the reported discard and treatment rates for all WEEE combined are used as a substitution. Chapter 3.1 discusses these equipment categories in more detail.

Geographic Boundaries – As ICT companies operate in a global market, it is necessary to examine waste treatment practices on a global scale. Due to the limited time available to conduct this study, only the most significant countries in each region are investigated. Significance is determined by the estimated volume of ICT waste generated by each country. National results are summarized to formulate regional and global EoLT scenarios.

3.6 Complexities and assumptions

A number of challenges exist when researching electronic waste generation and treatment flows. Where necessary, assumptions are made to enable use of data that supports the objective of the study. Some of the relevant challenges and assumptions are presented here to assist in explaining why the chosen methodologies were used and how they were applied. Any additional assumptions made in the study are specified as they are used.

It is well known that WEEE from developed countries is dumped in developing countries, but quantifying export flows is a very complicated, if not impossible, task. Among the many challenges described by Seum & Hermann (2010) and the Secretariat of the Basel Connvention (2011) the following are noted: no categorization exists to distinguish between new and used goods being exported, illegal shipments of UEEE or WEEE may be documented as legal shipments, federal statistics do not always match the data of local port systems, goods are declared using a variety of category codes, trade data are often reported in monetary value rather than by volume, customs declarations are submitted to the authorities as late as possible to avoid possible inspections. The recast of the EU WEEE Directive is addressing the lack of classification to distinguish between new and waste (or used) EEE by requiring several forms of documentation to verify the status of shipped goods in the future (European Union, 2012).

The unclear boundaries between various stages and actors within waste management systems make it difficult to identify waste streams. For example, waste equipment collected by a refurbisher does not automatically indicate that the equipment is repaired and reused. The same is true for recycled equipment, in both the formal and informal recycling sectors, where some non-valuable or non-recoverable waste fractions end up in a landfill. Accurately tracing the entire web of waste flows is a near impossible task, so the initial flows indicated are accepted as an estimate for the purpose of this study.

Using data from research covering a limited demographic or geographic area may be problematic when used to represent a greater population. Because national electronic waste flow data are not always available, results from smaller datasets are used as a representation for the larger population when necessary, despite the potential for demographic differences.

It is not always possible to distinguish between informal recycling practices and disposal to landfill; a grey line exists between the two EoLT categories because they share some characteristics. As discussed in the next chapter, landfills in some developing countries lack the controls necessary for managing discarded toxic materials. Disposing of waste in an uncontrolled landfill is similar to the open dumping activities associated with informal recycling. It will also be shown that scavengers collect valuable waste material from landfills for treatment in the informal recycling sector. These situations create exchanges between the two treatment categories and make it difficult to accurately distinguish between the two waste flows.

The techniques required to properly recycle some types of electronic waste demand highly advanced technological equipment that is extremely expensive. This leads to a limited number of locations in the world that have the capacity to perform some recovery activities, requiring the export of waste equipment for formal treatment. The implication is that exported waste may be processed in formal or informal sectors, making it difficult to identify which is the case for exported WEEE. Similarly, it is difficult to accurately identify export flows while various processing stages may be performed in different locations. Equipment that is partially processed prior to export is considered to be domestically treated for the purpose of this study.

4 Background

This chapter presents the necessary background information regarding electronic waste collection and treatment systems.

4.1 Electronic equipment categories

The hierarchy in Figure 2 suggests the relationship between each equipment grouping referred to throughout this study. The hierarchy is unique to this study and is developed to enable a more clear understanding of what is discussed. At the highest level, EEE indicates all electric and electronic equipment. Equipment is then subdivided based on the corresponding sector, such as ICT equipment. The next level of division separates ICT equipment into groupings of infrastructure equipment and end user goods. Network equipment on the infrastructure side is considered business-to-business (B2B) goods, whereas the end user devices could be considered either B2B or business-to-consumer (B2C) depending on the end user. For further clarification, B2B and B2C are a reference to the market in which products are used.

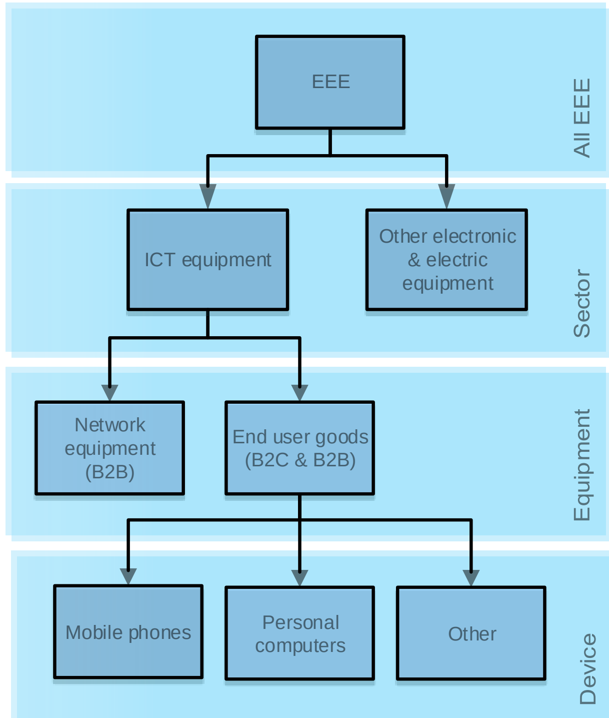

Figure 2: Electronic equipment hierarchy

Data collection is performed at the lowest level possible based on the data available. Because the granularity of data available varies significantly from region to region, data gaps are filled by substituting the most suitable data available.

4.2 Impacts from electronic waste

Electronics such as mobile phones and computers contain fiberglass- or epoxy resin-printed circuit boards that house numerous valuable metals such as gold, palladium, silver and copper, and a list of hazardous materials including gallium arsenide, antimony, beryllium, and brominated flame retardants (Hanafia et al., 2012). Around 3% of the gold and silver, 13% of the palladium, and 15% of the cobalt excavated each year are used in the manufacturing of just computers and mobile phones (UNEP, 2010). The statement by the European Commission in Figure 3 highlights some concerns over the proper end-of-life treatment of WEEE.

> *"WEEE is a complex mixture of materials and components that because of their hazardous content, and if not properly managed, can cause major environmental and health problems. Moreover, the production of modern electronics requires the use of scarce and expensive resources (e.g. around 10% of total gold worldwide is used for their production). To improve the environmental management of WEEE and to contribute to a circular economy and enhance resource efficiency the improvement of collection, treatment and recycling of electronics at the end of their life is essential."*

Figure 3: Importance of WEEE management (European Commission, 2014)

Improper disposal of electronic waste leads to a list of problems for both humans and the environment surrounding the area of disposal. Field research at a known informal electronic waste recycling site in China shows that soils are contaminated with several toxic substances; water contains high concentrations of lead, copper, zinc and other heavy metals; and air samples have 4 to 33 times the heavy metal particulate concentrations than other Chinese cities. The average concentration of polybrominated diphenyl ethers (PBDEs), a toxic substance, was measured to be 50 to 200 times higher in workers at the Chinese electronic waste treatment site than previously recorded in other populations. 80% of the children tested in the same area have elevated levels of lead in their blood (Manomaivibool, 2009). Uncontrolled treatment of electronic waste has also resulted in diseases of the stomach, skin, and other organs due to the practices that lack protection for workers (Terazono et al., 2006). To relate the level of significance compared to other waste streams, Li (2011) estimates that end-of-life electronic equipment are the source of about 40% of the heavy metals (lead, mercury, and cadmium) discarded in US landfills.

4.3 Electronic waste management systems

Electronic waste collection and treatment systems take a variety of forms. The flowchart in Figure 4, although somewhat simplified, shows the complex network of processes included in waste management system. Each square stage represents a potential process identified as an end-of-use flow. The two diamond stages, recycling and disposal, represent sub-processes within an end-of-use flow referred to as end-of-life treatment.

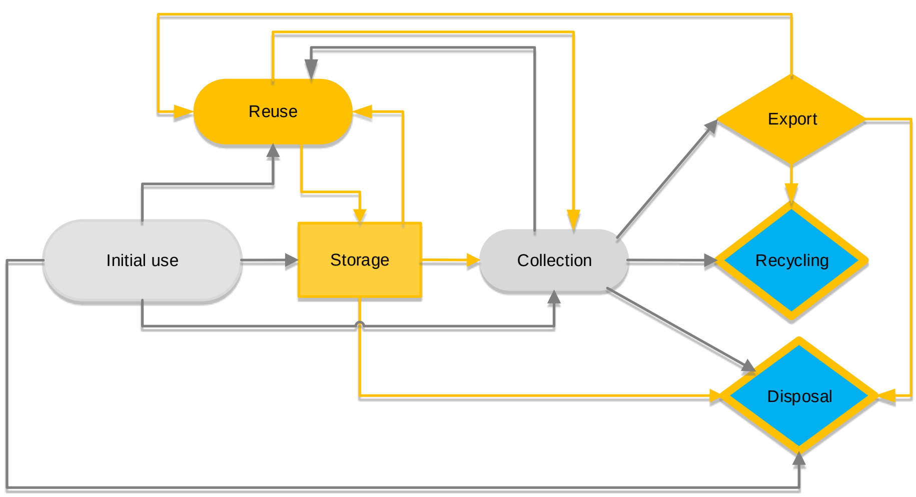

Figure 4: WEEE flows (as described by Duan et al., 2013)

Emmanouila et al. (2013) describe the flow of waste equipment in what might be considered an ideal formal waste management system. After transportation and a possible temporary storage period, collected equipment is tested to identify and separate functional devices from those no longer working. Functional devices are then sent for reuse, depending on the location, in the secondhand market, along with any items that can be repaired prior to reuse. The next step for any non-functioning equipment is disassembly to extract any reusable components, including valuable materials that can be recycled, along with any hazardous materials that require separate treatment prior to disposal. Any remaining equipment or materials are ultimately sent for disposal in a landfill or incinerated for energy recovery.

Informal collection and recycling activities are significant activities in some waste management systems. Figure 5 outlines the main flows of a waste management system, specifying the unique flows for both formal and informal sectors for collection and treatment activities. The main processes are described in more detail in the following sections.

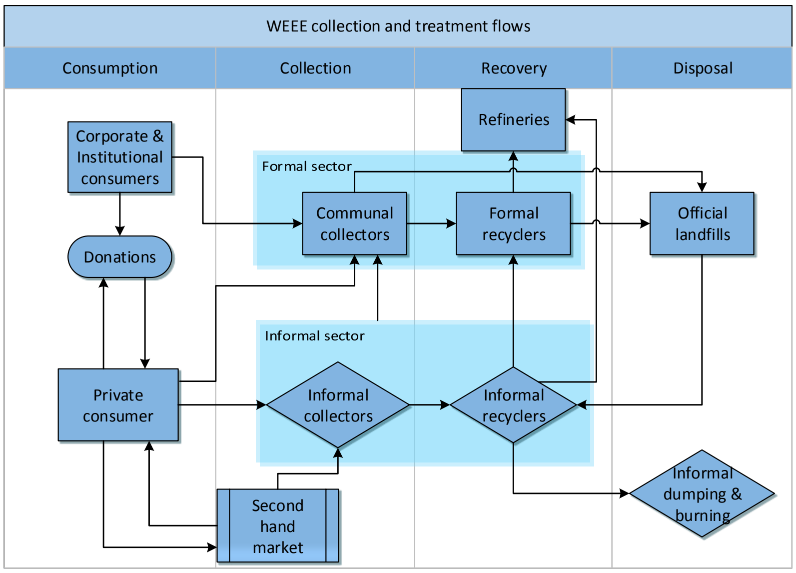

Figure 5: WEEE waste management system (ATE, 2012)

4.4 Waste management hierarchy

The waste management hierarchy pyramid in Figure 6 lists waste treatment options in order of the perceived level of environmental and human health impacts. Moving down the pyramid indicates an increase of negative impacts resulting from the end-of-life treatment activities performed. As the top two steps in the hierarchy relate to manufacturing rather than end-of-life treatment methods, they are not a focus in this study.

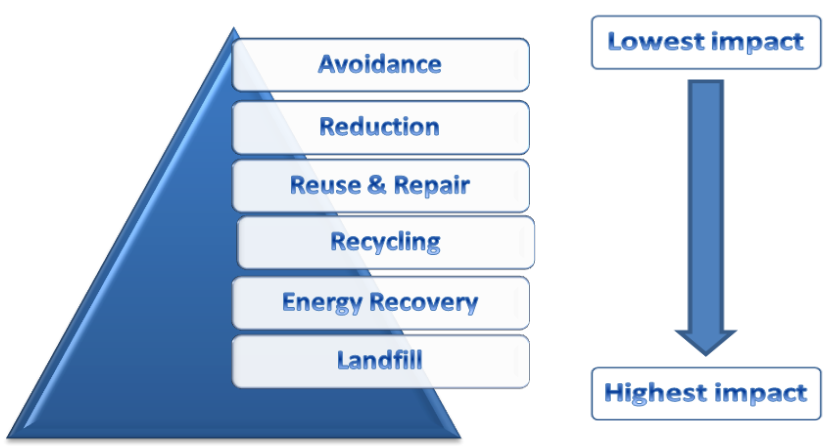

Figure 6: The waste management hierarchy
(Hierarchystructure.com, 2014) & (Dwivedy & Mittal, 2012)

4.4.1 Avoidance

At the top of the waste management pyramid is the absence of waste. Avoiding the production, consumption, and disposal of devices all together, for example through technological developments making a device obsolete, eliminates the use of rare resources and exposure to harmful waste flows. Another approach to avoiding negative impacts on the environment and human health is to avoid the use of harmful materials in the production of equipment. Replacing hazardous content with non-hazardous materials helps to avoid the impacts that would otherwise be present when dealing with waste equipment.

4.4.2 Reduction

Similar to avoidance, limiting the volume of waste generated is the next most effective option toward lowering environmental and/or human health impacts from end-of-life treatment. Again, this can be seen as a literal reduction in the volume of waste generated through a decrease in production and consumption volumes, or a reduction of hazardous materials embedded in the equipment used. Replacing toxic content for less harmful materials reduces potential impacts from discarded equipment.

4.4.3 Reuse and repair

The next step in the waste management hierarchy giving a further reduction of environmental and human health impacts is the reuse of products. As it relates to consumption of raw materials and energy, Dwivedy & Mittal (2012) discuss that the demand for virgin materials decreases by a third with a substantial secondhand market, and the energy used throughout the useful life of a computer is just one quarter of what is required to manufacture the computer. Choosing to recirculate a used product back into the market extends its lifetime and decreases volume of problematic waste generated.

Repair, included in the category of reuse, is the replacement or fixing of a broken component, bringing a device back to working order for further use. Reparation also includes refurbishment and remanufacturing, which are the upgrading of a device to achieve a higher quality result, and cannibalization which is the extraction of parts or components for reuse or refurbishment of other units (Thierry et al., 1995). Specialized equipment and valuable parts may also be upgraded for reuse, and equipment with no resale value may be broken down for components that can be reused (Huisman et al., 2012).

Although reuse and repair are more desirable than recycling according to their position in the waste management hierarchy, exports for reuse become problematic when the goods are repaired or eventually dumped or treated under unregulated conditions that result in negative impacts.

4.4.4 Recycling (material recovery)

According to Deubzer (2011), the main objective of recycling waste is to generate clean commodity materials that are similar to and can replace primary raw materials. Through recycling, end-of-life goods are broken down into secondary materials that can be recirculated back into raw material flows, reducing the demand for primary (virgin) raw materials that are otherwise extracted through energy intensive processes. As already noted, recycling activities take place under formal or informal conditions.

Formal recycling

Deubzer (2011) explains that electronic waste recycling begins with disassembly and fraction separation, steps that are especially important when considering the complex composition of EEE. Printed wiring boards inside computers, mobile phones and other ICT devices contain precious metals that may require separate treatment for better recovery results. There is also pre-processing and separation of metals fractions (iron, copper, and aluminum) that are sent to smelters for proper recycling. Various plastics are also separated, in some cases for reuse or recycling and other cases for incineration. According to USITC (2013), separated plastics are commonly reused to manufacture non-electronic goods such as outdoor furniture, wood composites, and toys. WEEE with highly toxic content, such as batteries or cathode ray tube (CRT) monitors, may require unique handling outside the processing described above (Amoyaw-Osei, 2011). Deubzer (2013) adds that separation and treatment of hazardous materials may be necessary before other materials are recovered. When recycled under proper conditions, hazardous materials and substances can be reused in a controlled state, avoiding the risk of environmental harm.

Manual disassembly of WEEE results in a higher percentage of precious metals recovered and a more pure output of commodity materials than if mechanically shredded. Recyclers with the advanced technology used to process equipment mechanically may therefor apply some manual disassembly, despite the high labor costs in many markets (USITC, 2013). For an example of specific material recovery and treatment activities performed, the Sims Recycling operational processes are outlined in Figure 7.

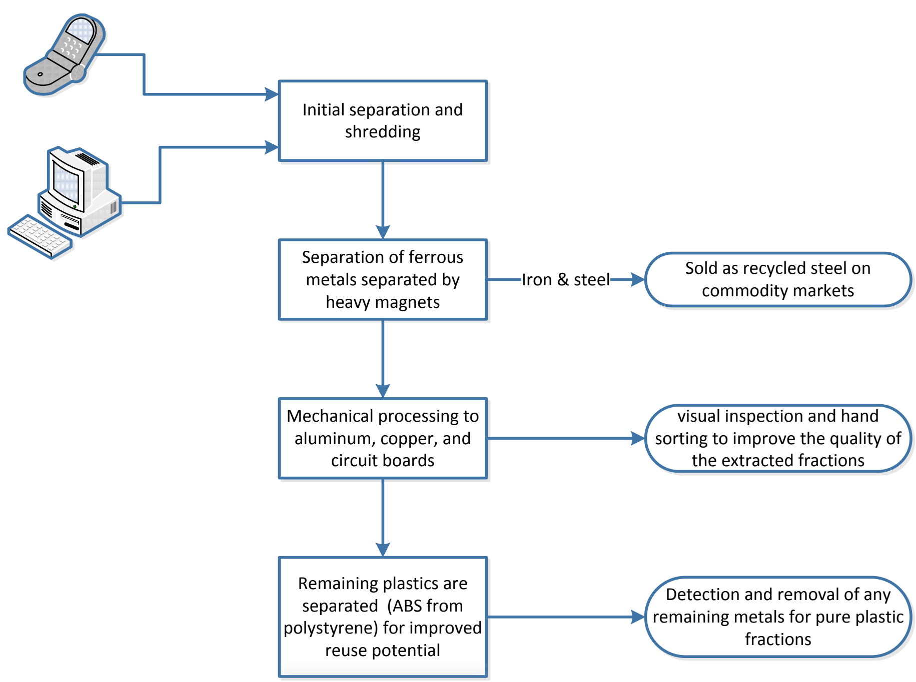

Figure 7: WEEE treatment process (Sims Recycling, 2014)

Informal recycling

The advanced processing necessary for metal recovery in formal recycling markets just described require highly skilled workers and technology that can cost hundreds of millions of US dollars (Sthiannopkao & Wong, 2013). Where technology and oversight are lacking, a number of problematic techniques are used to recover valuable materials; techniques that can result in the emission of large amounts of toxic organic pollutants and heavy metals, exposing the surrounding inhabitants and environment to harm (Wei & Liu, 2012). Such activities are referred to as informal recovery. According to Seum & Hermann (2010), informal treatment activities are partly driven by convenience and cost efficiency.

USITC describes informal recycling as the processing of used electronic equipment by individuals under unregulated conditions where safety or human and environmental health concerns are often ignored. In many developing countries, including China, Ghana, India, and Bangladesh, plastics are burned and acid baths are used to recover valuable materials from waste devices. The resulting toxic residues are often dumped in surrounding soil or water systems (USITC, 2013).

Informal recyclers tend to focus their recovery efforts on only the valuable materials that are easily extracted (usually copper and very limited amounts of gold), while other valuable and rare metals such as indium, palladium and ruthenium are lost due of the crude methods performed (Sthiannopkao & Wong, 2013).

A common activity in the informal sector is to heat PCBs by open flame to remove any attached components and lead solder, and then dip the stripped boards in acid baths to remove gold and copper. The residual toxic solution may then be dumped in surrounding areas. Another informal treatment method performed is to burn the plastic coating from metal components, such as PVC wires, to recover the valuable metal content, resulting in a harmful release of toxic dioxins and furans (Manomaivibool, 2009). The release of persistent organic pollutants and toxic metals causes serious and irreparable damage to the surrounding environment and inhabitants. Figure 8 lists some of the crude techniques performed during informal e-waste treatment.

- Manual material separation using simple tools and bare hands
- Heating printed circuit boards over coal-fired stoves to remove components
- Using open-pit acid baths to recover valuable metals
- Chipping and melting plastics without proper ventilation
- Open burning of unwanted material and cables to access internal copper wires
- Dumping unwanted materials in fields and riverbanks

Figure 8: Harmful activities associated with informal recycling (Chi et al., 2011)

In some areas, as reported regarding some African countries (SBC, 2011), informal recycling activities focus primarily on recovering steel, aluminum and copper, while the recovery of other metals is said to be very inefficient. In fact, Manomaivibool (2009) reports that the acid baths commonly used in India to extract gold from PCBs result in a recovery rate of up to 20%, whereas modern techniques performed in formal facilities can achieve a recovery rate of 95%, and with lower emission levels. SBC (2011) estimates an effective material recovery rate of just 52% from the waste processed by the informal sector in Nigeria.

The collection of electronic waste in developing countries often takes place door-to-door and the value for reusable materials is well known. The manual disassembly performed in informal recycling sectors gives the advantage of a more complete separation of goods, resulting in recovered fractions that are more valuable (USITC, 2013).

4.4.5 Incineration (energy recovery)

Through incineration, the hazardous nature and volume of a substance or material are decreased, and the inert remains from incineration can be more safely discarded (Eurostat, 2013). Ideal for discarded waste fractions that are not recyclable, incineration is a process to transform waste into energy oxidation or other thermal treatment (burning) to produce district heating and electricity through hygienic and environmentally safe methods. The incineration process produces bottom ash that is landfilled or used as gravel, and fly ash that can also be landfilled or used for such purposes as neutralizing empty mines (Avfall Sverige, 2013).

Incineration activities performed in informal sectors without regulatory controls have a much different outcome. Without systems in place to control the release of hazardous substances, the incineration of materials containing toxic substances risks the harmful impacts previously discussed.

4.4.6 Disposal to landfill

Avfall Sverige (2013) describes landfilling as a method for treating waste when recycling is not possible or appropriate. Waste discarded to a modern formal landfill is stored in a controlled manner where it remains safe for a long period of time. According to European Union restrictions, as specified in article 6 of the WEEE Directive (European Commission, 2013), the landfilling of WEEE that has been separately collected by member states, which includes Sweden, is prohibited if proper pre-treatment has not been performed.

The above description covers properly controlled landfills; however, not all landfills provide the same level of control over discarded waste. Without proper controls to protect against leachate or runoff, the risk of harmful exposure to the surrounding environment and residents exists as with open dumping. The quality of landfills has not been investigated in depth for this study, so all landfills are categorized as one treatment flow, regardless of quality. An indication is made when landfills are known to lack proper controls. This distinction should be kept in mind, and it may be helpful to research the quality of landfills in each country or region for a more accurate assessment of end-of-life impacts in future studies.

4.5 Storage

Storage of retired equipment is important in terms of delaying the reuse, recovery, or treatment of the stored items. According to Peagam et al. (2013), this phenomenon may occur due to several behavior dynamics, including a lack of knowledge regarding proper disposal, a perceived value of the devices, or an emotional attachment to the objects. Old computers are stored for an average of three years by individuals, whereas commercial users tend to store much larger quantities of equipment than household consumers, but for shorter periods (Estrada-Ayuba & Kahhat, 2014). As an intermediary stage within a product life cycle, stored items will eventually move to another use or treatment stage.

4.6 Export

Despite legislation against the export of hazardous waste, it is widely known that WEEE is exported from developed countries for informal treatment in some developing countries. The primary driver for this waste stream, according to Kahhata et al. (2008), is that both the developing and developed countries experience an economic benefit. The arrangement offers developed nations access to cheaper labor costs, while developing nations gain access to a flow of cheap used equipment needed to fill existing demands for secondhand goods.

Ayodeji (2011) attributes the lack of control over international trade to the abolition of a previous practice where ships were inspected before leaving the country of origin, a practice that encouraged thorough documentation and limited the under declaration of WEEE shipments. Pre-shipping inspections have since ended possibly due to the influence of corruption.

The exportation of WEEE does not indicate the method of use or treatment practiced once waste or received in the destination country. However, some assumptions are made based on the waste management practices observed in the importing countries. As already mentioned, it is also the case that equipment is exported for formal treatment when proper technology does not exist where waste is generated.

4.7 B2B and B2C sector differences

According to Peagam et al. (2013), EEE used in the commercial sector accounts for a significant portion of the total volume of EEE produced globally. B2B equipment tends to have a shorter operational lifetime than the same equipment when used in B2C markets, implying that goods discarded by companies may be more suitable for reuse and have high potential resale value. Although B2B equipment is commonly reused or recycled, the reuse and treatment streams used are likely not reported. ATE (2012) also suggests that B2B products tend to have more value than the corresponding B2C products, and that businesses tend to manage discarded electronic waste effectively through recycling programs to avoid negative environmental impacts.

Corporate users tend to dispose of old electronics through methods resulting in higher financial returns. Any functioning equipment with resale value is sold to brokers or auctions in the second hand market (Espejo, 2010). As an example, mobile phones have a material value of around 1 euro (Deubzer, 2011), and Odeyingbo (2011) estimates the price of untested mobile phones to be at least five euros if sent to Nigeria.

For a complete understanding of waste management systems and end-of-life treatment rates, it is necessary to identify any differences in the way waste is discarded by consumer (B2C) and commercial (B2B) sources. Available data are often limited to the collection and treatment of B2C waste, so more research is needed regarding what happens to B2B equipment. Information regarding differences in the treatment of B2B and B2C waste in each country is presented in Appendix III.

4.8 Waste management legislation

Many countries have policies in place to regulate the collection and treatment of electronic waste. A few relevant aspects of electronic waste management policy are presented in this section.

4.8.1 Extended producer responsibility

Extended producer responsibility (EPR), a principle founded on the objectives of improving product design and end-of-life treatment, is the basis for many waste management programs. EPR based programs extend the physical, financial, and reporting responsibilities of manufacturers through the end-of-life stage of equipment they produce (Manomaivibool, 2009). Thierry et al. (1995) criticize EPR based policies claiming that such a principle will not lead to sound solutions because of illegal exports and the corresponding additional energy demands from transportation and reuse. Another criticism is that the incentives for manufacturers to design products in a more environmentally-friendly manner are limited.

4.8.2 The Basel Convention

The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes was adopted in 1989 with the intention to address the growing trend of exporting hazardous waste to countries with weak or poorly enforced regulations. The objective of this legislation is to protect human health and the environment against the potential harm caused by hazardous waste. The aims of the convention are outlined in Figure 9. At least 181 countries (nearly all countries that exist today) are party to the convention. The United States, however, is a signatory to, but has not yet ratified the convention (SBC, 2014).

- The reduction of hazardous waste generation and the promotion of environmentally sound management of hazardous wastes, wherever the place of disposal
- The restriction of transboundary movements of hazardous wastes except where it is perceived to be in accordance with the principles of environmentally sound management
- A regulatory system applying to cases where transboundary movements are permissible

Figure 9: Aims of the Basel Convention (SBC, 2014)

5 Data Collection

The following chapter presents the data collected in each case study. The waste treatment systems in each country are investigated to identify the EoU and EoLT flows for ICT network waste.

Specific data are collected for mobile phone, personal computer, and network equipment waste flows when available. Data reported for all WEEE categories combined are considered when no information is available for the specific ICT categories. Waste flows are reported as a percentage of the total volume (by weight) of WEEE generated, unless another measurement is specified. When data for a specific type of equipment is reported in units rather than weight, it is assumed that each product is of a similar weight and the results are the same as if measured by weight. Again, two datasets are presented, end-of-use flows and end-of-life treatment flows, and both data sets include an “unknown” option when necessary to ensure the inclusion of any unidentifiable flows. The sum of flows for each dataset then comes to 100% per product category. When storage rates are not known, the flow is left out of the dataset. Findings are reported as shown in Table 2.

Table 2: Data reporting template (by percentage of weight)

	End-of-Use					End-of-Life Treatment			
Equipment Category	Storage	Reuse	Export	EoLT	Unknown	Formal Recycling	Informal Recycling	Landfill	Unknown
Mobile phones	-	-	-	-	-	-	-	-	-
Personal computers	-	-	-	-	-	-	-	-	-
Network equipment	-	-	-	-	-	-	-	-	-
All WEEE	-	-	-	-	-	-	-	-	-

5.1 Sub-Saharan Africa

Nigeria, South Africa and Ghana are the countries of most interest within the Sub-Saharan Africa region. Nigeria and South Africa have the highest mobile phone subscription counts (Table 3), and Ghana is reported to import large volumes of electronic waste for reuse or treatment. The totals do not add up exactly due to rounding.

Table 3: Mobile phone counts - Sub-Saharan Africa (World Bank, 2014)

Country	Mobile phone subscriptions	Share of region
Nigeria	127 M	21%
South Africa	78 M	13%
Ghana	28 M	5%
3 country total	**233 M**	**38%**
Sub-Saharan Africa total	**618 M**	**100%**

As suggested by Baldé et al. (2015), there is a lack of infrastructure and regulation to manage electronic waste across most of the African continent. A lack of control, especially in West Africa, leads to the dumping of electronic waste from other regions of the world. The eastern and southern regions of Africa have managed to limit such imports.

5.1.1 Nigeria

Management of electronic waste in Nigeria is mostly limited to informal methods of collection and recycling, but refurbishments are done under more formal conditions by registered companies that pay taxes based on their operations (Espejo, 2010). SBC (2011) indicates that most collection and recycling activities are performed by scavengers that collect waste by going house to house offering small payments for unwanted equipment. Collected items are dismantled in scrap metal markets for recoverable metals that are sold to local industry or traders that may arrange larger bulk sales to refineries. Materials not recovered are dumped or burned. Electronics discarded along with household waste are collected by the municipal waste management system and dumped in landfills where scavengers pick out anything containing recoverable materials of value. Ongondo et al. (2011) report that discarded WEEE with no recovery value is normally burned to reduce the volume, and the remains are dumped in uncontrolled landfills. None of the landfills in Nigeria are equipped with systems to monitor or control the potentially harmful leachate (Ayodeji, 2011).

Waste flows

Approximately 30% (around 200,000 tonnes) of all the electronic waste imported to Nigeria in 2010 is assumed to have been non-functioning. Half of that volume was repaired and resold, while the remaining 100,000 tonnes were not reparable and were recycled in the informal sector. Of the 500,000 units of used computers imported into Lagos each year, 25% are said to be in working condition and the remaining 75% are eventually burnt or dumped (Amarchree, 2013).

As reported by Ogungbuyi et al. (2012), an estimated 1 million tonnes of obsolete electronic waste is generated annually in Nigeria. 340,000 tonnes are treated or discarded as waste, while the rest is either stored or reused. A diagram of the main WEEE flows in Nigeria is presented in Figure 10. About 260 tonnes were collected for processing by informal recyclers, 160,000 tonnes collected from private households and another 90,000 tonnes are collected by scavengers from official dumpsites. Not shown in the flowchart are the 190,000 tonnes of household waste and 80,000 tonnes of corporate waste remaining in storage. A fraction of the waste collected by informal recyclers is also shown to end up in informal dump sites.

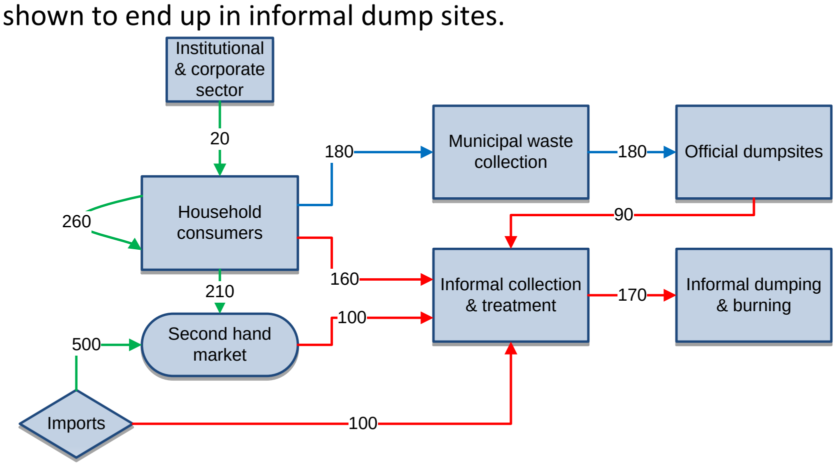

Figure 10: 2010 Nigerian WEEE mass flows in kilotonnes (Ogungbuyi et al., 2012)

Responses to a household survey on how electronic waste is discarded are summarized in Figure 11. The survey offers insight to waste flows according to the initial method of discard chosen by household end users.

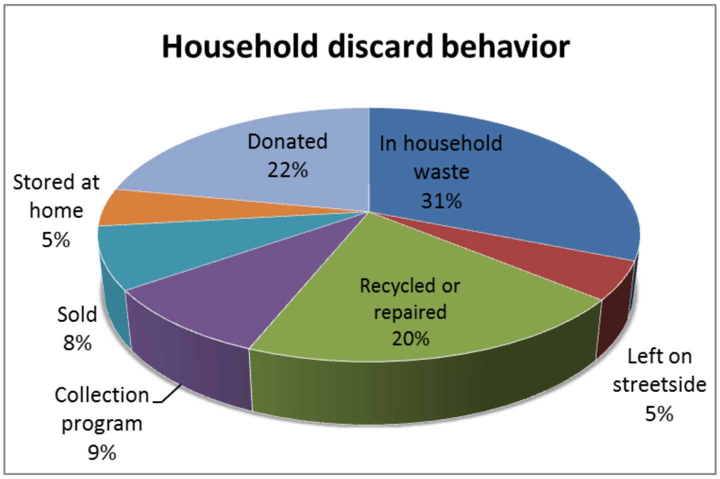

Figure 11: Survey responses on discarded WEEE (Ogungbuyi et al., 2012)

Ibrahim et al. (2013) estimate that 35% of the used computer equipment discarded in Nigeria is put to reuse, 41% is kept in storage, and 21% is disposed of as waste. Table 4 summarizes the EoU and EoLT rates for the personal computers and household WEEE generated in Nigeria.

Table 4: EoU and EoLT rates - Nigeria

	End-of-Use				End-of-Life		
Equipment Category	**Storage**	**Reuse**	**Export**	**EoLT**	**Formal Recycling**	**Informal Recycling**	**Landfill**
Personal computers	41%	35%	0%	24%	0%	100%	
All WEEE	18%	48%	0%	34%	0%	74%	26% *

* landfills in Nigera do not have controlls in place to collect and treat leachate.

5.1.2 South Africa

Collection of electronic waste in South Africa takes place both formally and informally, and between the two sectors, much of the waste considered to have value is collected for recovery before being lost in a landfill. Items dumped in landfills include scrap from IT equipment, televisions, white goods, telecom equipment, and any other materials recyclers have not managed to find a buyer for. Only a small fraction of discarded electronic waste ends up in landfills properly designed for hazardous waste, and no large scale incineration takes place in the country (Finlay & Liechti, 2008). Based on a report by ATE (2013), the well-established recycling activities in South Africa are limited to ferrous and non-ferrous metals, while the recovery of other materials has yet to be seen as sustainably performed.

Monitors, keyboards, TVs, batteries and similar items are mostly sent to landfills through municipal waste streams, where informal collectors gather what is considered valuable (ATE, 2012). Finlay & Liechti (2008) add that informal collectors also gather materials on sidewalks during municipal collection days, in landfills, or at municipal collection sites.

Formal recycling companies in South Africa, such as Desco and Universal Recycling, have been operating since the early 1990's and have focused primarily on managing the electronic waste generated by public and commercial sectors rather than what is generated by household users. Smaller recycling companies, however, may collect electronic waste from landfills, private homes, and some small businesses (Finlay & Liechti, 2008). The smaller recyclers disassemble collected items into material fractions that can be sent to bigger recycling companies or scrap dealers for further processing. PCBs may be separated from other fractions and sent to refineries or smelters that can extract any precious metal contents. Some material fractions, such as plastics, non-ferrous metals or PCBs may even be exported for recovery in other markets. According to ATE (2012), a majority of the electronics manufacturers in South Africa also manage some form of program to collect, reuse and recycle end-of-life equipment, but such programs are limited to collecting generated waste from corporate customers.

Refurbishment activities are also performed both formally and informally, and the level of organization around the refurbishment of electronic equipment, especially IT goods, has been described as its own industry. Refurbished goods are sold to the private sector, schools, or non-profit school projects in disadvantaged communities. Up to 30% of the personal computers sold in South Africa are estimated to have been refurbished (Finlay & Liechti, 2008).

Waste flows

An estimated 20% of all electronic waste generated in South Africa is recycled in the formal sector (ATE, 2012). According to Finlay and Liechti (2008), the formal processing rate for IT products (including mobile phones, computers, printers, and TVs) is much higher at around 45%. Batteries are commonly thrown away with domestic waste, and it is assumed that small devices are not likely to be recovered. It is also estimated that 5-15% of the waste equipment intended for the refurbishment market ends up being recycled rather than reused. The estimated flows of computer equivalents, based on the weight of computer waste, are indicated in the Figure 12 mass flow diagram. Import and export volumes of computer waste are not known, but the flows may offset each other if exports for treatment in Europe and Asia do not slightly outweigh imports. Storage of WEEE is described as being significant for both commercial and household users, but specific volumes are not indicated.

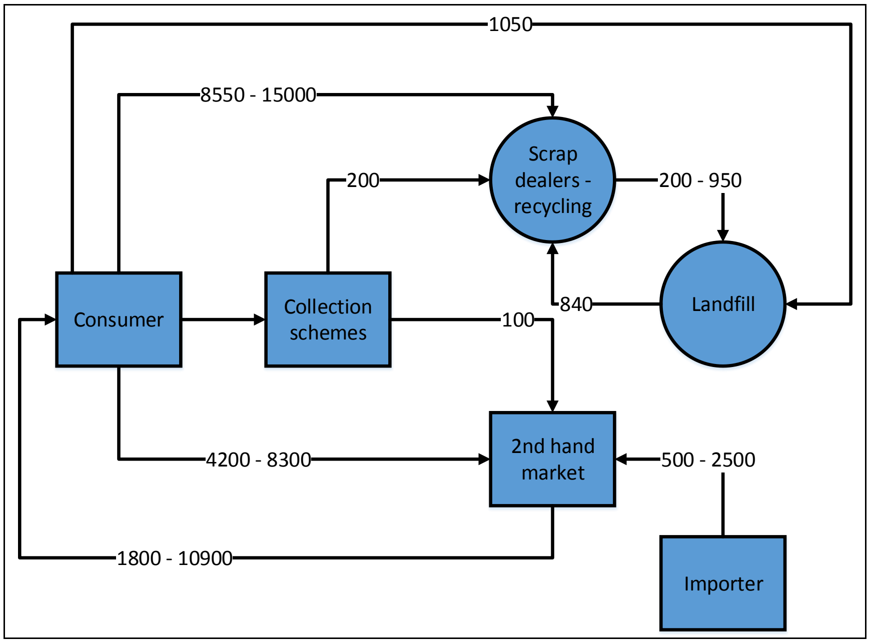

Figure 12: Mass flow diagram for PC waste (Finlay and Liechti, 2008)

The waste computer flows in South Africa are translated to national end-of-use and end-of-life treatment flow rates in Table 5. Storage and export flows are not included in the data set.

Table 5: EoU and EoLT rates - South Africa

	End-of-Use				End-of-Life		
Equipment Category	**Storage**	**Reuse**	**Export**	**EoLT**	**Formal Recycling**	**Informal Recycling**	**Landfill**
Personal computers	-	35%	0%	65%	66%	25%	9%

5.1.3 Ghana

Ghana is not one of the countries in Africa generating the largest volume of electronic waste, but it is the African country receiving the second largest volume of e-waste imports, with Nigeria being the largest. According to SBC (2011), the collection and recycling systems in place in Ghana are similar to what takes place in Nigeria. Both activities are conducted by scavengers, who are often migrant workers from rural areas that normally depend on small-scale farming but face problems with variable rainfall that leads to food shortages.

Waste flows

Up to 95% of available WEEE in Ghana is collected for treatment. The sources for WEEE collected and processed in the informal sector are: 25% from domestic consumption of new goods, 60% from used devices that were imported and reused in Ghana, and 15% from imports of waste (SBC, 2011).

As shown in Figure 13, only 1% of the estimated 280,000 tons of WEEE generated in 2009 was collected by the formal sector. While most waste receives informal treatment, a very small amount ends up in landfills. When considering the flow of material from imports and repair shops to informal recyclers, the total percentage of electronic waste generated that is treated by the formal sector decreases to 0.2%.

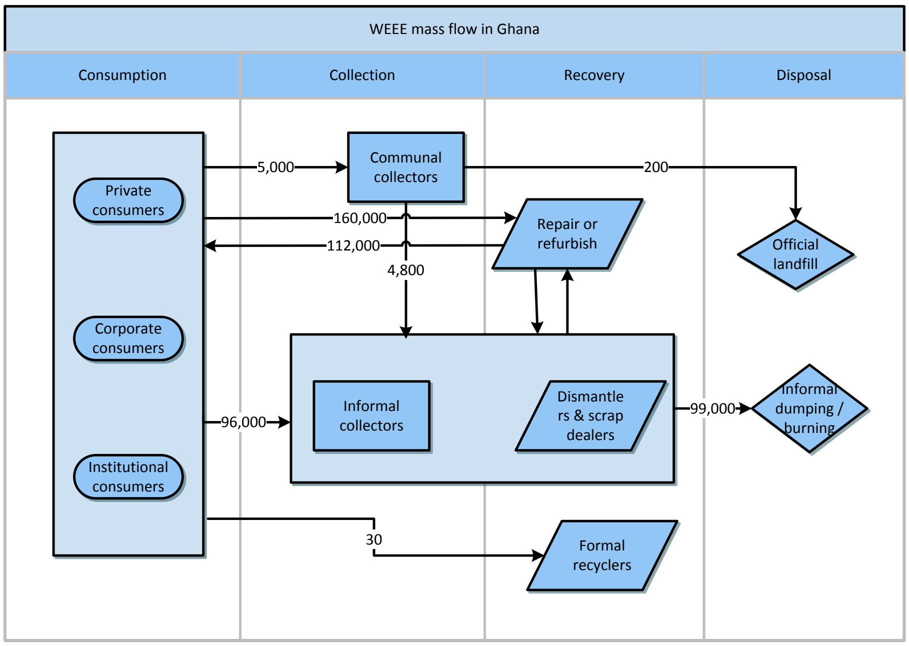

Figure 13: 2009 Ghana WEEE mass flows (Amoyaw-Osei et al., 2011)

Excluding the unknown percentage of e-waste remaining in storage, the rates for each discard and treatment method are indicated in Table 6. The storage rate is excluded from the data set.

Table 6: EoU and EoLT rates – Ghana

	End-of-Use				End-of-Life		
Equipment Category	Storage	Reuse	Export	EoLT	Formal Recycling	Informal Recycling	Landfill
All WEEE	-	62%	0%	38%	1%	98%	1%

5.2 The Middle East and Northern Africa

As reported by Alameer (2014), most countries in the Middle East view other hazardous waste streams as a higher priority than electronic waste. As a result, along with a lack of investment and a limited awareness of e-waste issues, proper recycling facilities or programs do not exist in most of the region. Waste collected for treatment must then be exported to countries with proper facilities if proper treatment is to take place. The portion of waste that is ultimately exported for proper treatment is a small fraction of the total volume generated, while most collection and treatment of end-of-life equipment is performed by scavengers using informal methods. Tunisia is reported to be the only country in the region with a functioning facility to process all types of electronic waste. The most significant countries in the region in terms of electronic waste volumes generated are Pakistan and Egypt (Table 7). National results are not given for this region due to a lack of data, but the available information is used to estimate a regional scenario in section 5.1.2.

Table 7: Mobile phones - Middle East & N. Africa (World Bank, 2014)

Country	Mobile phone subscriptions	Share of region
Pakistan	128 M	17%
Egypt	100 M	13%
2 country total	227 M	31%
Middle East & N.Africa total	740 M	100%

5.2.1 Pakistan

Although limited information is available regarding the electronic waste management systems in Pakistan, the country is now recognized as a significant destination for e-waste exported from developed countries, including those in the EU, the US, and Australia. It is also known that only about 2% of the used computers imported to Pakistan end up being reused. Nearly all of the imported end-of-life electronics are scrapped and recycled under crude informal conditions (Sthiannopkao & Wong, 2013).

5.2.2 Egypt

Rather than being classified as a hazardous waste, as is the case in many other countries, electronic waste is considered to be consumer waste in Egypt. Therefore no framework exists to ensure safe management of the growing fraction. However, the import of used personal computers into Egypt was made illegal as of 2013 (Seitz, 2014).

Similar to the situation in other Arab countries, the amount of electronic waste generated in Egypt is increasing. Although flows are increasing, the volume of waste generated has not reached levels large enough to attract the significant investment necessary in the waste treatment industry. Egyptian Electronic Recycling Co., the first facility in Egypt to recycle electronic waste (Alameer, 2014), has a limited treatment capacity but offers a sign that progress is being made. No complete information is available regarding volumes of electronic waste processed in Egypt, but several private companies are known to collect a portion of the generated waste. Recyclobekia, for example, reports that its first 2.5 tons of electronic waste were exported for processing in China (Seitz, 2014). The informal sector in Egypt collects some electronic waste, focusing mostly on circuit boards that are exported to countries with the proper processing technologies. Some plastic and metal components are recycled domestically (Alameer, 2014).

Research on recycling rates shows that 74% of the waste generated in Egypt is treated in the informal recycling sector and almost 11% in the formal sector (Wilson et al., 2009). Though this data corresponds to the collection and treatment of all waste streams, not just WEEE, it may offer some indication of how WEEE is managed.

5.3 Europe

As presented in this chapter, European countries are a significant source of electronic waste exported to developing regions of the world, yet they also have some of the most developed waste management systems. Russia, Germany, Italy, and the UK are investigated as they are the biggest ICT waste generators in the region (Table 8).

Table 8: Mobile phone counts – Europe (World Bank, 2014)

Country	Mobile phone subscriptions	Share of region
Russia	218 M	23%
Germany	98 M	10%
Italy	97 M	10%
United Kingdom	78 M	8%
4 country total	492 M	51%
Europe total	970 M	100%

5.3.1 Russia

As explained by Baldé et al. (2015), the electronic waste situation in Russia is one that lacks transparency. There is currently no active e-waste management system or relevant legislation in place in the country. Regulation discussion has recently included the introduction of EPR principles, which may be seen as a step toward specific legislation covering electronic waste management. With no data available for Russia, there is nothing to report regarding the specific discard and treatment flow rates.

5.3.2 Germany

The formal system for managing electronic waste in Germany consists of collection sites arranged by municipalities and the requirement for users to dispose of old electronics as separate fractions at the designated collection points (Espejo, 2010). The estimated number of collection points in Germany is said to be between hundreds and thousands (Sander & Schilling, 2010).

According to Espejo (2010), a small amount of electronic waste is informally collected on the side of the street. Items are left with signs claiming that they are left for anybody to take and reuse, along with an indication of working condition. Another method of passing on old equipment is through donations to charity organizations, which is done by both private and corporate donors. Items worth only their material recovery value may be sold to informal recyclers. Anything with little or no secondhand value are picked up by private collectors for recycling or sent directly to recyclers.

When arranged by a broker, it is not always known whether the waste equipment is treated domestically in Germany or if the treatment is performed under sound conditions. An overview of the electronic waste management system in Germany is offered in Figure 14.

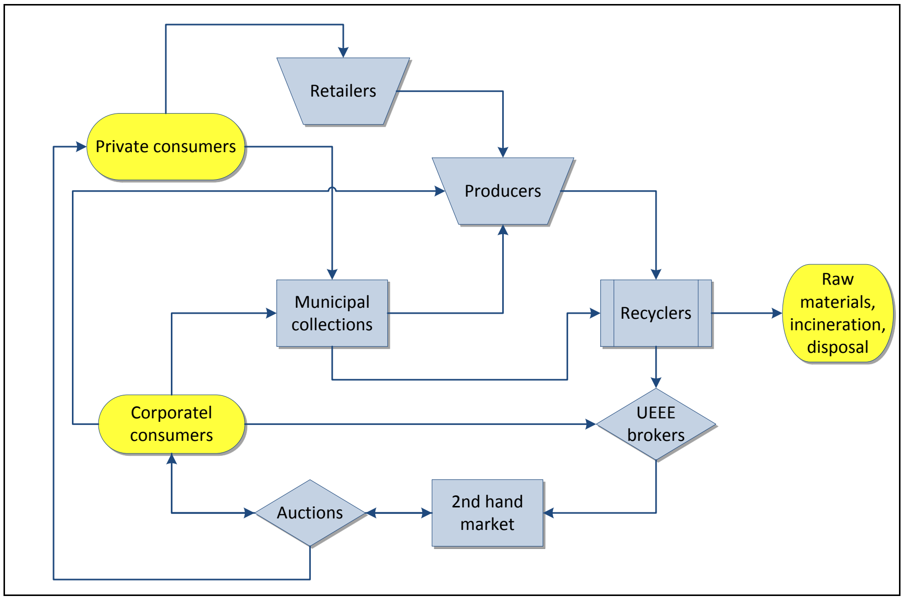

Figure 14: E-waste disposal flowchart (Espejo, 2010)

Waste flows

The market for EEE Germany is considered to be saturated, implying that all new goods put on market are assumed to replace existing goods that are being retired. With nearly 1.884 million tonnes of EEE put on market in 2008, and an estimated 694,000 tonnes formally collected, the collection rate for treatment is around 40% of the waste volume generated. Of the WEEE collected by the formal system in Germany, nearly 98% is treated domestically, while around 1% was sent to other European countries for treatment (Deubzer, 2011). According to Espejo (2010), about 1% of the WEEE formally collected is sold by recyclers for reuse on the secondhand market, a figure that is slightly higher at 3% when considering just IT and telecom equipment.

Of the electronic waste not collected by the formal system, up to 216,000 tonnes (over 11% of the waste generated) is likely exported to developing countries each year through informal collectors and exporters. Additional volumes may also be collected and treated domestically through other recycling systems not formally tracked (Deubzer, 2011). The volumes of WEEE that are reused or treated outside the formal collection/treatment system are unknown.

Based on the volume of EEE put on market in 2010, Germany achieved a 45% collection rate. For ICT equipment the collected rate is 76%. About 83% of the formally collected WEEE was either recycled or reused (Table 9). Baldé et al. (2015) report that just over 39% of the volume of EEE put on market in 2014 were collected through the formal take back system in Germany, at least another 6% ended up disposed of in household waste streams, and around 5% exported for reuse.

Table 9: 2010 E-waste collection stats for Germany (Eurostat, 2014)

Statistic	All WEEE (tonnes)	IT & Telecom equipment (tonnes)
Products put on the market	1,730,794	285,284
Waste collected	777,035	217,917
Waste collected from households	722,567	197,252
Waste collected from other sources	54,468	20,665
Treated in the Member State	755,588	208,126
Treated in another Member State of the EU	10,386	3,413
Treated outside the EU	2,187	730
Reuse	8,873	5,648
Recovery	736,321	205,214
Total recycling and reuse	643,079	179,171
Recovery/ collected	95%	94%
Collected / POM	45%	76%

The average rate for WEEE separately collected for treatment in the European Union is around one third of the volume put on market; however, an additional one third of the generated WEEE is collected and recycled by treatment operators outside of the producer sponsored take back system. Including the unofficial collection and treatment flows, the actual recycling rate in Germany may be around 67% (CECED, 2013). The exact type of treatment performed outside of the officially reported waste management system is unknown, but it is assumed for this study that most recycling activities in Germany use proper technologies under controlled conditions. The distribution of domestically recycled WEEE is estimated to be 90% formal and 10% informal, which is considered conservative considering the conditions in Germany.

Sander (2012) estimates that of the nearly 1.9 million tonnes of WEEE put on market in Germany in 2008, the combined volume collected and treated in was 12.1 kg per capita (8.4 kg via formal take back systems and 3.7 kg through other collection streams). The report also claims that 3.7 kg per capita is exported as used UEEE and another 1.2 kg per capita is discarded in household waste streams. Using the estimated population statistics reported by Eurostat (2015), the collected data is translated to the following discard rates: 16% exported, 5% landfilled, and 53% recycled. This again indicates a large flow of recycled WEEE, just over 30%, treated outside the reported system.

In combining the data collected above, the estimated end-of-use and end-of-life treatment rates for Germany are presented in Table 10.

Table 10: EoU and EoLT rates - Germany

	End-of-Use				End-of-Life		
Equipment Category	Storage	Reuse	Export	EoLT	Formal Recycling	Informal Recycling	Landfill
Household WEEE	31%		11%	58%	82%	9%	9%

To account for the eventual treatment of exported WEEE flows, the practices performed in the export destination countries are combined with the domestic treatment rates. WEEE exports from Germany tend to end up in developing countries in Africa and Asia. The type of equipment exported consists mostly of monitors, computers, TVs, cooling and freezing equipment, and small electronic devices (Deubzer, 2011). According to reports by Seum & Hermann (2010), Germany together with UK make up nearly all of the used computer and TV monitor exports from Europe to West Africa. As the UK share has declined in recent years, Germany has become the dominant exporter of these devices (SBC, 2011).

Assuming storage and reuse flows are eventually exported or treated according to the same distribution seen for the initial export and EoL flows, 16% of WEEE is exported and 84% is treated domestically. Considering exported waste flows, the final waste treatment rates for WEEE generated in Germany are presented in Table 11.

Zoeteman et al. (2010) claim that up to 60% of exports from Europe end up in China and India, 20% go to Eastern Europe, and another 20% goes to West Africa. According to research by REC (2001), most Central and Eastern European countries do not have a separate collection and recycling system in place for WEEE. This, along with the fact that waste is being exported there, indicates that WEEE treatment in Central and Eastern European countries may be performed under less than formal conditions. For a conservative estimate regarding the treatment of WEEE exported to Eastern Europe it is assumed that only 20% is formally recycled, 40% is informally recycled, and 40% is sent to landfill. The export flows to Eastern Europe only represent 3% of all end-of-life flows, so any adjustment to the estimated treatment rates will have little impact to the overall national results.

Table 11: EoLT rates - WEEE generated in Germany

		Weight	Formal Recycling	Informal Recycling	Landfill
Treatment in Germany		84%	82%	9%	9%
Exports	Eastern Europe	3%	20%	40%	40%
	West Africa	3%	0%	80%	20%
	China	5%	30%	65%	5%
	India	5%	0%	95%	5%
Weighted Total			71%	19%	10%

5.3.3 Italy

Collection of household electronic waste in Italy takes place through both municipal and retail channels. Producers of electronic goods are required to join a compliance scheme that holds them responsible for transporting e-waste from collection points to approved treatment centers as well as reporting data on collection and treatment volumes. A clearinghouse oversees the operations of each compliance scheme to ensure collection and treatment is done according to Italian requirements. Retail and municipal collection centers that have registered with the clearinghouse collect used electronics free of charge on behalf of the compliance scheme they are assigned to.

As described by Magalini et al. (2012), the electronic waste generated in the commercial sector in Italy is managed under different guidelines than household waste. Producers are financially responsible for the collection, transport and treatment of waste electronics from the commercial sector, based on the amount of new goods put on market, but the procedures for collection and treatment of commercially generated waste vary according to the arrangements made by each manufacturer, such as contracting the services out to waste management companies. Data on the collection of commercial products is reported directly by producers through what is called a MUD declaration. The flows of WEEE through the management system in Italy are shown in Figure 15.

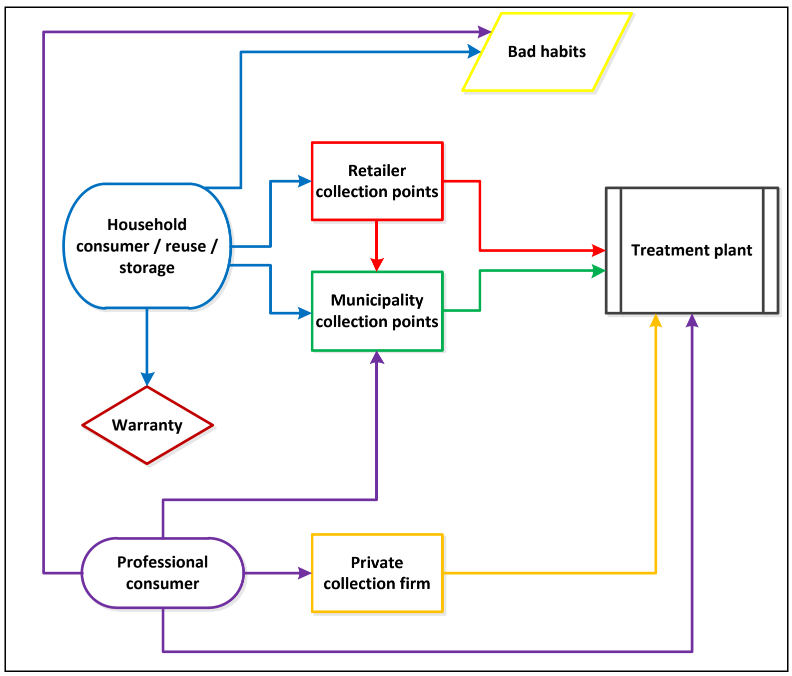

Figure 15: WEEE management system in Italy (Magalini et al., 2012)

Waste flows

Retailers and municipal collection points collected a combined 68% of all the household electronic waste generated in Italy; however, the actual treatment rate within the formal recycling system in Italy is estimated at just 24% of the total waste volume generated. In terms of equipment per inhabitant, Italians generate an average of 19 kg each of electronic waste, but less than 5 kg are collected by the official waste management system. An estimated 8% of the WEEE collected by the official system, 2% of the total volume of waste generated, is exported for treatment outside the EU (Eurostat, 2014).

Magalini et al., (2012) describes the flows of waste generated by Italian households as shown in Table 12. Storage is not reported, except for the extended life flow described as equipment left in old properties after tenants have moved. Storage rates are otherwise estimated to be 10% of the volume of electronic equipment in use, indicating that more equipment is storaged than is generated as waste each year. Household WEEE is discarded as follows: up to 14% in household waste streams, 13% is reused, and 26% recycled by the formal treatment system, and up to another 25% collected by retailers that could circumvent the formal compliance schemes and be sent directly for treatment without being reported.

Table 12: Household E-waste flows in Italy (Magalini et al., 2012)

Discard method	Kg of R4 waste/capita	Share of R4 waste	Kg of WEEE/capita	Share of WEEE
Retailers	0.7	12%	4	25%
Municipal collection points	2.5	42%	7.2	44%
Life extension	0.2	3%	0.6	4%
Reuse	1.1	19%	2.1	13%
Bad habits	1	17%	1.6	10%
Warranty replacement	0.1	2%	0.1	1%
Unknown	0.4	7%	0.7	4%
Total*	**5.90**	**100%**	**16.30**	**100%**

** Totals do not match exactly due to rounding*

The R4 equipment category listed in Table 12 includes a number of electric/electronic devices including ICT devices, small household appliances, consumer equipment, tools, toys, lighting equipment, medical devices, and automated dispensers. Although the category includes a diverse group of equipment, ICT equipment accounts for about 62% by weight of all the R4 waste collected and treated by the formal waste management system in Italy (Magalini et al., 2012).

It is assumed that most of the WEEE treatment in Italy is performed under controlled conditions, including the waste collected outside the officially reported system. To take a conservative approach, 10% of the recycled waste is reported under informal treatment. The storage flow indicated is based only on the equipment assumed to be left in homes after the tenants have moved. Storage rates are likely much higher than indicated, but the flow is not included in this data set. The remaining flows that are unknown are reported as such. No indication is given for the treatment of the specific equipment under the R4 category so the best estimate is based on the pattern observed for all types of household WEEE. For example, less than 2% of UK WEEE exports come from households, but data reported by Magalini et al. (2012) indicates a 10% export rate when considering all WEEE generated. Table 13 summarizes the estimated WEEE flows for Italy.

Table 13: EoU and EoLT rates – Italy (exports include B2C & B2B flows)

	End-of-Use					End-of-Life		
Equipment Category	Storage	Reuse	Export	EoLT	Unknown	Formal Recycling	Informal Recycling	Landfill
R4 equipment (B2C)	3%	19%	10% *	58%	10%	64%	7%	29%
Household WEEE	4%	13%	10%	60%	17%	75%	8%	17%

Based on export and EoLT flows alone, the distribution is 15% exported and 85% treated. All R4 waste flows indicated above in Table 13 are translated to an eventual end-of-life treatment in Table 14. Commercially generated exports from Italy go primarily to China and Pakistan (Magalini et al., 2012).

Table 14: EoLT rates - R4 waste generated in Italy

		Weight	Formal Recycling	Informal Recycling	Landfill
Treatment in Italy		85%	64%	7%	29%
Exports	China	8%	30%	65%	5%
	Pakistan	8%	6%	89%	5%
Weighted Total			57%	17%	26%

5.3.4 United Kingdom

Similar to practices in Germany, IT waste generated by corporate users in the UK is commonly recycled or refurbished for reuse; however, the treatment streams are likely not reported as part of the formal waste management system. Small companies tend to make informal arrangements to dispose of electronic waste, whereas larger organizations tend to use contractors. The most common channel for discarding EoL equipment is through the supplier (Peagam et al., 2013).

Waste flows

In 2009, over 1.2 million tonnes of household electronics were reported as put on market in the UK, and 454,000 tonnes (nearly 38% of the put on market weight) were collected (Peagam et al., 2013). Eurostat (2014) reports collections rate of 31% for WEEE and 49% for waste IT and telecom equipment (Table15). The average formal recycling rate over the last three reported years (2010-2012) for all WEEE is 24%.

Table 15: 2010 E-waste collection stats for the UK (Eurostat, 2014)

Statistic	IT & Telecom equipment (tonnes)	All WEEE (tonnes)
Products put on the market	338,838	1,534,576
Waste collected	165,626	479,356
Waste collected from households	160,022	463,157
Waste collected from other sources	5,604	16,199
Treated in the Member State	146,316	440,276
Reuse	19,310	39,080
Collected / POM	49%	31%

Research by WRAP (2012) suggests that 38% of WEEE generated in UK households is recycled, though not all through the official treatment system. Another 38% is disposed of in landfills, and around 7% is reused (WRAP, 2014). As in Italy, the flow for some of the generated waste in the UK is unknown (8%) and is reported as such. Again, considering the level of development and regulations in the EU, the level of informal recycling is assumed to be just a small percentage (10%) of what is recycled. The end-of-use flows in Table 16 do not include equipment held in storage.

Table 16: EoU and EoLT rates - United Kingdom

	End-of-Use					End-of-Life		
Equipment Category	**Storage**	**Reuse**	**Export**	**EoLT**	**Unknown**	**Formal Recycling**	**Informal Recycling**	**Landfill**
Household WEEE	-	7%	10%	75%	8%	45%	5%	50%

Following the same distribution observed between export and domestic EoLT flows, assuming all other flows will eventually be exported or treated domestically, an estimated 12% of waste generated will be exported and 88% treated domestically. Without specific data for UK exports, the destinations and eventual treatment rates for exported WEEE are assumed to be similar to what is estimated for German exports. The final EoLT rates for electronic waste generated in the UK are presented in Table 17.

Table 17: EoLT rates - WEEE generated in the UK

		Weight	Formal Recycling	Informal Recycling	Landfill
Treatment in the UK		88%	45%	5%	50%
Exports	Eastern Europe	2%	20%	40%	40%
	West Africa	2%	0%	80%	20%
	China	4%	30%	65%	5%
	India	4%	0%	95%	5%
Weighted Total			41%	13%	46%

5.4 Asia Pacific

With a combined share of 65%, China and India dominate the Asia Pacific region in volume of electronic waste generated. Along with Indonesia and Japan, the 4 highest e-waste generating countries in the region, 79% of the waste in the region is accounted for (Table 18).

Table 18: Mobile phones counts – APAC (World Bank, 2014)

Country	Mobile phone subscriptions	Share of region
China	1,229 M	38%
India	886 M	27%
Indonesia	304 M	9%
Japan	146 M	5%
4 country total	2,566 M	79%
APAC total	3,231 M	100%

5.4.1 China

Most electronic waste in China is disposed in one of three ways: sold to the secondhand market, donated to the poor, or recycled by private informal recyclers. A majority of households store equipment at home rather than discarding it, at least until collectors offer a reasonable price for the used goods (Wei and Liu, 2012). To illustrate the scale of this industry, Wang et al. (2013) reports that 700,000 people work in some way for the electronic waste management system in China. An estimated 98% of those workers are considered to be part of the informal side of the industry, 250,000 of which are involved in material recovery activities.

The flow of waste to China's secondhand market comes from hawkers going door-to-door to buy equipment for a small fee. The collected goods are then separated, and anything reusable is sold to traders who bring the goods to local secondhand market vendors. Vendors then market the used goods to migrant workers, students, and others that cannot afford the cost of new items. Any items that are not reusable but still have material value are sold to scrap dealers (Veenstra et al., 2010).

Although comparatively limited, formal electronic waste treatment practices do exist in China. As of 2010, there were 130 e-waste recycling companies registered on the E-waste Dismantling Enterprise List; however, competition from the informal sector prevents such organizations from collecting enough waste to meet their capacity (Veenstra et al., 2010). For example, Haier is a company with an annual recycling capacity of 600,000 units, but the company only managed to collect and dispose of 8,000 units between 2004 and 2007 (Wei & Liu, 2012).

Waste flows

An estimated 70% of end-of-life electronic consumer goods in China are stored for varied periods in homes or offices because they are seen to contain a financial or useful future value (Ongondo et al. 2011). While most retired mobile phones are stored at home or sold to informal collectors, around 1% is recycled in the formal treatment sector (Wei & Liu, 2012). The end-of-life treatment rates for mobile phones in China based on results of a consumer survey are shown in Figure16.

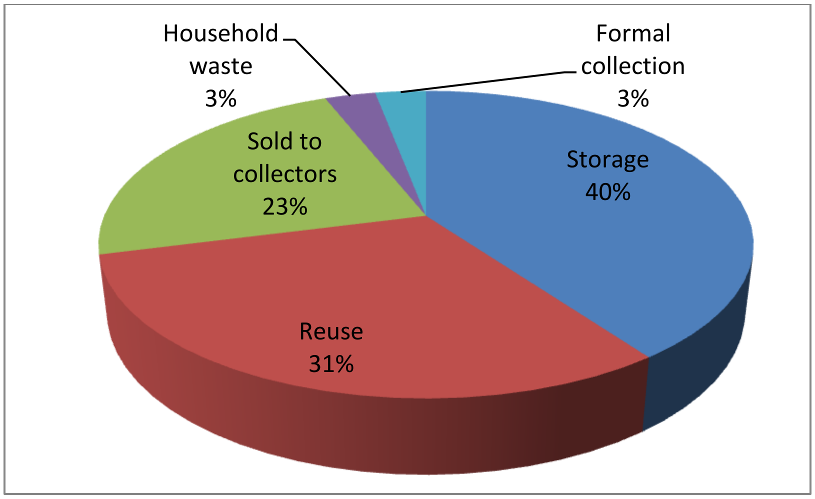

Figure 16: Discard of mobile phones in China (Yang, 2008)

Figure 17 is a proposed material flow diagram based on the results of a 2005 survey conducted in Beijing. The model is used to identify the eventual treatment method of all equipment passing through the system (5.3% to landfill and 94.7% recycled). Based on the flows indicated, the end-of-use and end-of-life treatment rates after initial use are given in Figure 18.

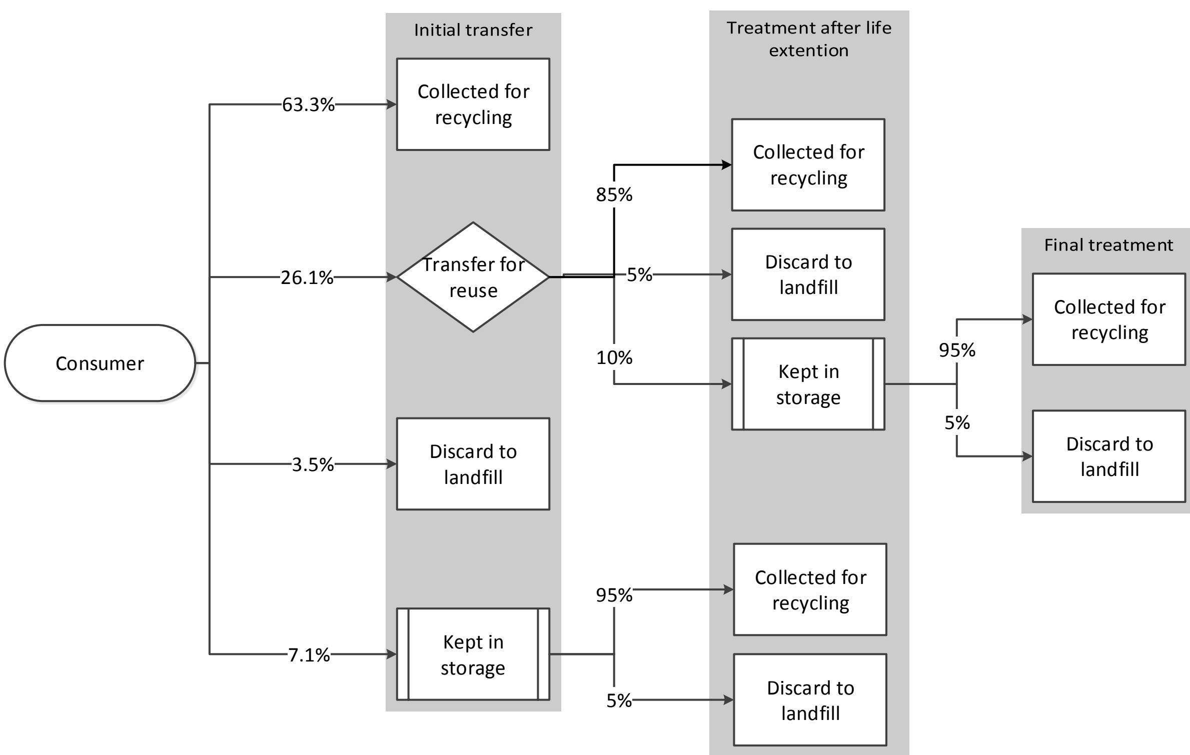

Figure 17: Beijing WEEE flowchart by (Liu et al., 2006)

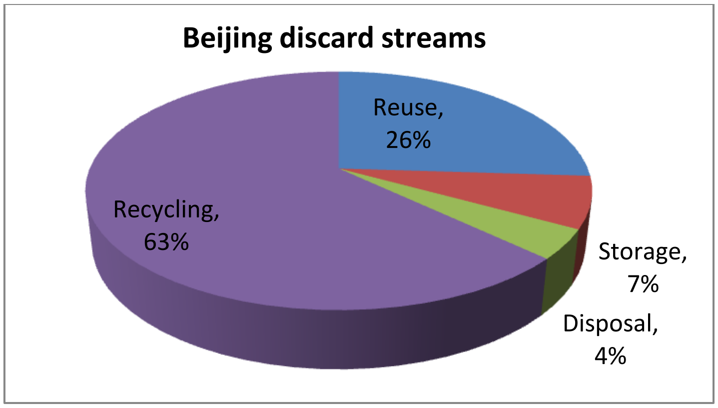

Figure 18: 2005 WEEE flows in Beijing after initial use

A 2004 survey by Veentra et al. (2010) in Xian offers similar findings. The results, shown in Figure 19, are rather complex, making it difficult to accurately identify specific waste treatment rates. According to the waste streams directly after the initial use, the following rates are identified: 26% of waste volumes are reused by friends or family, 7% is kept in storage, 50% is picked up by collectors, 14% is returned to or collected by retailers and dealers, and 4% is discarded as waste.

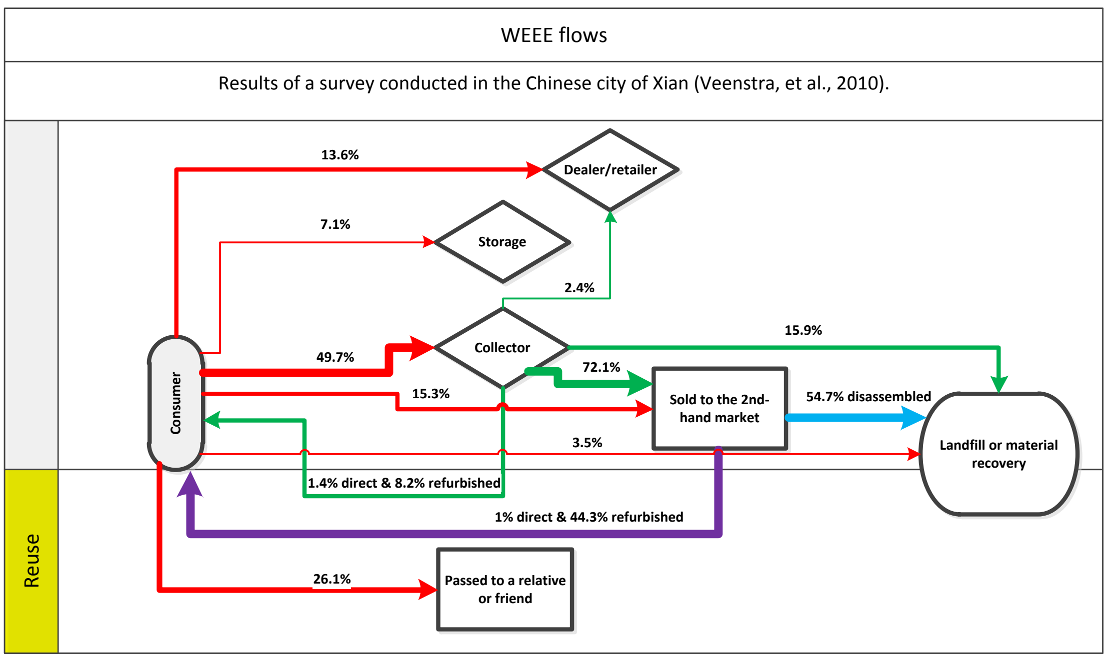

Figure 19: Mass flow diagram for e-waste in China (Veentra et al., 2010)

As for the recycling methods performed in China, around 30% of the WEEE recycled in 2010 was treated in the formal sector (Zhou & Xu, 2012). The research also points out that only 8% of the recycled WEEE was generated domestically, with the remaining 82% imported for treatment from other countries. Table 19 summarizes the WEEE flows in China.

Table 19: EoU and EoLT rates - China

	End-of-Use				End-of-Life		
Equipment Category	**Storage**	**Reuse**	**Export**	**EoLT**	**Formal Recycling**	**Informal Recycling**	**Landfill**
Mobile phones	40%	31%	0%	29%	10%	79%	10%
All WEEE	7%	26%	0%	67%	28%	66%	6%

5.4.2 India

Wath et al. (2011) describes the electronic waste management activities in India, across the board from collection to dismantling, as being mostly performed manually by unorganized actors that have limited access to proper equipment and techniques, leading to dangerous consequences. The informal system for dealing with e-waste generated in India has possibly developed from the already existing sector for managing the scrap from end-of-life ships and cars, along with demolition waste. With such low wages in India, the labor intensive disassembly of electronic equipment for repairs becomes economically possible (Manomaivibool, 2009). Ezeah et al. (2013) estimates that 6 million informal waste pickers exist in the country.

According to Sthiannopkao & Wong (2013), only three facilities with the ability to properly manage electronic waste exist in India. The majority of electronic waste available in India is therefore processed in the informal sector. As in China, obsolete goods are considered to hold value and are sold to door-to-door collectors. In an earlier study by Manomaivibool (2009), only two facilities authorized to deal with electronic waste existed in India. Despite each facility having the capacity to process five tonnes of e-waste each day, the actual combined volume of waste processed was reported at 800 tonnes a year. Such performance falls just over 20% of existing capacity and covers less than 1% of e-waste volumes available for recycling. Dwivedy & Mittal (2012) suggest that 23 recycling facilities are in their development stage (as of 2012) and could eventually providing a combined capacity to recycle 60% of the nation's e-waste generated each year once fully operational. As for landfill quality, Singh et al. (2013) indicate that of the 8 landfills investigated in major cities throughout India, none have a proper system to collect and remove leachate.

Waste flows

Manomaivibool (2009) finds that only 10% of the used computers imported to India are reusable, while the rest ends up in the recycling or refurbishment sectors. Discarded PC flows are indicated in Figure 20 and translated EoU and EoLT rates in Figure 21.

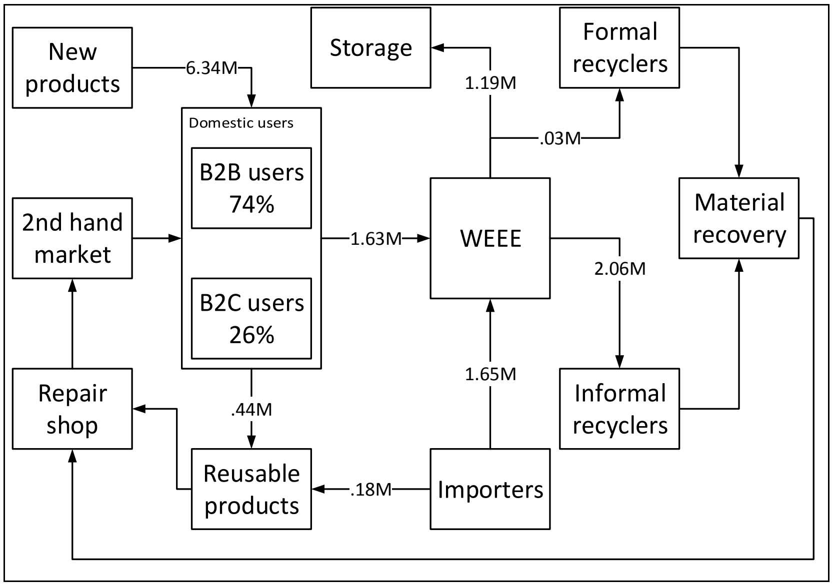

Figure 20: Computer waste flows in million units (Manomaivibool, 2008)

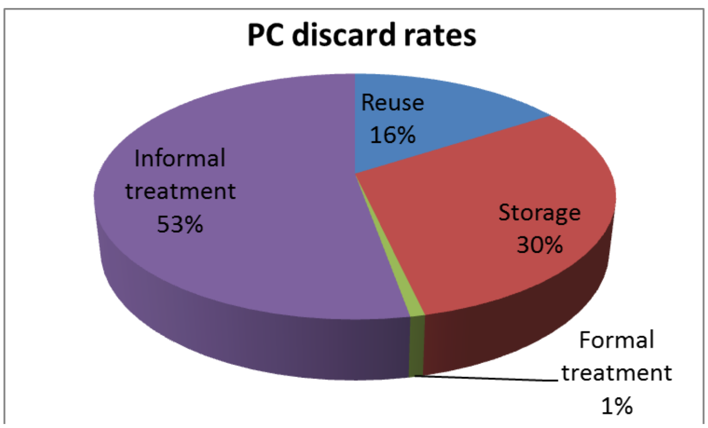

Figure 21: Survey results on discarded PCs

Until a formal electronic waste management system is in place, an estimated 95% of WEEE receiving end-of-life treatment in India goes through the informal recycling system (Dwivedy & Mittal, 2012). Table 20 summarizes the end-of-use and end-of-life treatment flows in India.

Table 20: EoU and EoLT rates - India

	End-of-Use				End-of-Life		
Equipment Category	**Storage**	**Reuse**	**Export**	**EoLT**	**Formal Recycling**	**Informal Recycling**	**Landfill**
Personal computers	30%	16%	0%	54%	2%	98%	0%
All WEEE	-	-	-	-	1%	95%	4%

5.4.3 Indonesia

Andarani & Goto (2014) claim that mobile phones make up an estimated 83% of e-waste in Indonesia in terms of units generated. By weight, televisions make up the largest fraction of electronic waste, at 37%. Formal electronic waste recycling methods are rarely used in Indonesia, and very little e-waste ends up in formal landfills. Any discarded electronic waste finding its way to dumpsites is likely to be collected by scavengers who sell the items for reuse or spare parts. Unusable components tend to be recycled under informal conditions (backyard recycling) or discarded in open dump sites. Households are the source for most electronic waste generated in Indonesia, so household discard rates for mobile phones and computers are used to identify the e-waste streams within the country. The end-of-use discard rates for mobile phones and computers in Indonesia are shown in Figure 22.

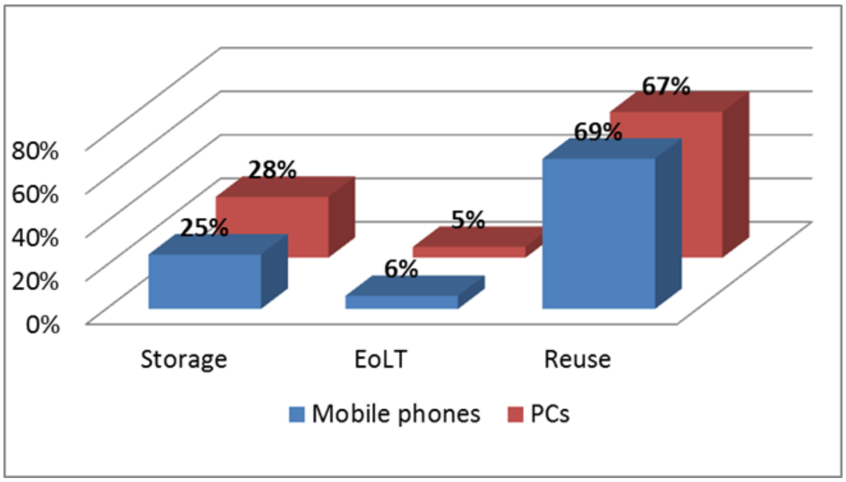

Figure 22: Indonesia EoU rates (Andarani & Goto, 2014)

As in other developing countries, the little formal recycling of electronic waste that does occur in Indonesia is limited to waste generated by the commercial sector (Terazono et al. 2012). The end-of-use and end-of-life treatment rates for waste mobile phones and computers in Indonesia are indicated in Table 21. The EoLT rates are based on what is observed in other countries in the region with similar conditions.

Table 21: EoU and EoLT rates - Indonesia

	End-of-Use				End-of-Life		
Equipment Category	Storage	Reuse	Export	EoLT	Formal Recycling	Informal Recycling	Landfill
Mobile phones	25%	69%	0%	6%	10%	80%	10%
Personal computers	28%	67%	0%	5%	10%	80%	10%

5.4.4 Japan

According to Sthiannopkao & Wong (2013), Japan introduced the principle of "reduce, reuse, and recycle" during a G8 meeting in 2004. However, the electronic waste management system in Japan is similar to that of many EU countries in that it is based primarily on recycling end-of-life equipment rather than focusing on reuse (Yoshida & Yoshida, 2010). With a limited domestic market for used equipment and an existing demand in foreign markets, discarded equipment with reuse value are often exported. Similar to the EU e-waste management model, collection and recycling activities in Japan are managed by an association that is funded by the electronics manufacturers.

Waste flows

The officially reported collection and treatment rate for discarded personal computers in Japan in 2006 is just over 9% (by number of units), and the total recycled number of PCs represents 28% of what was discarded. Of the estimated 33% that are exported, 60% are intended for recycling and 40% are for reuse (Yoshida & Yoshida, 2010). The main flows of waste personal computers in Japan are depicted in the Figure 23 flow chart.

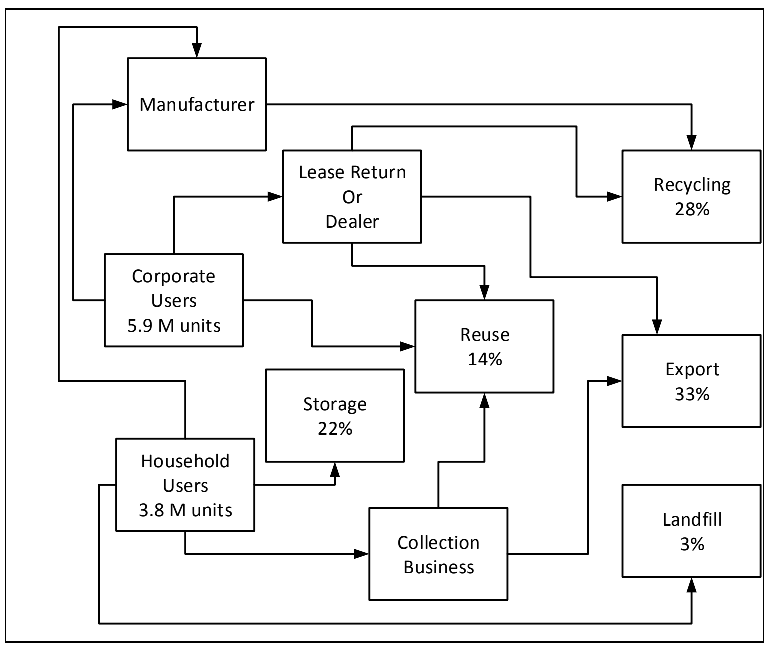

Figure 23: PC waste flows in Japan (Yoshida & Yoshida, 2010)

For mobile phones, 15% of discarded equipment is collected by the formal sector (Yoshida & Yoshida, 2010). Ongondo et al. (2011) estimates the collection rate for end-of-life mobile phones in Japan to be much higher at 40%, and Baldé et al. (2015) report a formal collection and treatment rate of 24% for all WEEE generated.

Sthiannopkao and Wong (2013) suggest that all domestic recycling activities in Japan follow best practice to ensure that the release of toxic substances is limited. Each end-of-use and end-of-life treatment rate for personal computers discarded in Japan is indicated in Table 22.

Table 22: EoU and EoLT rates – Japan

	End-of-Use				End-of-Life		
Equipment Category	Storage	Reuse	Export	EoLT	Formal Recycling	Informal Recycling	Landfill
Personal computers	22%	14%	33%	31%	90%	0%	10%

As reported by Zoeteman et al. (2010), WEEE exports from Japan are sent to China (60%), India (30%), and Africa (10%) due to geographic location and financial considerations. Using the export to EoLT ratio of 52% - 48%, all storage, reuse, and export flows are distributed to eventual end-of-life treatment rates in Table 23. Exports to China are assumed to follow the treatment practices observed for mobile phones in China as mobile phone treatment is assumed to be more similar to personal computers than to all WEEE combined.

Table 23: EoLT rates – PCs generated in Japan

		Weight	Formal Recycling	Informal Recycling	Landfill
Treatment in Japan		48%	90%	0%	10%
Exports	China	31%	10%	80%	10%
	India	16%	2%	98%	0%
	Africa	5%	0%	80%	20%
Weighted Total			47%	44%	9%

5.5 North America

Mexico is geographically located within the North America region, but Mexico is grouped with other Latin America countries in this study. The two countries making up nearly 99% of the region are Canada and the United States, as shown in Table 24.

Table 24: Mobile phone counts – North America (World Bank, 2014)

Country	Mobile phone subscriptions	Share of region
United States	306 M	90%
Canada	28 M	8%
2 country total	**333 M**	**99%**
North America total	**338 M**	**100%**

5.5.1 The United States of America

Due to time constraints, as well as the overwhelming majority of electronic waste in the region coming from the United States, data collection for the North America region is limited to the United States.

As one of the largest markets for electronic goods in the world, waste management practices in the U.S. are extremely important. As reported by the USITC (2013), the electronic waste management industry in the US has seen a transition toward recycling rather than refurbishment activities. This shift is linked to an increase in the cost of raw materials, some of which have nearly doubled in the recent years, as well as cheaper technology and local legislative requirements. IDC (2011) estimates that between 600 and 1000 WEEE recycling companies operated in the United States during 2010.

Certification programs have a big impact on WEEE/UEEE management practices in the US. Downstream audits are performed by 87% of certified UEEE facilities, while only 13% of uncertified facilities do the same. An estimated 18% of companies working with used electronic products (UEPs) and 27% of UEEE exporters require that downstream partners also take part in a certification program. Additionally, 80% of certified UEEE facilities track the transport of their goods through to treatment destinations, compared to only 6% of uncertified facilities (USITC, 2013). Between 2011 and June of 2014, the number of companies holding voluntary certification increased from 100 to 565 (ITFES, 2014).

Because of a limited capacity for smelting in the US, a majority of components requiring such treatment are sent to European countries where shredding and disassembly facilities exist. Despite a lack of data quantifying e-waste exports that are treated under uncontrolled and unsafe conditions, it is likely the case for some export volumes. It may also be the case that goods exported are given one or more reuse lives before final treatment or disposal. An estimated 65% of the e-waste generated by the commercial sector in 2011 was collected by exporting companies. Non-exporting companies on the other hand tend to receive WEEE from household originating sources such as non-governmental collection schemes or manufacturer take back contracts (USITC, 2013).

Waste flows

Research on treatment rates in the United States varies. Wagner (2009) suggests that the preferred choice for retired WEEE is storage. Excluding stockpiled equipment, Ongondo et al. (2011) estimate that just 18% of WEEE generated in the U.S. during 2007 was recycled, and most of the remaining 82% of waste is disposed of in landfills. Zoeteman et al. (2010) estimate that up to 20% of WEEE generated by U.S. households in 2005 was exported and only 2% was recycled domestically, while the remaining waste was held in storage or discarded to landfills. According to USEPA (2012), the recycling rate for all WEEE in 2009 was 25%.

Duan et al. (2013) estimate a 56% collection rate for all WEEE generated in the United States during 2010. Around 3% of the collected waste was exported, implying an overall export rate of around 2% of the waste generated. The collection rate for discarded mobile phones is estimated at 68% (by number of units), 10% of which are subsequently exported. The collection rate for computers is 73%

(also in number of units), 5% of which is then exported. The supporting data from Duan et al. (2013) are presented in Tables 25-27.

Table 25: Used mobile phone flows – per million units (Duan et al., 2013)

Equipment	Sector	Generated	Collection	Collection rate	Exported	Export rate
Mobile phones	B2B	55	48	87%		
	B2C	121	71	59%		
	Both	176	119	68%	12	7%

Table 26: Used computer flows – per million units (Duan et al., 2013)

Equipment	Sector	Generated	Collection	Collection rate	Exported	Export rate
Desktop computers	B2B	8.2	6.5	79%		
	B2C	14.4	10.2	71%		
	Both	22.6	16.7	74%	0.33	1%
Laptop computers	B2B	3.6	2.8	78%		
	B2C	3.7	2.7	73%		
	Both	7.3	5.5	75%	0.87	12%
Total computers	B2B	11.8	9.3	79%		
	B2C	18.1	12.9	71%		
	Both	29.9	22.2	74%	1.2	4%

Table 27: Used computer flows – per million units (Duan et al., 2013)

Equipment	Sector	Generated	Collection	Collection rate	Exported	Export rate
CRT monitors	B2B	3.3	2.9	88%		
	B2C	7.5	5.1	68%		
	Both	10.8	8	74%	0.26	2%
Flat panel monitors	B2B	4	2.7	68%		
	B2C	3	2	67%		
	Both	6.9	4.8	70%	0.55	8%
Total monitors	B2B	7.2	5.6	78%		
	B2C	10.4	7.1	68%		
	Both	17.7	12.8	72%	0.81	5%

USEPA (2012) estimates that 8% of discarded mobile phones and 38% of discarded computers were recycled in 2009. Figure 24 shows the U.S. distribution of discard flows for mobile phones and laptop computers based on 2006 data.

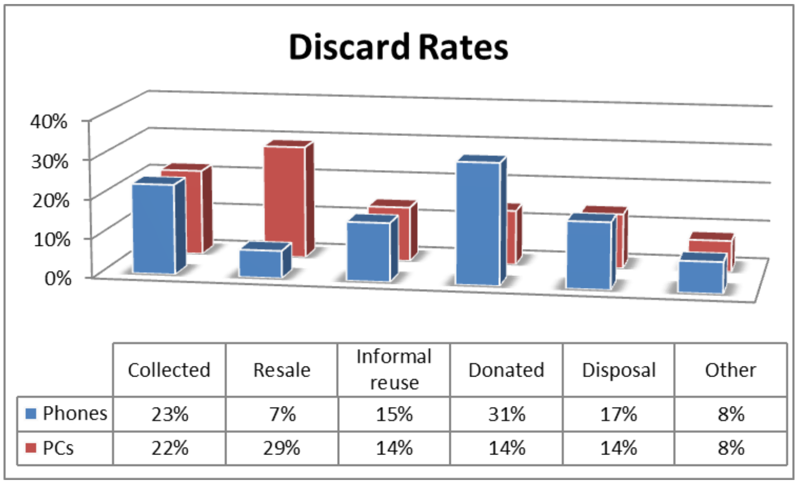

Figure 24: Mobile phone and PC discard rates (Miller et al., 2012)

Although survey results from IDC (2011) indicated that almost 39% of collected equipment is intended for repair or reuse (not including parts), the actual rate is adjusted down to 15% due to portions of this flow being redirected to recycling or being sold off as equipment still needing repair. The survey responses based on the treatment of WEEE received by U.S. recycling companies are summarized in Table 28.

Table 28: Treatment of WEEE collected by recyclers (IDC, 2011)

Treatment	Volume (tons)	Share
Commodity scrap	2,318,374	72.5%
Equipment for repair/resuse	497,811	15.6%
Parts for repair/reuse	267,719	8.4%
Landfill or incineration	67,025	2.1%
Other	47,984	1.5%
Total	**3,198,913**	**100%**

None of the studies on U.S. waste management practices provide a complete picture of WEEE flows. Nevertheless, the data are pieced together to estimate the end-of-use and end-of-life treatment flows indicated in Table 29. Storage flows are not included in the data set.

Table 29: EoU and EoLT rates – United States

	End-of-Use				End-of-Life		
Equipment Category	Storage	Reuse	Export	EoLT	Formal Recycling	Informal Recycling	Landfill
Mobile phones	-	53%	7%	40%	20%	0%	80%
Personal computers	-	31%	4%	65%	58%	0%	42%
All WEEE	-	13%	20%	67%	36%	0%	64%

According to USITC (2013), at least 57% of UEEE and WEEE exports from the U.S. are sent to countries in Asia, while most of the remaining flows are split between the Europe and Latin America regions. The exact destination countries are not indicated so regional treatment rates are taken as an estimate for exported flows in Table 30. The destination country for exports may differ according to the type of equipment exported, but the same overall estimated export flows from the U.S. are applied to each equipment category.

Table 30: EoLT rates – ICT waste generated in the U.S.

		Treatment Location	Weight	Formal Recycling	Informal Recycling	Landfill
Mobile Phones		Domestic	85%	20%	0%	80%
	Exports	APAC	8%	8%	85%	7%
	Exports	Europe	3%	57%	17%	26%
	Exports	Latin America	3%	17%	44%	39%
		Weighted Total		20%	9%	71%
Computers		Domestic	94%	58%	0%	42%
	Exports	APAC	3%	8%	85%	7%
	Exports	Europe	1%	57%	17%	26%
	Exports	Latin America	1%	17%	44%	39%
		Weighted Total		56%	4%	41%
All WEEE		Domestic	77%	36%	0%	64%
	Exports	APAC	13%	8%	85%	7%
	Exports	Europe	5%	57%	17%	26%
	Exports	Latin America	5%	17%	44%	39%
		Weighted Total		32%	14%	53%

5.6 Latin America

End-of-life treatment rates for the Latin America region are based on the top 3 WEEE generating countries in the region as indicated in Table 31.

Table 31: Mobile phone counts - Latin America (World Bank, 2014)

Country	Mobile phone subscriptions	Share of region
Brazil	271 M	39%
Mexico	105 M	15%
Argentina	66 M	9%
3 country total	442 M	63%
Region total	698 M	100%

5.6.1 Brazil

Brazil is now one of the largest electronic products markets in the world, generating vast volumes of end-of-life goods that require proper treatment if environmental harm from disposal of toxic materials is to be avoided. An estimated 10,000 repair and refurbishment shops exist in Brazil to recirculate waste equipment with reuse potential; however, the true size of the sector is unknown due a lack of information on all the informal and unregistered actors. Though a number of electronic waste management companies have emerged in recent years showing sign of a potential industry to address the waste stream in the coming years, most do not have the technology required to properly manage circuit boards or flat screen monitors. Certain components and waste fractions may be exported to countries with the technology where they can be recycled properly. While most of the waste generated in Brazil, considering all waste streams, ends up discarded in landfills, the majority of electronic waste is sent to recycling facilities (Nes, 2012).

The 3 options for recycling WEEE in Brazil are through collection programs set up by social organizations, retailers, or manufacturers. No facilities in Brazil have the capacity to fully recycle WEEE, but there are a number of recycling companies that do recover metals fractions that are more easily separated. Printed circuit boards may be sent to other countries for further processing (Oliviera et al., 2012).

Waste flows

Over a third of all end-of-life electronics in Brazil remain stored in homes, and only 7% is discarded as waste. An estimated 50% is either sold or donated for reuse (Nes, 2012). No data indicate the specific portions of WEEE recycled in the formal and informal sectors so an assumption is made that 75% of recycled WEEE is done so informally. The estimated WEEE flows for Brazil are given in Table 32.

Table 32: EoU and EoLT rates - Brazil

	End-of-Use				End-of-Life		
Equipment Category	Storage	Reuse	Export	EoLT	Formal Recycling	Informal Recycling	Landfill
All WEEE	35%	50%	0%	15%	13%	40%	47%

5.6.2 Mexico

It is evident that scavengers (called pepenadores in Mexico) are present collecting discarded electronics from municipal waste streams, but little data are available on electronic waste management practices in Mexico, (Estrada-Ayub & Kahhat, 2014).

Based on research conducted in various areas in the city of Mexicali, Ojeda-Benitez et al. (2013) suggest that 21% of end-of-life electronic devices are discarded along with household waste; however, scavengers are known to pick through this waste stream to collect items with material recovery value. The remaining 79% of household electronic waste is kept in storage, some to be reused or refurbished in the future. Cabrera-Cruz et al. (2014) report that the capacity for formal WEEE recycling in Mexico is around 10% of the generated waste volumes, whereas about 20% is covered by the informal sector.

Household discard and treatment rates based on a survey in the northeastern Mexican state of Nuevo Leon are given in Figure 25.

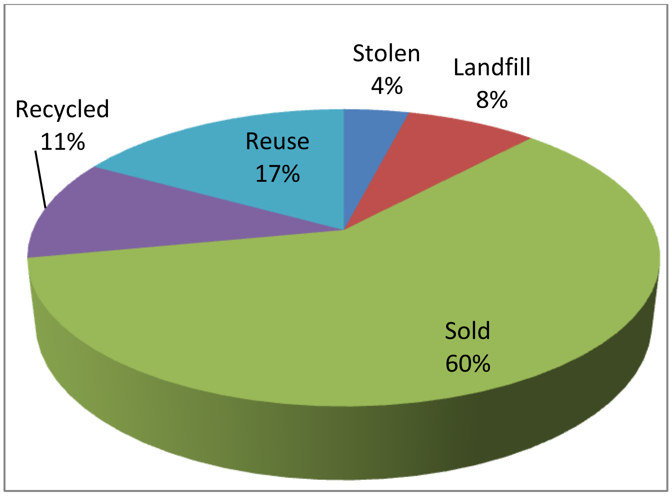

Figure 25: Discarded computer flows (Garcia et al., 2012)

Excluding equipment kept in storage, the information collected regarding the waste management system in Mexico is used to approximate the end-of-use and end-of-life treatment rates as shown in Table 33. Due to the presence of an informal treatment sector, it is assumed that no WEEE is exported.

Table 33: EoU and EoLT rates - Mexico

	End-of-Use				End-of-Life		
Equipment Category	**Storage**	**Reuse**	**Export**	**EoLT**	**Formal Recycling**	**Informal Recycling**	**Landfill**
Personal computers	-	77%	0%	19%	58%	42%	
All WEEE	55%		0%	45%	22%	45%	33%

5.6.3 Argentina

Ongondo et al. (2011) report that the electronic waste management system in Argentina consists of both formal and informal activities. Despite the extensive informal recycling sector in Argentina, the sector has not made electronic waste a major focus yet. While a number of companies operate take back programs to collect end-of-life equipment, large amounts of e-waste are dumped in landfills. Due to a perceived value, the most frequent way of dealing with equipment no longer used is to keep it in storage.

According to Devia (2013), an estimated 5% of e-waste generated in Argentina is collected and managed by formal operations, while the remaining waste volumes are either held in storage or discarded along with municipal waste. Cartoneros, the word used for scavengers in Argentina, tend to collect most equipment that ends up dumped on roadsides or in landfills, focusing on metal recovery and discarding the remaining materials under uncontrolled conditions. Roveri & Lujambio (2010) estimate that 35% of the electronic waste generated in Argentina is from computers and telecommunications equipment. A handful of private sector companies in the country run a business around the processing of collected electronic waste. State run collection initiatives account for less than a 5% share of all the e-waste treated in the country.

Osório (2012) reports that around a dozen authorized recyclers treat between 2% and 15% of the waste generated in Argentina. The rest of the collected equipment is sent for treatment in Europe where more advanced technology enables proper processing. In total, only 24-32% of electronic waste generated in Argentina is either reused or recycled. Another 30-35% is kept in storage by household or commercial users, and the remaining 30-35% is landfilled or discarded in open dump sites. Based on the data collected, the e-waste flows in Argentina are approximated in Table 34. Based on the earlier claim that scavengers collect and direct most equipment in landfills, it is assumed that around 75% of the dumped WEEE is collected and treated in the informal sector.

Table 34: EoU and EoLT rates - Argentina

	End-of-Use				End-of-Life		
Equipment Category	Storage	Reuse	Export	EoL Treatment	Formal Recycling	Informal Recycling	Landfill
All WEEE	35%	20%	0%	45%	22%	60%	18%

6 Results

The data presented in chapter 4 are consolidated in the following chapter in order to estimate the end-of-life treatment scenario for ICT waste at regional and global levels.

6.1 Regional end-of-life treatment scenario

The data used to model regional waste treatment flows is taken from national results at the lowest equipment grouping level available (device level is preferred over "All WEEE"). Mobile phone subscription counts are again used to weight each country according to the estimated percentage of waste each country generates within the regional grouping. Results for the exporting regions (Europe and North America) are shown from two perspectives. The first approach estimates end-of-life treatment rates for each region according to the waste generated within the region, and the destination and EoLT rates for export flows are also indicated. The second approach estimates EoLT rates according to the waste treated in each region, and the export flows are therefore excluded and the regional weight for each country is adjusted to account for the loss of export flows.

For regions that export waste, end-of-life treatment results are estimated according to the percentage of waste generated within the region as well as the percentage waste treated within the region (excluding export flows).

6.1.1 Sub-Saharan Africa

The regional EoLT flows for the region of Sub-Saharan Africa are indicated in Table 35.

Table 35: EoLT rates - Sub-Saharan Africa

Country	Equipment Category	Regional Weighting	Formal Recycling	Informal Recycling	Landfill
Nigeria	All WEEE	55%	0%	74%	26%
South Africa	Personal computers	33%	66%	25%	9%
Ghana	All WEEE	12%	1%	98%	1%
Weighted Total:			22%	61%	17%

Given that most of Africa resembles what is observed in Ghana and Nigeria, and that South Africa is the only country in the region with a capacity to formally treat relevant volumes of electronic waste, another picture can be drawn for the region. Table 36 shows the estimated e-waste treatment rates for the region adjusted to minimize the impact of South Africa as an outlier. The adjusted weight used is based on the nation's share of total waste generated in the region. The remaining weight is split between the two other countries according their original weighting and treatment rates

Table 36: EoLT rates – Sub-Saharan Africa (S.Africa weight adjusted)

Country	Equipment Category	Regional Weighting	Formal Recycling	Informal Recycling	Landfill
Nigeria	All WEEE	82%	0%	74%	26%
South Africa	Personal computers	13%	66%	25%	9%
Ghana	All WEEE	5%	1%	99%	1%
Weighted Total:			9%	69%	23%

6.1.2 Middle East & Northern Africa

No specific treatment rates are available for the Middle East & North Africa region. Rather than disregarding the entire region, assumptions are made using all available information to estimate reasonable rates for the region. As few countries in the region have the capacity to recycle even limited volumes of WEEE under formal conditions, and very little waste equipment ends up in landfills, the conditions closely resemble what is observed in Asia. It is therefore assumed that the EoLT rates for Asia are an appropriate estimate for the Middle East and Northern Africa region (Table 37).

Table 37: EoLT rates – Middle East & N. Africa

Region	Equipment Category	Formal Recycling	Informal Recycling	Landfill
Middle East & N. Africa	Mix of ICT devices	7%	87%	6%

6.1.3 Europe

Due to a lack of data for Russia, the country is excluded from the regional assessment. This in turn increases the regional weight of the three countries considered, and possibly overestimates the level of formal treatment rates indicated for the region. The UK, Italy, and Germany are investigated in this study because of the high level of ICT consumption (ICT waste generated), which clearly corresponds to economic status. Assuming these 3 countries are more developed than some other European countries, it is possible that informal waste treatment methods are practices more frequently in the countries not investigated. For more accurate account of the treatment rates within Europe, results for Russia and other countries in the region should be included in future studies. The EoLT rates for Europe, based on the 3 countries considered, are presented in Table 38.

Table 38: EoLT rates for waste generated in Europe

Treatment Location		Equipment Category	Regional Weight	Formal Recycling	Informal Recycling	Landfill
Germany		Household WEEE	30%	82%	9%	9%
Italy		Household IT & Telecom	30%	64%	7%	29%
United Kingdom		All WEEE	26%	45%	5%	50%
Exports	Eastern Europe*	All WEEE	2%	20%	40%	40%
Exports	West Africa	All WEEE	2%	0%	80%	20%
Exports	China	Household WEEE	6%	28%	66%	6%
Exports	Pakistan	Mix of ICT devices	3%	7%	87%	6%
Exports	India	All WEEE	3%	1%	95%	4%
Weighted Total:				58%	17%	26%

Table 39 shows the EoLT rates for waste treated within Europe, not including the equipment exported for treatment outside the region. This data gives insight to the actual treatment methods performed within Europe. Waste from the investigated countries is exported to Eastern European, flows that are still considered for the EoLT occurring within the region.

Table 39: EoLT rates for waste treated in Europe

Treatment Location	Equipment Category	Weight	Formal Recycling	Informal Recycling	Landfill
Germany	Household WEEE	34%	82%	9%	9%
Italy	Household IT & Telecom	34%	64%	7%	29%
United Kingdom	All WEEE	30%	45%	5%	50%
Eastern Europe	All WEEE	2%	20%	40%	40%
Weighted Total:			63%	8%	29%

6.1.4 Asia Pacific

The results for the Asia Pacific region based on the 4 countries investigated are presented in Table 40. Exports from Japan are integrated, resulting in a slight increase in the regional weight assigned to China and India. The remaining exports to Africa represent just a fraction of a percent when considering waste generated throughout the region, so it is not included.

Table 40: EoLT rates - Asia Pacific

Treatment Location	Equipment Category	Weight	Formal Recycling	Informal Recycling	Landfill
China	Mobile phones	50%	10%	80%	10%
India	Personal computers	36%	2%	98%	0%
Indonesia	Mobile phones & PCs	11%	10%	80%	10%
Japan	Personal computers	3%	90%	0%	10%
Weighted Total:			10%	84%	6%

6.1.5 North America

No weighting or consolidation is performed as U.S. data are used to represent the North America region. The EoLT rates for U.S. generated WEEE are indicated in Table 41. As the data is taken from just one country, the rates for waste treated within the region are indicated under the 'domestic' category.

Table 41: EoLT rates - United States

		Treatment Location	Weight	Formal Recycling	Informal Recycling	Landfill
Mobile Phones		Domestic	85%	20%	0%	80%
	Exports	APAC	8%	8%	85%	7%
	Exports	Europe	3%	57%	17%	26%
	Exports	Latin America	3%	17%	44%	39%
		Weighted Total		20%	9%	71%
Computers		Domestic	94%	58%	0%	42%
	Exports	APAC	3%	8%	85%	7%
	Exports	Europe	1%	57%	17%	26%
	Exports	Latin America	1%	17%	44%	39%
		Weighted Total		56%	4%	41%
All WEEE		Domestic	77%	36%	0%	64%
	Exports	APAC	13%	8%	85%	7%
	Exports	Europe	5%	57%	17%	26%
	Exports	Latin America	5%	17%	44%	39%
		Weighted Total		32%	14%	53%

6.1.6 Latin America

The estimated regional EoLT flows for the Latin America region are presented in Table 42.

Table 42: EoLT rates – Latin America

Country	Equipment Category	Weight	Formal Recycling	Informal Recycling	Landfill
Brazil	All WEEE	61%	13%	40%	47%
Mexico	All WEEE	24%	22%	45%	33%
Argentina	All WEEE	15%	22%	60%	18%
Weighted Total:			17%	44%	39%

6.2 Global end-of-life treatment scenario

Regional findings are aggregated in this section to estimate a global end-of-life treatment scenario for ICT equipment. Again, mobile phone subscription counts are the basis for estimating the portion of waste generated in each region. The weights are also adjusted based on identified export flows (Table 43).

Table 43: Mobile phone counts – by region (World Bank, 2014)

Region	Mobile phone subscriptions	Weight (generated)	Weight (treated)
Sub-Saharan Africa	618 M	9%	9%
Middle East & N. Africa	740 M	11%	11%
Europe	970 M	15%	13%
APAC	3,231 M	49%	51%
North America	452 M	7%	6%
Latin America	584 M	9%	9%
Global total	**6,595 M**	**100%**	**100%**

U.S. data used to estimate global results are based on an average of the rates for mobile phones and personal computers. The difference in EoLT rates between the two equipment categories is significant at the regional level; however, a sensitivity analysis of the global impact of changing from one product category to the other is less than a 2 % shift in each treatment flow.

Table 44 shows the estimated global EoLT rates weighted according to the volume of waste treated in each region (taking into consideration the identified import and export flows). The rates given for each region indicate how waste is treated within each region, so the rates for North America and Europe are adjusted to exclude export flows.

Table 44: EoLT rates – by share of waste treated in each region

Region	Weight	Formal Recycling	Informal Recycling	Landfill
Sub-Saharan Africa	9%	9%	69%	23%
Middle East & N. Africa	11%	7%	87%	6%
Europe	13%	63%	8%	29%
Asia Pacific	51%	10%	84%	6%
North America	6%	39%	0%	61%
Latin America	9%	17%	44%	39%
Global	100%	19%	64%	17%

Due to the high level of uncertainty in the proposed scenario, a sensitivity analysis is recommended to determine the level of impact the end-of-life stage has on the overall LCA results. The impact range is found by comparing the results of the 3 possible extreme EoLT scenarios - each scenario assuming a different end-of-life treatment method (informal recycling, formal recycling, and landfill) to be at 100% as shown in Table 45. Because a life cycle assessment is not conducted as part of this study, the overall impacts from using this proposed EoLT scenario are not known until the scenario is applied to an LCA study.

Table 45: Scenarios for LCA sensitivity analysis

	Informal recycling	Formal recycling	Landfill
Scenario 1	100%	0%	0%
Scenario 2	0%	100%	0%
Scenario 3	0%	0%	100%

6.3 Network equipment

Very little quantitative data is available regarding the end-of-life treatment of network equipment; nevertheless, qualitative information collected from company reports and discussions with a few professionals in the field is used to approximate end-of-life treatments rates for network infrastructure equipment. In some cases, even in regions where recycling of B2C equipment is limited to informal treatment, B2B equipment is collected and stored for possible formal treatment in the future (Ogungbuyi et al., 2012). Reuse is also a practice for B2B equipment as they are considered an asset that should provide the highest possible return.

Lin (2013) reports that telecommunications operators are dependent on stockpiles of replacement parts in different locations to ensure they are able to keep networks running in situations such as components failing or natural disasters damaging installed equipment. According to GSMA (2009), it is becoming more common for suppliers to include provisions in contracts requiring that decommissioned or replaced equipment is taken back for recycling or reuse. In the case of Sprint decommissioning its Nextel National Network in the United States, the company reports that of the more than 45 million tonnes of equipment from 30,000 installation sites that was not reused, nearly all is to be recycled (Sprint, 2013).

Equipment removed from upgraded networks may be relocated for reuse in the countryside or other less advanced regions, and network equipment reuse is often limited to parts or smaller components (Zide, 2014). According to Bergmark (2015), a major European ICT network operator claimed at a recent European Telecommunications Standards Institute event that the network equipment they use in Africa is either reused or sent to Europe for recycling. On the other hand, Umair (2014) claims to have witnessed informal recycling of ICT network equipment during a research visit to Pakistan.

This section contains data intended for internal Ericsson use only, so it has been omitted from the external version of the report.

Table 46: End-of-life treatment rates – network equipment (REMOVED)

7 Discussion

The observations made based from the data collected in this study are presented here, along with an assessment of any perceived shortcomings in the research methods applied.

7.1 Regional waste treatment trends

A few trends are seen when comparing the estimated end-of-life treatment rates for each region (Figure 26). Informal recycling activities are the most common form of end-of-life treatment practiced in each developing region (Latin America, APAC, Middle East & North Africa, and Sub-Saharan Africa). It is also clear that the developing countries lack formal processing of ICT waste. Latin America indicates the highest level of formal recycling amongst the developing regions at just 17% of waste volumes. Landfill rates fluctuate amongst the developing regions from just 6% in the Middle East/N. Africa and APAC regions to 39% in Latin America.

While developing regions are dominated by informal EoLT practices, the opposite is true in the developed regions (Europe and North America), where informal recycling activities are the least common form of end-of-life treatment. Equipment treated in Europe receives the highest level of formal treatment compared to all other regions (63% is formally recycled), and a majority (61%) of the equipment treated in North America ends up in landfills.

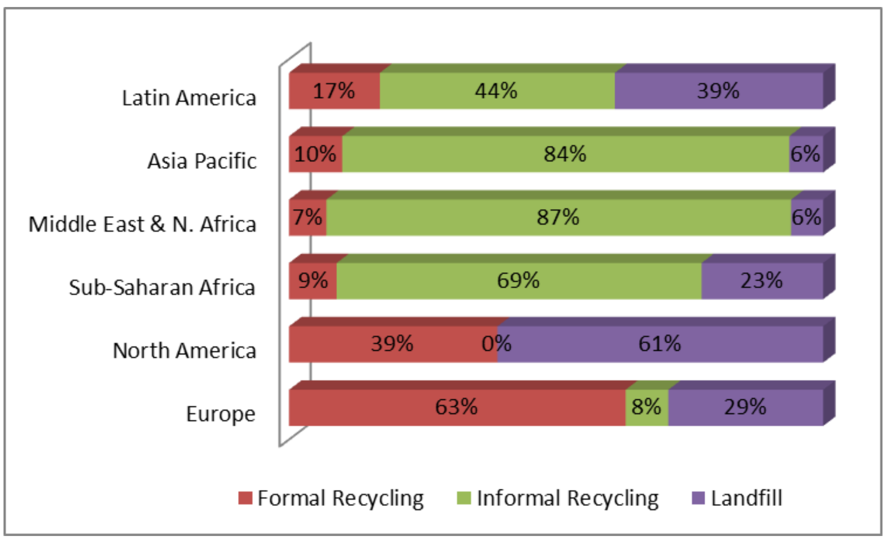

Figure 26: Regional EoLT rates – by treatment location

Despite the lack of a formal system to process waste in most developing countries, the informal sector takes advantage of the material flows available for collection and recycling. The high recycling rate would be a great achievement if it were not for the list of harmful techniques performed in the informal sector that dominates developing countries.

Europe and North America on the other hand recycle far greater portions of WEEE under formal conditions than the developing regions. While Europe is a distance ahead of the United Sates in terms of percentage of waste recycled, both regions show room for improvement. Developed countries also export ICT waste to developing countries for both reuse and end-of-life treatment. Cheaper labor and a lack of control over treatment practices in developing countries in a sense offer a subsidized option for discarded equipment that may otherwise incur a cost if disposed of in developed countries.

7.2 Revised LCA EoLT assumptions

With an estimated 82% of waste treated outside the formal waste recycling sector, the approach of assuming complete formal recycling for all discarded ICT equipment seems to be unrealistic.

As explained in the introduction, the EoLT rates assumed in a previous Ericsson mobile phone LCA were 25% formal recycling, 25% informal recycling, and 50% landfill. However, the global scenario developed in this study estimates that 64% informal recycling, 19% formal recycling, and 17% disposal to landfill. A comparison of the two scenarios in Figure 27 shows a relative similarity in formal waste treatment rates, but a significant difference is seen in the estimated informal recycling and landfill rates. The negative impacts associated with informal recycling are significantly understated under the previous scenario, and the amount of material lost to landfills is overstated. If considering the incomplete nature of some informal recycling, where non-recoverable materials are dumped or landfilled, the differences between the scenarios may be slightly less than indicated.

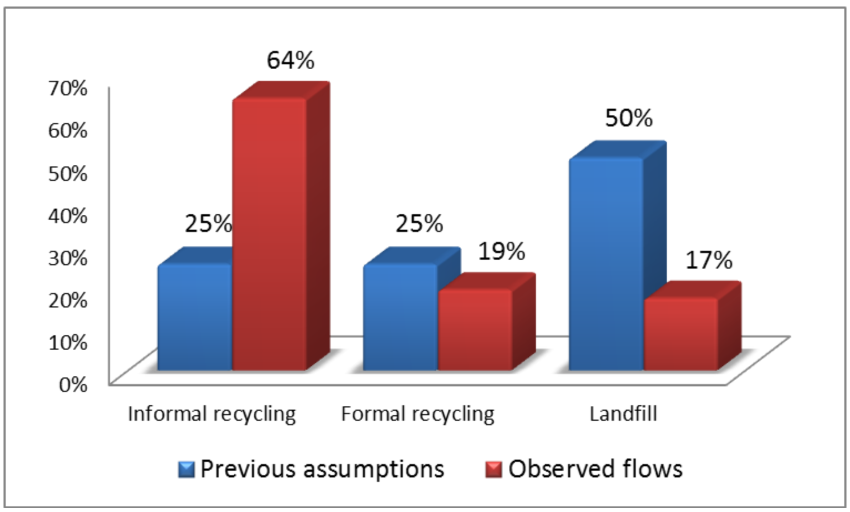

Figure 27: Previous assumption vs observed EoLT scenario

7.3 Possible issues with the results

Both the data collected and the method used to estimate EoLT practices for ICT equipment present a number of issues. The many data gaps require assumptions to be made, creating a level of uncertainty in the results. The methodologies used may contribute to uncertainty in the results, but the developed scenario is considered to be reasonable with no other approach identified as offering a higher degree of certainty. The issues surrounding the data collection and methods used are addressed here.

Due to a lack of reporting or possible confidentiality reasons, most of the data used to support the model are based on the collection and treatment of household waste. Because B2B ICT waste is often discarded using the most financially beneficial methods, it is assumed that officially reported data on waste exports are underreported. As discussed, developing regions report large quantities of imported waste, but the data does not always match what is reported by exporting countries. It is therefore likely that the scenario developed in this study under represents the level of ICT waste exported from developed to developing countries. This lack of B2B data may not change the treatment rates estimated for each region, but it could significantly impact the overall global EoLT outcome. The proposed sensitivity analysis would show the extent to which LCA results are affected by adjustments made to the EoLT scenario.

The number of mobile phone subscriptions is used as an indicator for the level of ICT network waste generated in each country, which is the basis for weighting regional and global shares of waste generated in each country. This can be problematic because the number of phones in use may not directly indicate the number of all types of ICT equipment being used. Future ICT waste treatment research should not use one product as the primary indicator for all equipment unless it offers a fair representation of all waste investigated. The number of phones in use can provide some insight into the scale of infrastructure used to support the communication network in a given area; however, the density of active phones per network station in a region could be dependent on other factors such as the type of technology used or local economic conditions. Substituting data from one equipment category for another can also lead to a misrepresentation when it comes to end-of-life flows if the type of treatment performed is dependent on the type of equipment being treated. More research is needed to fully understand any differences in the flows of different equipment categories.

Similarly, estimating waste volumes based on the number of devices put on market in each country can be an issue. Because the lifetime of a mobile phone varies between regions, average mobile phone lifetimes in each country should be considered to accurately estimate the volume of phone waste generated in a given period of time. Although such data are not readily available, using actual volumes of waste generated during a given period rather than volumes of equipment in use would resolve this issue.

As demonstrated in chapters 4 and 5, the estimated regional and global EoLT rates presented in this study are constructed from a collection of national datasets. In estimating regional treatment rates from a group of national datasets, data representing different equipment categories are combined in almost every case. This process is necessary due to a lack of available research in the field, but it also risks inaccurate results. Much of the data collected for this study are in reference to all WEEE categories; however, the regional and global results are used to determine the impacts associated with the end-of-life treatment of ICT equipment. The implied assumption is that all equipment categories receive the same end-of-life treatment in each country. Data from Mexico and United States indicate that treatment practices can vary within a country based on the type of equipment discarded. Several other case studies indicate that end-of-life treatment practices remain somewhat the same regardless of the type of equipment discarded, as is seen for Nigeria, Italy, China, India, and Indonesia. The remaining case studies only contain data for one category of equipment so any variations in treatment are unknown. Further research is needed to determine what differences exists regarding the EoLT for each type of equipment.

The unit of measure is an important factor when calculating and comparing waste flows. Most of the data presented in this study are based on volumes by equipment weight, but there are cases where the volumes are given as number of units. The measurement unit is irrelevant when measuring one equipment type, but measuring a mix of equipment categories becomes problematic if a consistent measurement is not maintained throughout the study. As an example, mobile phones may dominate the export flows when measured in number of units, but a much smaller number of exported desktop computers may represent a majority of export flows if measured by weight. For more accurate results, more research should be done to convert all data into a standard unit of measure.

Regional estimations for Europe, Africa, and the Middle East are based on datasets smaller than a majority representation for the region. An obstacle for Europe is that no data is available for waste treatment practices in Russia. It is assumed however that waste treatment practices are similar throughout each of the 3 regions so expanding the data collection area would not significantly change the findings. Additional research could be done to obtain a greater representation for each region and reduce the uncertainty behind the assumptions otherwise made.

Data compiled in this study are based on the most recent information available. It is assumed that the most current datasets are the most relevant, but that may not always be true. Temporary changes to policy or market conditions could result in abnormal data for the collection period. A comparison against data from other periods could help validate the data used in the current study.

For some regions investigated in this study, the data are limited to household waste flows. There is indication that B2B equipment is treated in a different way than B2C equipment, so the exclusion of unknown B2B flows contributes to uncertainty in this study. This is especially true in areas where B2B waste makes up a significant share of total waste volumes generated. More research is needed to fully understand B2B waste flows and how they affect the overall treatment rates for all ICT waste.

Waste is identified as being either landfilled or recycled, and recycling activities are performed under informal or formal conditions. Open dumping of waste is categorized as informal recycling in this study, but it could be the case that no recycling activities are performed at all. This modeling performed in this study does not allow for a distinction between informal recycling and informal dumping because of the difficulty in distinguishing between the two activities. Landfill quality can also vary significantly across different regions, but anything identified as ending up in a landfill is reported as such in this study. Little distinction is made between controlled and uncontrolled landfills. Although these end-of-life treatment methods are grouped together in the same category, differences may exist when it comes to the impacts from each activity. Such differences are clearly important in an LCA study that is performed with the objective of quantifying environmental impacts. More research into the extent to which each specific activity is performed is necessary for a more accurate estimation of the resulting impacts.

8 Conclusions

As a result of this study, the following conclusions are drawn:

- More research is needed to fill the gaps in knowledge regarding ICT waste collection and treatment flows around the world. A general lack of data exists for ICT equipment, and B2B waste flows should be given specific attention, especially regarding exports.
- Almost no quantitative data is available regarding the end-of-life treatment of network equipment.
- 3 out of 4 developing regions recycle a majority of waste in the informal sector, and the remaining region (Latin America) shows a significant 47% informal recycling rate.
- In developed regions, most ICT waste is landfilled or formally recycled rather than recycled in the informal sector.
- Developed nations are the main source for ICT waste exported to developing countries that lack control over the EoLT activities performed.
- Just about half of all ICT waste is generated in the Asia Pacific region.
- The proposed end-of-life treatment scenario for LCA studies of ICT equipment is 19% of waste is formally recycled, 64% is informally recycled, and 17% is discarded to landfills (Figure 28).

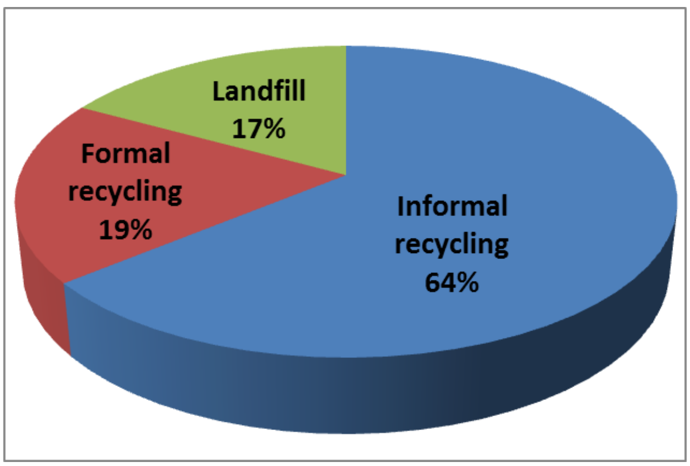

Figure 28: Global EoLT rates

- The proposed EoLT scenario should be combined with a sensitivity analysis to investigate what effect the end-of-life stage has on the overall results of a LCA study. The range of sensitivity is determined by considering the three extreme possibilities: assuming that each treatment method is performed at 100% (complete informal recycling, complete formal recycling, and complete disposal to landfill).

Definitions

B2B (business-to-business) – Goods and services sold on commercial markets to corporate or institutional users. For this study B2B goods can include both mobile network infrastructure equipment as well as end user goods such as computers and phones.

B2C (business-to-consumer) – Goods and services that are sold to and used in private consumer markets. In the context of this study, B2C primarily refers to the goods sold to household end users.

EoL (end-of-life) – The point where a good or service is longer to serve its intended function. Disposal is the next step in the life cycle this stage, and some of treatment is performed, referred to as end-of-life treatment (EoLT).

EPR (extended producer responsibility) – An approach applied to policy that holds manufacturers responsible of the whole life cycle of their products. The basic principle behind EPR is that if manufacturers are made responsible, they will be inclined to pursue more sustainable business models.

ICT (information and communications technology) – The term identifying the overall network of phone and computer communication systems, which includes everything from network infrastructure to end user devices.

UEEE (used electrical and electronic equipment) – Devices that have been discarded or passed on by the initial user for the purpose of being reused. UEEE is frequently used in reference to equipment in the secondhand market.

WEEE (waste electrical and electronic equipment) – Also referred to as E-waste, WEEE has a number of varying definitions. This study follows the definition used by Yang (2008) as discarded, surplus, obsolete, or broken electronic devices that enter the waste stream but are subsequently appropriated as reused, resold, salvaged, recycled, or disposed. Goods are considered to be waste once retired from use by the initial user.

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Appendices

Appendix I Thesis project proposal from Ericsson

Supervisor and contact at Ericsson:
Mine Ercan – Supervisor
Craig Donovan – Responsible Manager

Timeline:
The work is planned to start in September 2014, and to last for a total of 20 weeks.
The thesis work will be conducted on site at Ericsson in Kista.

Research questions to be investigated:
What is the e-waste situation today?
What is the environmental impact of e-waste?
What recycling technologies are used and which ones should be included in the scope of any study relating to Ericsson products?
Are electronics manufacturers taking action to mitigate e-waste in any way?
Which realistic end-of-life scenarios are there for different ICT product categories and what is the statistical apportionment?
Can an LCA model be created for other e-waste management options (reuse, refurbishment, etc.) other than recycling?
Can any conclusions be made regarding environmental impact trends for e-waste in the past 20 years?
What are the uncertainties and data limitation to performing a life cycle assessment to quantitatively investigate the environmental impacts of e-waste?

Background and thesis description:
Ericsson Research (ER) is the corporate research division of Ericsson. ER provides Ericsson with system concepts, technology and methodology. World class innovation is achieved through cooperation within Ericsson and with partners, customers, universities and research institutes.
Life cycle assessment (LCA) is a method used to analyze the environmental impact of a product or service. To consider the full life cycle of products, hence quantify the impacts, all life cycle stages need to be included. Ericsson has been conducting LCAs on ICT products, networks and services since the early 90s.
Electrical and electronic waste (e-waste) is becoming one of the fastest growing waste streams in the world. E-waste is chemically and physically distinct from other forms of municipal or industrial waste and contains many different substances that fall under 'hazardous' and 'non-hazardous' categories.
E-waste handling, specific to ICT products, needs to be reflected in the LCA models of ICT. The aim of this thesis is to provide a deeper understanding of the environmental impacts of e-waste and an up-to-date quantitative LCA model of the end-of-life stage for ICT.

The thesis contains the following activities:
Perform a background study on e-waste, applicable scenarios and the environmental impacts of each.
Identify how much e-waste is produced each year and the recyclable materials in electronic products.
Create realistic EoLT scenarios for selected ICT product categories
Create LCA models for these scenarios and validate them to the extent possible based on publically available data and previous models.
Align the models with industry recognized LCA standards.

Investigate if the model can be created for other e-waste management options (reuse, refurbishment, etc.) other than recycling and expand the model if so.
Identify limitations and allocations in the scenarios and models and propose a strategy for maintaining their relevance going forward.
Apply the model on a ICT product LCA to quantitatively investigate the relative environmental impacts of e-waste Possibly extend the scope by including the e-waste LCA results in a selected LCA parameter model developed 2013.
Possibly investigate if electronics manufacturers are taking action to mitigate e-waste in any way.

Qualifications:
A thesis project is a very good opportunity to gain an insight into our multi-national work environment where you are encouraged to find creative ways to succeed. Please include your CV, academic record, and letter of motivation.
This Master's thesis is suitable for one student.
Your study area should be in engineering within the field of electronics, Telecommunications or similar and you should also have strong interest in sustainability and relevant competence in life cycle assessment.
Excellent skills in both written and spoken English are a prerequisite.
We are looking forward to receiving your application.

Appendix II National mobile phone *subscription* counts

Table 45: Mobile phone subscriptions per country (World Bank, 2014)

Country	Region	MP subscriptions	Global %
Afghanistan	Middle East / Northern Africa	21,388 M	0%
Albania	Europe	3,686 M	0%
Algeria	Middle East / Northern Africa	39,997 M	1%
Angola	Sub-Saharan Africa	13,285 M	0%
Argentina	Latin America	65,910 M	1%
Armenia	Middle East / Northern Africa	3,346 M	0%
Australia	APAC	24,940 M	0%
Austria	Europe	13,272 M	0%
Azerbaijan	Middle East / Northern Africa	10,130 M	0%
Bahrain	Middle East / Northern Africa	2,210 M	0%
Bangladesh	APAC	105,051 M	2%
Belarus	Europe	11,114 M	0%
Belgium	Europe	12,315 M	0%
Benin	Sub-Saharan Africa	9,627 M	0%
Bhutan	APAC	544 M	0%
Bolivia	Latin America	10,426 M	0%
Bosnia and Herzegovina	Europe	3,491 M	0%
Botswana	Sub-Saharan Africa	3,247 M	0%
Brazil	Latin America	271,100 M	4%
Brunei Darussalam	APAC	469 M	0%
Bulgaria	Europe	10,487 M	0%
Burkina Faso	Sub-Saharan Africa	11,241 M	0%
Burundi	Sub-Saharan Africa	2,537 M	0%
Cabo Verde	Sub-Saharan Africa	499 M	0%
Cambodia	APAC	20,265 M	0%
Cameroon	Sub-Saharan Africa	15,665 M	0%
Canada	North America	27,582 M	0%
Central African Republic	Sub-Saharan Africa	1,360 M	0%
Chad	Sub-Saharan Africa	4,561 M	0%
Chile	Latin America	23,659 M	0%
China	APAC	1,229,113 M	19%
Colombia	Latin America	50,295 M	1%
Comoros	Sub-Saharan Africa	348 M	0%
Congo, Dem. Rep.	Sub-Saharan Africa	29,507 M	0%
Congo, Rep.	Sub-Saharan Africa	4,660 M	0%
Costa Rica	Latin America	7,112 M	0%
Cote d'Ivoire	Sub-Saharan Africa	19,391 M	0%
Croatia	Europe	4,912 M	0%
Cuba	North America	1,996 M	0%
Cyprus	Europe	1,086 M	0%
Czech Republic	Europe	14,047 M	0%
Denmark	Europe	7,163 M	0%
Dominican Republic	Latin America	9,200 M	0%
Ecuador	Latin America	17,542 M	0%
Egypt, Arab Rep.	Middle East / Northern Africa	99,705 M	2%
El Salvador	Latin America	8,635 M	0%
Equatorial Guinea	Sub-Saharan Africa	511 M	0%
Eritrea	Sub-Saharan Africa	355 M	0%
Estonia	Europe	2,055 M	0%
Ethiopia	Sub-Saharan Africa	25,647 M	0%
Fiji	APAC	891 M	0%
Finland	Europe	9,318 M	0%
France	Europe	63,324 M	1%
Gabon	Sub-Saharan Africa	3,590 M	0%
Gambia, The	Sub-Saharan Africa	1,849 M	0%
Georgia	Europe	4,993 M	0%

Country	Region	MP subscriptions	Global %
Germany	Europe	98,470 M	1%
Ghana	Sub-Saharan Africa	28,026 M	0%
Greece	Europe	13,000 M	0%
Guatemala	Latin America	21,716 M	0%
Guinea	Sub-Saharan Africa	7,436 M	0%
Guinea-Bissau	Sub-Saharan Africa	1,263 M	0%
Guyana	Latin America	555 M	0%
Haiti	North America	7,160 M	0%
Honduras	Latin America	7,767 M	0%
Hong Kong SAR, China	APAC	17,194 M	0%
Hungary	Europe	11,590 M	0%
Iceland	Europe	356 M	0%
India	APAC	886,304 M	13%
Indonesia	APAC	303,695 M	5%
Iran, Islamic Rep.	Middle East / Northern Africa	65,246 M	1%
Iraq	Middle East / Northern Africa	32,450 M	0%
Ireland	Europe	4,755 M	0%
Israel	Middle East / Northern Africa	9,500 M	0%
Italy	Europe	96,904 M	1%
Jamaica	North America	2,796 M	0%
Japan	APAC	146,455 M	2%
Jordan	Middle East / Northern Africa	10,314 M	0%
Kazakhstan	Middle East / Northern Africa	29,676 M	0%
Kenya	Sub-Saharan Africa	31,309 M	0%
Korea, Dem. Rep.	APAC	2,420 M	0%
Korea, Rep.	APAC	54,681 M	1%
Kuwait	Middle East / Northern Africa	6,410 M	0%
Kyrgyz Republic	APAC	6,737 M	0%
Lao PDR	APAC	4,481 M	0%
Latvia	Europe	2,800 M	0%
Lebanon	Middle East / Northern Africa	3,885 M	0%
Lesotho	Sub-Saharan Africa	1,790 M	0%
Liberia	Sub-Saharan Africa	2,555 M	0%
Libya	Middle East / Northern Africa	10,235 M	0%
Lithuania	Europe	4,566 M	0%
Luxembourg	Europe	788 M	0%
Macao SAR, China	APAC	1,722 M	0%
Macedonia, FYR	Europe	2,237 M	0%
Madagascar	Sub-Saharan Africa	8,284 M	0%
Malawi	Sub-Saharan Africa	5,290 M	0%
Malaysia	APAC	42,996 M	1%
Maldives	APAC	625 M	0%
Mali	Sub-Saharan Africa	19,749 M	0%
Malta	Europe	557 M	0%
Mauritania	Sub-Saharan Africa	3,988 M	0%
Mauritius	Sub-Saharan Africa	1,534 M	0%
Mexico	North America	105,006 M	2%
Moldova	Europe	3,697 M	0%
Mongolia	APAC	3,526 M	0%
Montenegro	Europe	994 M	0%
Morocco	Middle East / Northern Africa	42,424 M	1%
Mozambique	Sub-Saharan Africa	12,401 M	0%
Myanmar	APAC	6,832 M	0%
Namibia	Sub-Saharan Africa	2,539 M	0%
Nepal	APAC	19,865 M	0%
Netherlands	Europe	19,060 M	0%

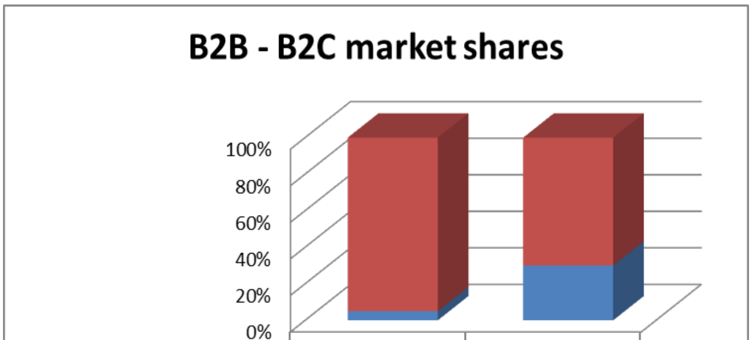
Country	Region	MP subscriptions	Global %
New Zealand	APAC	4,766 M	0%
Nicaragua	Latin America	6,809 M	0%
Niger	Sub-Saharan Africa	7,006 M	0%
Nigeria	Sub-Saharan Africa	127,246 M	2%
Norway	Europe	5,874 M	0%
Oman	Middle East / Northern Africa	5,617 M	0%
Pacific island small states	Europe	1,492 M	0%
Pakistan	Middle East / Northern Africa	127,737 M	2%
Panama	Latin America	6,298 M	0%
Papua New Guinea	APAC	3,000 M	0%
Paraguay	Latin America	7,053 M	0%
Peru	Latin America	29,793 M	0%
Philippines	APAC	102,824 M	2%
Poland	Europe	57,332 M	1%
Portugal	Europe	11,991 M	0%
Puerto Rico	Latin America	3,085 M	0%
Qatar	Middle East / Northern Africa	3,310 M	0%
Romania	Europe	22,910 M	0%
Russian Federation	Europe	218,300 M	3%
Rwanda	Sub-Saharan Africa	6,689 M	0%
Saudi Arabia	Middle East / Northern Africa	50,882 M	1%
Senegal	Sub-Saharan Africa	13,134 M	0%
Serbia	Europe	9,199 M	0%
Sierra Leone	Sub-Saharan Africa	2,689 M	0%
Singapore	APAC	8,421 M	0%
Slovak Republic	Europe	6,208 M	0%
Slovenia	Europe	2,284 M	0%
Somalia	Sub-Saharan Africa	5,183 M	0%
South Africa	Sub-Saharan Africa	77,826 M	1%
South Sudan	Sub-Saharan Africa	2,853 M	0%
Spain	Europe	50,167 M	1%
Sri Lanka	APAC	20,315 M	0%
Sudan	Sub-Saharan Africa	27,658 M	0%
Suriname	Latin America	687 M	0%
Swaziland	Sub-Saharan Africa	893 M	0%
Sweden	Europe	11,906 M	0%
Switzerland	Europe	10,808 M	0%
Syrian Arab Republic	Middle East / Northern Africa	12,257 M	0%
Tajikistan	Middle East / Northern Africa	7,537 M	0%
Tanzania	Sub-Saharan Africa	27,443 M	0%
Thailand	APAC	92,463 M	1%
Timor-Leste	APAC	650 M	0%
Togo	Sub-Saharan Africa	4,263 M	0%
Trinidad and Tobago	North America	1,944 M	0%
Tunisia	Middle East / Northern Africa	12,712 M	0%
Turkey	Middle East / Northern Africa	69,661 M	1%
Turkmenistan	Middle East / Northern Africa	6,125 M	0%
Uganda	Sub-Saharan Africa	16,569 M	0%
Ukraine	Europe	62,459 M	1%
United Arab Emirates	Middle East / Northern Africa	16,064 M	0%
United Kingdom	Europe	78,144 M	1%
United States	North America	305,743 M	5%
Uruguay	Latin America	5,268 M	0%
Uzbekistan	Middle East / Northern Africa	21,500 M	0%
Venezuela, RB	Latin America	30,896 M	0%
Vietnam	APAC	120,000 M	2%
West Bank and Gaza	Middle East / Northern Africa	3,190 M	0%
Yemen, Rep.	Middle East / Northern Africa	16,845 M	0%
Zambia	Sub-Saharan Africa	10,396 M	0%
Zimbabwe	Sub-Saharan Africa	13,633 M	0%
Grand Total		[illegible]	100%

Appendix III B2B and B2C sector differences

Additional findings related to the differences in the treatment of ICT waste between B2B and B2C sectors are presented in this appendix.

Nigeria

The Lagos State Environmental Protection Agency (LSEPA) is developing a formal collection system for waste generated in the B2B sector, and the collected waste is being stored for treatment once formal methods are possible (Secretariat of the Basel Convention, 2011). Corporate consumers are responsible for an estimated 100,000 tonnes of electronic waste, consisting mostly of ICT equipment. Rather than discarding equipment for treatment, 20% is donated for reuse, and the rest is held in storage (Ogungbuyi et al., 2012). Ongondo et al. (2011) estimate that households are the source of 90% of the electronic waste generated in Nigeria, with over half being large household appliances. Institutional and corporate consumers are therefore responsible for only 10% of the waste generated, around 73% of which is ICT equipment (mobile phones and personal computers). As shown in Figure 29, the distribution of ICT equipment is around 70% to consumer markets and 30% to institutional and corporate markets.



	All electronics	ICT equipment
Private	95%	70%
Corporate/ Institutional	5%	30%

Figure 29: WEEE generated in each sector (SBC, 2011)

South Africa

ATE (2012) suggests that a majority of electronics manufacturers in South Africa do have some form of collection and treatment program in place for corporate customers. The corporate sector includes government and business entities and is said to be 60-65% of the market for IT equipment. Having strict policies regarding how waste is handled, much of the end-of-life equipment from these sectors is stored until proper disposal or reuse methods are set.

Germany

Deubzer (2011) shows that of all the WEEE collected for formal treatment in Germany during September of 2010, none of the categories generated a profit. The estimated cost associated with treating ICT waste is around 200 euros per ton of equipment. These WEEE management costs encourage commercial users, retailers, and brokers to dispose of equipment through the informal markets where higher values and lower processing costs are experienced (Seum & Hermann, 2010). In fact, less than 10% of the total volume of WEEE collected for treatment by the formal WEEE management system in Germany comes from the B2B sector (Deubzer, 2011).

In a survey of German commercial organizations, more respondents claim to dispose of some portions of their WEEE for recycling and refurbishment than for just recycling, just refurbishment, or neither. The option least selected by respondents was to neither recycle nor refurbish end-of-life equipment. Of those companies choosing to not recycle or refurbish old equipment, smaller companies outnumbered the medium and large sized companies. The survey also indicates that more small companies dispose of WEEE through informal arrangements in Germany than do medium or large size companies. On the other hand, contractors tend to be used for WEEE disposal equally regardless of company size (Peagam et al., 2013).

Italy

As shown in Figure 29, consumer markets were the destination for 85% of the electronic equipment sold in 2011. When considering just the equipment falling under previously described R4 category, which includes ICT devices, the B2C market share increases to 87%.

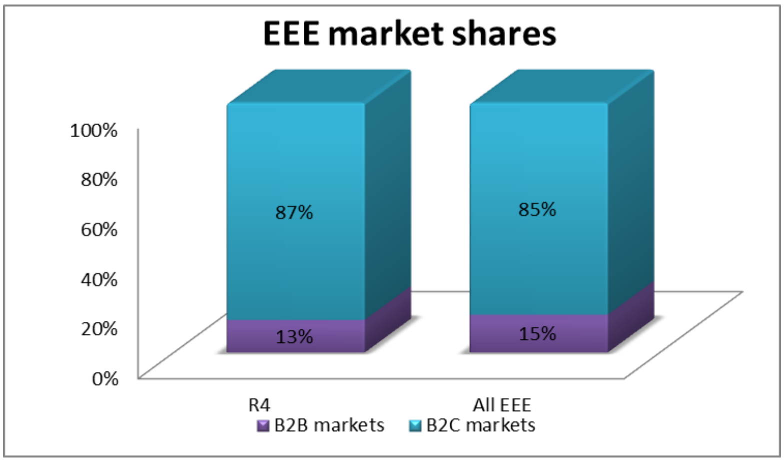


Figure 31: Market shares for EEE in Italy (Magalini et al., 2012)

United Kingdom

Of the estimated 300,000 tonnes of EEE placed on market in the UK commercial sector in 2009, 113,000 tonnes (38%) were ICT equipment. Assuming a saturated market, the reported 7,189 tonnes of ICT waste collected from the B2B sector in 2008 indicate a collection rate of approximately 6% (Peagam et al., 2013).

India

The corporate sector in India is the source for around 80% of generated WEEE (Borthakur & Sinha, 2013). Manomaivibool (2009) reports that 26% of computer waste comes from households and 74% comes from the commercial sector.