BASELINE STUDY, MARKET ANALYSIS, AND STUDY OF REGULATIONS FOR E-WASTE IN THE BAJA CALIFORNIA REGION PROJECT

TAA15-025

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Final Report

Overview

This report provides examples of used electronics management systems in countries in Latin America and around the world. Although some of the methods for managing e-waste included in this report resemble Mexicali's existing system, each has its own distinct set of regulations and interactions amongst formal and informal actors. It is our hope that rather than "reinventing the wheel," the used electronics system ultimately re-designed for Mexicali can effectively learn from successes and failures of systems launched in cities and regions worldwide.

Contents

Introduction

Used and obsolete electronics are the fastest growing component of municipal solid waste worldwide, and low and medium-income countries are expected to increase their volume of waste electronic devices by three times over the next five years. Municipalities located in the border region between the United States and Mexico have developed a lively market for repaired and reused electronic products, further increasing the amount of e-waste generated in these locales. The town of Mexicali, Baja California, Mexico (population 746 thousand) has become a secondary market and a dumping ground for both US originated and local e-waste.

Growth of Used Electronics in Mexico

To put the importance of used electronics recovery in perspective, below is a recent estimate of the total and per capita used electronics generation in Latin American countries. In 2014 Mexico was the second highest overall at around 900,000 tons, and higher than most countries' per capita rate at 8.2 kg/capita, excepting Panama, Chile, Uruguay, and Suriname (GSMA 2015). This is a substantial quantity of material that should be managed properly in order to extract financial benefit for communities and avoid environmental and public health issues. Note that the scope of these estimates includes electrical and electronic equipment, ranging from refrigerators and air conditioners to laptops and phones.

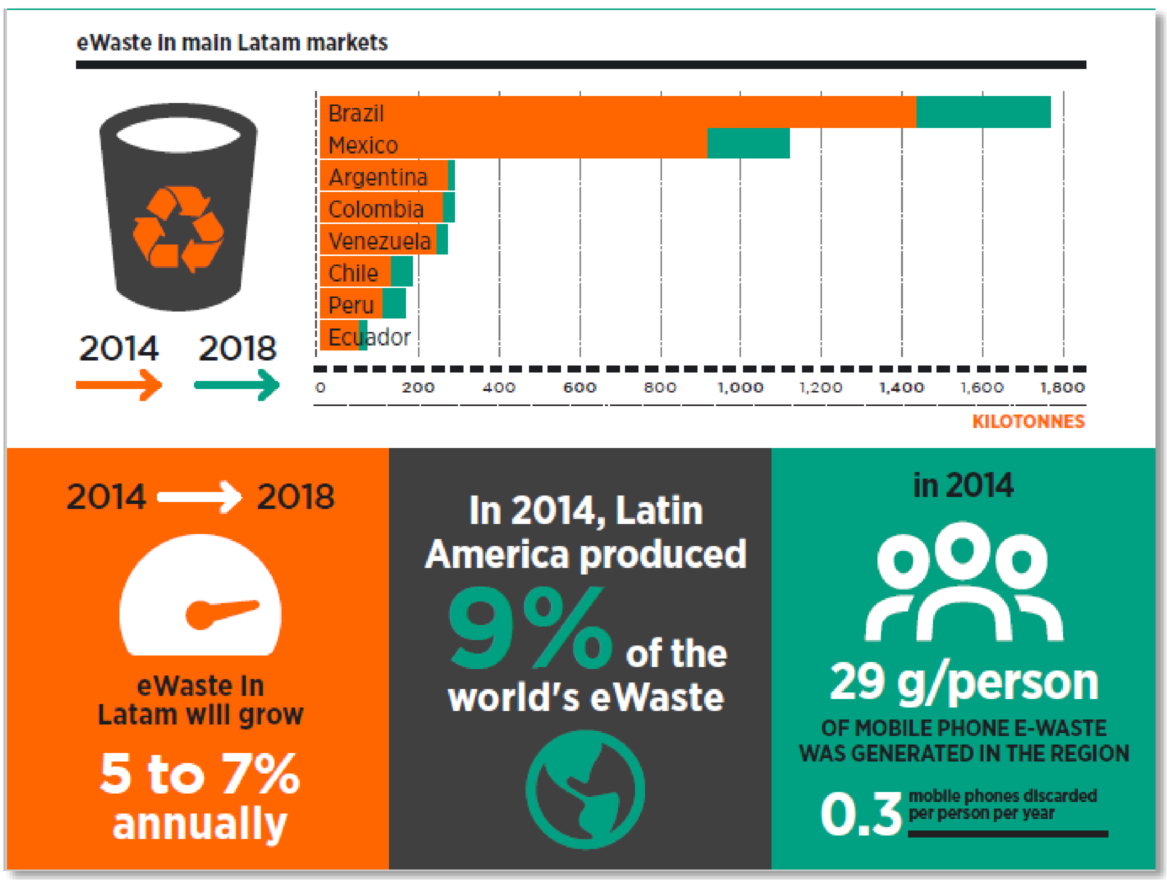

Figure 1: Overview of used electronics generated in Latin America. Source: (GSMA 2015)

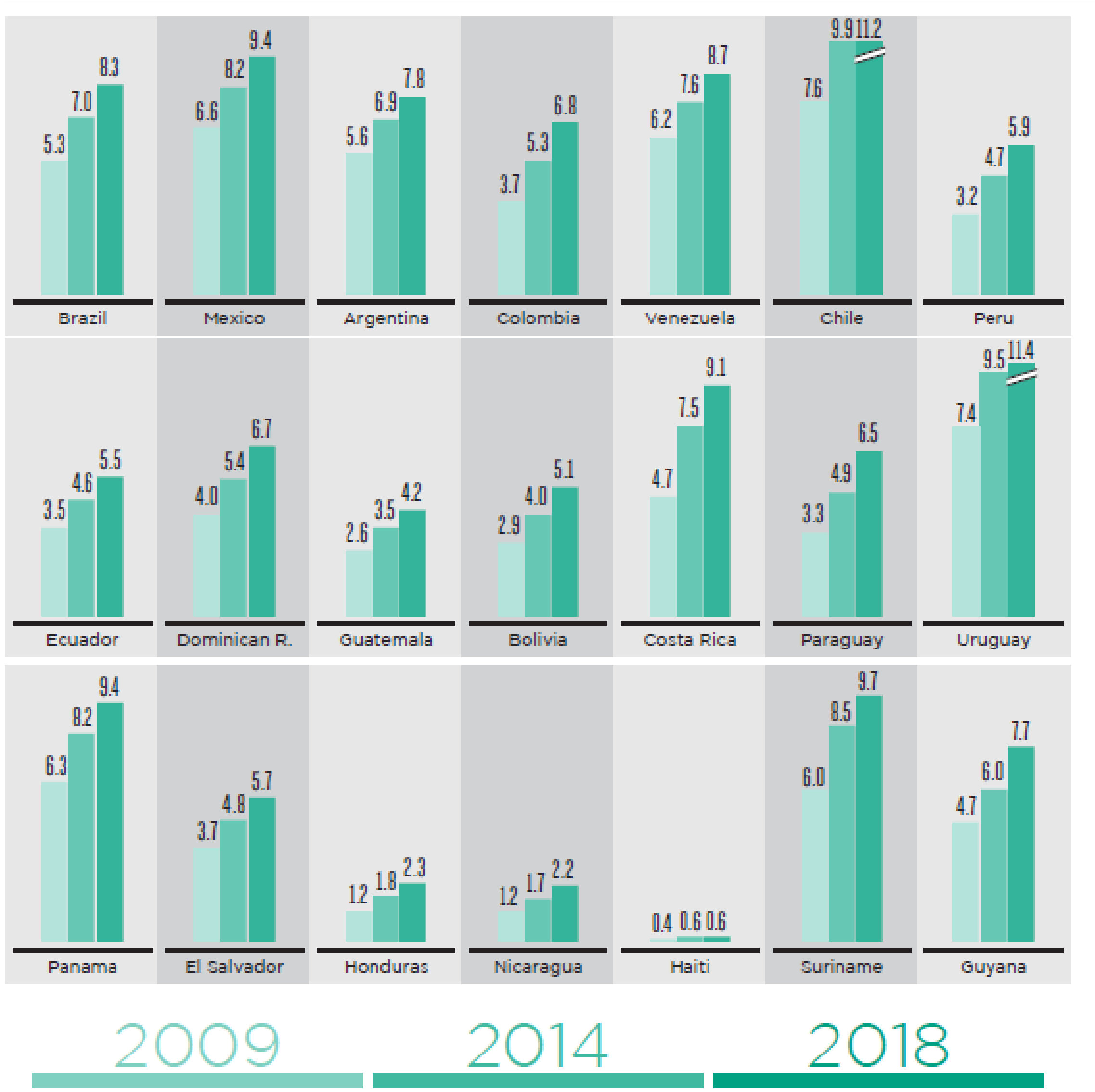

Figure 2: Used electronics generated in Latin America (kg / capita). Source: (GSMA 2015)

Mexicali E-Waste Project

The excess electronic waste in Mexicali is currently inadequately managed. For example, since 2013 Mexico has been switching from analog to digital TVs. Amidst what is referred to as an analog shutdown, the move towards digital has created an increased supply of waste analog CRT TV sets which contain toxic substances, most notably lead. Despite policies in place, residents do not have an option for properly managing their obsolete equipment.

We consider *e-waste* to be a subset of used electronics which are not suitable for reuse, and therefore should be refurbished or recycled. CRT TVs and monitors, for instance, are almost always included in this category. We use a separate term *generated* to refer to a used product at a stage in its lifecycle when it will either be landfilled or managed by a recycling firm. Some generated items may be e-waste, while others still have useful life.

Currently in Mexicali, there are a few channels for proper management of generated used electronics. The second-hand market and refurbish/repair sector extends the useful life of consumer electronics and appliances, leading to fewer new items being purchased. Corporations and institutions can hire a formal recycling firm to securely process their used IT equipment and export it to the US.

Other channels lead to less preferable management. Small scrap recycling businesses purchase e-waste from individuals, both the owners and informal waste scavengers, and extract the valuable materials. Concerns exist around the management of materials that are lacking in value or contain hazardous substances.

Items that do not make it through any of the above routes are discarded in abandoned lots or end up in a poorly managed non-engineered landfill. The items that are currently landfilled or abandoned are the target of this effort.

The Mexicali E-Waste Project was launched in Mexicali in 2014. It aims to improve the management of e-waste by increasing public awareness about the environmental and public health hazards that can be attributed to improper e-waste management; training informal e-waste workers; supporting the growth of existing, small e-waste businesses; and potentially creating a public-private entity to make the current system more effective and comprehensive. Ultimately the project's goal is to boost socioeconomic, health and environmental benefits to populations in Mexicali and around the US/Mexico border. The direct beneficiaries of the project are the informal e-waste workers (and their families) that use unsafe methods to extract valuable material from e-waste and receive little revenue due to ineffective methods for extraction. The indirect beneficiaries are the inhabitants in and around Mexicali that will benefit from cleaner air due to reduced burning of e-waste in the area and safer drinking water as a result of minimized illegal dumping and leaching of toxins into waterways.

Structure of report

The following program report was written to inform the creation of an effective e-waste management system for collecting, processing and selling valuable e-waste components. The report is part of a larger Inter-American Development Bank (IADB) initiative to develop institutional capacity for waste and recycling in accordance with internationally recognized best management practices that incorporate informal waste pickers into appropriate waste management systems. Ultimately the report is to be used to support the implementation of an existing EPA and BECC Cooperative Agreement that has been integrated into an IADB partnership, addressing e-waste management that incorporates the informal sector in the border region of Baja California.

The report initially provides a discussion of the growth of used electronics in Mexico and then offers examples of waste electronic reverse supply chains in countries and cities throughout the world. Segments on regulations for the safe handling of e-waste and strategies for including waste pickers in formalized e-waste management systems suggest key features that could be applied to the Mexicali context. Similarly potential solutions to key challenges in the current and proposed Mexicali e-waste management system, for instance open burning of copper cables and handling of CRT screens, are suggested for potential inclusion. Research conducted for the study was then used to suggest a feasible e-waste management program to be implemented in Mexicali that significantly reduces the risk of environmental exposure to hazardous toxins related to e-waste, strengthens a subset of existing small recycling businesses, provides formalized employment to waste pickers, and effectively increases the amount of e-waste that is collected and properly treated, diverting waste electronic devices from ending up in illegal dumpsites and the landfill.

Insights from used electronics reverse supply chains around the world

This section compares used electronics' reverse supply chains from several countries around the world in order to identify commonalities or differences with Mexicali and therefore allow us to identify best practices or alternative configurations that the proposed Mexicali system might adapt. For each system, we identify and describe the flows of the used electronics between them. Quantitative estimates of the flows are provided when available. Note that the scope of some of the systems reviewed is a country, while for others it is a city; this is a function of the assessments undertaken and available for review. While we are aiming to design a system for the city of Mexicali, in an effort to be thorough we have gained insights from system features at the national level as well.

Some features to consider when designing the system in Mexicali are summarized below, ordered roughly by region. Common themes include systems of collection points and retailer take-back in popular areas free to households which are funded by industry partners, creation of cooperatives, linking used electronics processing outputs with domestic manufacturing industries, and optimizing profit by disaggregating parts and materials:

United States

- Implementing producer-funded take-back schemes could be very beneficial financially.
- Founding an organization to coordinate electronics recycling management across the country could accelerate progress.

Colombia

- A donation and refurbishment program extends the life of electronics while employing local refurbishers and enabling children to use computers at school.
- The proposed incorporation of a waste-picking cooperative in the reverse supply chain is promising for a number of reasons. In particular, "cooperatives can negotiate better prices from bigger intermediaries or recycling companies" implies that for the same work, informal collectors can earn more.

Santiago, Chile

- The *punto limpio* offers a sound option for residents to properly manage their used electronics.

Dhaka, Bangladesh

- Linking outputs of the industry with domestic manufacturing (or maquilas in Mexicali) potentially enhances the financial viability of recovery.

- Higher profits are achieved with further disaggregation of materials.
- It is important to ensure living wages for workers; the wages in Bangladesh are too low.

Tianjin, China

- The large collection and distribution center seems like an efficient mechanism for capturing a variety of products from all sectors and enabling proper management.

Accra, Ghana

- The Agbogbloshie Scrap Dealers Cooperative offers a potential model to ensure the sustainability of a new used electronics recycling facility.

South Africa

- The model of industry-funded drop-off sites in bustling areas directs the collected products to a large recycler that can manage them properly.

Netherlands

- An effective producer responsibility program.
- Required municipal collection points, which also gather chemicals, and associated regional sorting centers.
- If an online marketplace can be developed in Mexicali, it could facilitate more household-to-household reuse. In Tijuana, the Craigslist page for *computadoras* contains thousands of listings (tijuana.craigslist.com.mx). There is not currently a Craigslist page for Mexicali, however it could be very beneficial.
- Retailer take-back makes collection easy for consumers since there are so many options near where they already shop, and the businesses are already set up with a location and staff.

United States

An overview of the flow of electronics materials in the United States is depicted below in Figure 3.

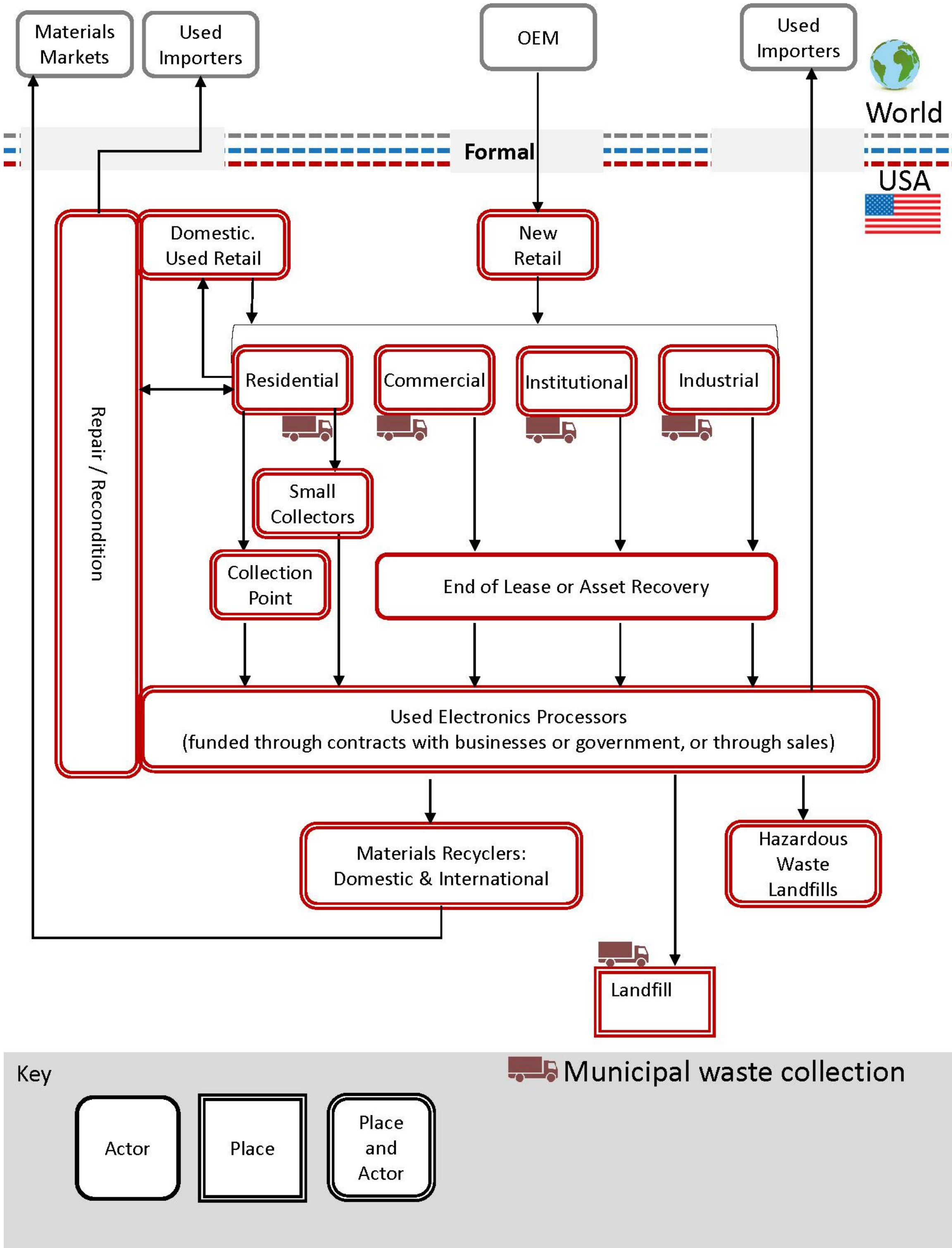

Figure 3: Diagram showing basic material flow stages for used electronics

Mexico's neighbor to the north has a variety of practices in place to manage used electronics. The patchwork of legislation is described below in the section on *Regulations on used electronics around the world*. In the figure above, we see that most of the electronics consumed are imported from foreign OEMs, and distributed through retailers or lease agreements.

Residential electronics owners might send it to be repaired if not functioning properly, or sell their used products to one another via the internet. If they are aware of used electronics products recycling collection programs available in their area, they may use that option. The collection routes vary depending on the state or even municipality. In states where there is a landfill ban on electronics, users *must* find an alternative means of disposal at the end of life. In some states, small collectors are incentivized by per-pound reimbursement rates to travel around in-state and gather used electronics to deliver to state-sanctioned electronics recyclers who are reimbursed after providing proof of proper management. Retailers such as Best Buy and thrift shops such as Goodwill have offered relatively convenient options for their management by householders. In Figure 4, a depiction of the products recycled by Best Buy is presented. Generally, it is free to recycle if the items are brought to the store, but there is a fee associated with having them picked up at homes. Still, plenty of items are landfilled.

Figure 4: Products recycled by retailer Best Buy, bestbuy.com

The commercial, industrial and institutional electronics owners tend to manage their products through contracts with electronics recycling and/or asset management companies; sometimes the products are on lease and are therefore collected at regular time intervals. A key concern is data sensitivity, so it will often be required that the device hard drives be wiped clean or destroyed. Smaller organizations may not have the resources to manage their devices in such a manner.

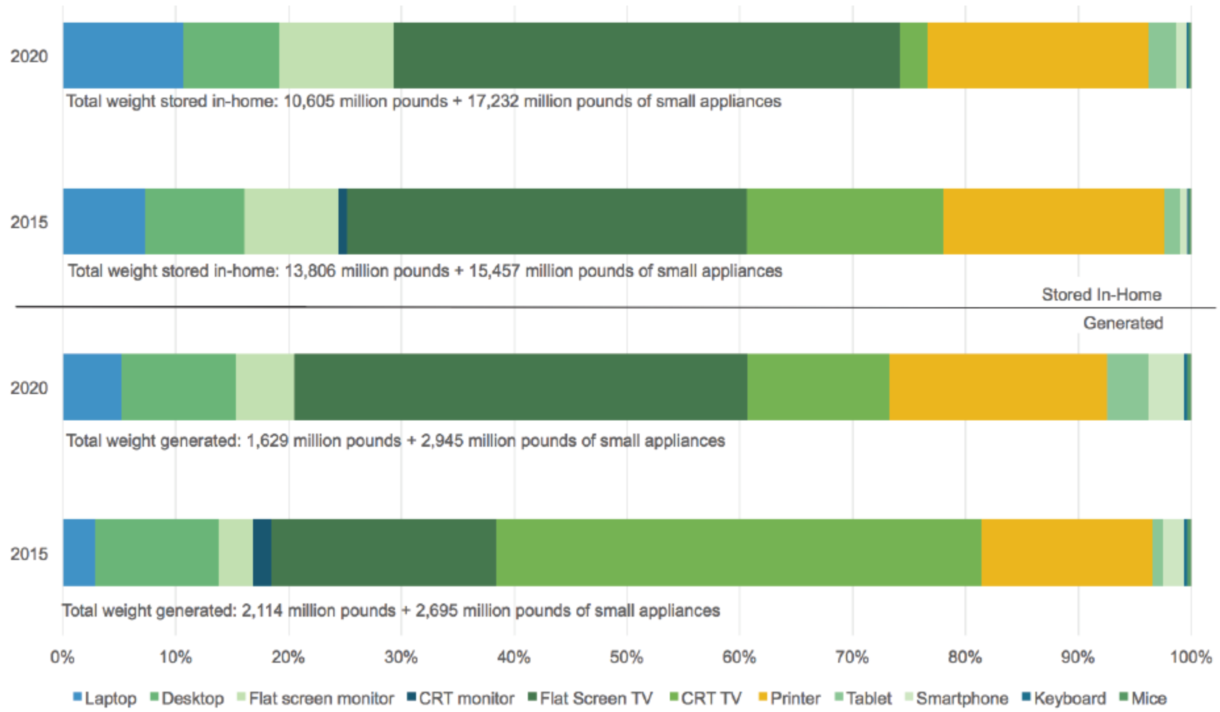

Figure 5: Percentage by weight of devices generated and stored in-home, 2015 and 2020 (million pounds) (Mars, Nafe et al. 2016)

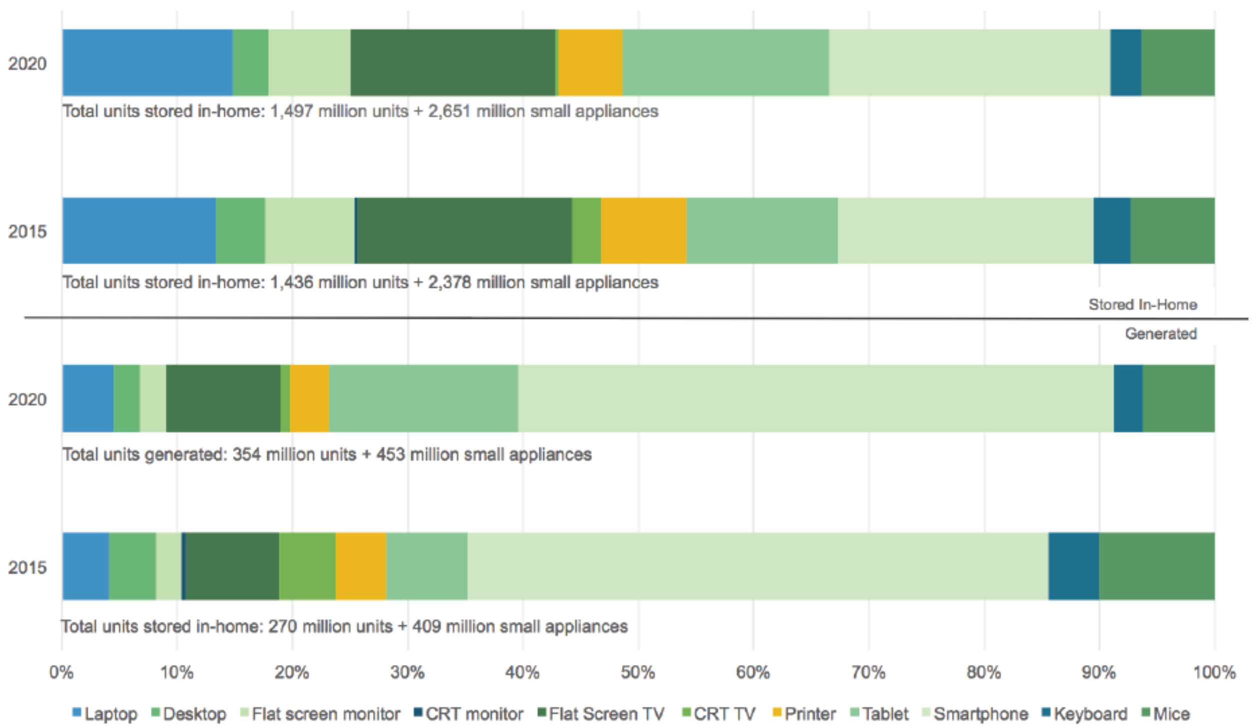

Figure 6: Percentage by number of devices generated and stored in-home, 2015 and 2020 (million devices) (Mars, Nafe et al. 2016)

Given the size of the US, it is difficult to track the flows directly. Therefore, surveys of electronics user behavior in combination with sales data are often used to estimate what is taking place. In Figure 5 and Figure 6, the share of the weight and quantity, respectively, of electronics still in the home and generated, is compared from 2015 to 2020 (Mars, Nafe et al. 2016)[1]. TVs are expected to dominate the weight of the generated products, while smartphones will dominate the quantity (due to their lighter weight). We will see a similar trend in the material flow analysis of Mexicali at the end of the study.

Comparison of United States with Mexicali

Similarities

- Formal companies exist to manage used electronics for other companies.
- Currently, some discarded used electronics enter into the landfills.
- There exist online marketplaces for interpersonal sale for reuse of products. In the US, the websites *Craigslist.org, ebay.com* and *amazon.com* are popular. In Mexicali, *Mercado Libre* is an option.

Differences

- Half of the states in the US have electronics recycling programs put in place by legislation. Almost all of these provide a financial mechanism to facilitate the program by requiring the manufacturers to cover the costs.
- Twenty states have landfill bans prohibiting these products from entering the landfills.
- Major retailers enable free collection of used electronics and appliances at their stores as part of their corporate social responsibility. Thrift stores also act as channels for reuse and recycling.
- Wastepickers and scrap dealers are not as present in the US. In cities, many wastepickers collect beverage containers to receive the nickel deposit on the eve of trash collection, and some drive trucks to gather scrap metal items on the curb, but in general the informal recycling economy is not as well developed.
- There exists a National Center for Electronics Recycling which facilitates several of the state programs, along with several national and many local non-profit organizations that help coordinate efforts.

Features to consider

- Implementing producer-funded take-back schemes could be very beneficial financially.
- Founding an organization to coordinate electronics recycling management across the country could accelerate progress.

[1] Note that author T. Reed Miller prepared the estimates for that report. Please reach out to him with questions.

Colombia

Current system

An in depth study of used electronics management in five major cities in Colombia looked at the sales and subsequent management by the formal and informal sectors (Leon 2010). Some formal e-waste recyclers have an environmental license allowing them to manage commercial and industrial e-waste. A unique feature of the system in Colombia that is worth noting is that there is a vibrant donation program collecting 20,000 computers annually. These electronics are then distributed to public schools all over the country. Another feature is that public institutions have to sell their used electronics via a public auction organized by the institution, or donate them.

Around 80,000 families work in the informal sector collecting recyclables, with around 15% organized in cooperatives in 2010; some reported gathering electronics. The repair and refurbishers buy used equipment from public auctions or businesses. Informal dismantlers recover materials like steel, aluminum and copper; the functional parts are already removed by the collectors or others. They often work in the streets or homes, commonly without protective equipment. Printed wiring boards are not typically leached for gold because of connections between large e-waste companies and scrap metal dealers. The figures below present the flows of used computers and monitors in Colombia in 2009. Important to note that more than 50% of the material that enters the informal manual dismantling sector is sold to the formal sector (i.e. Scrap metal dealing).

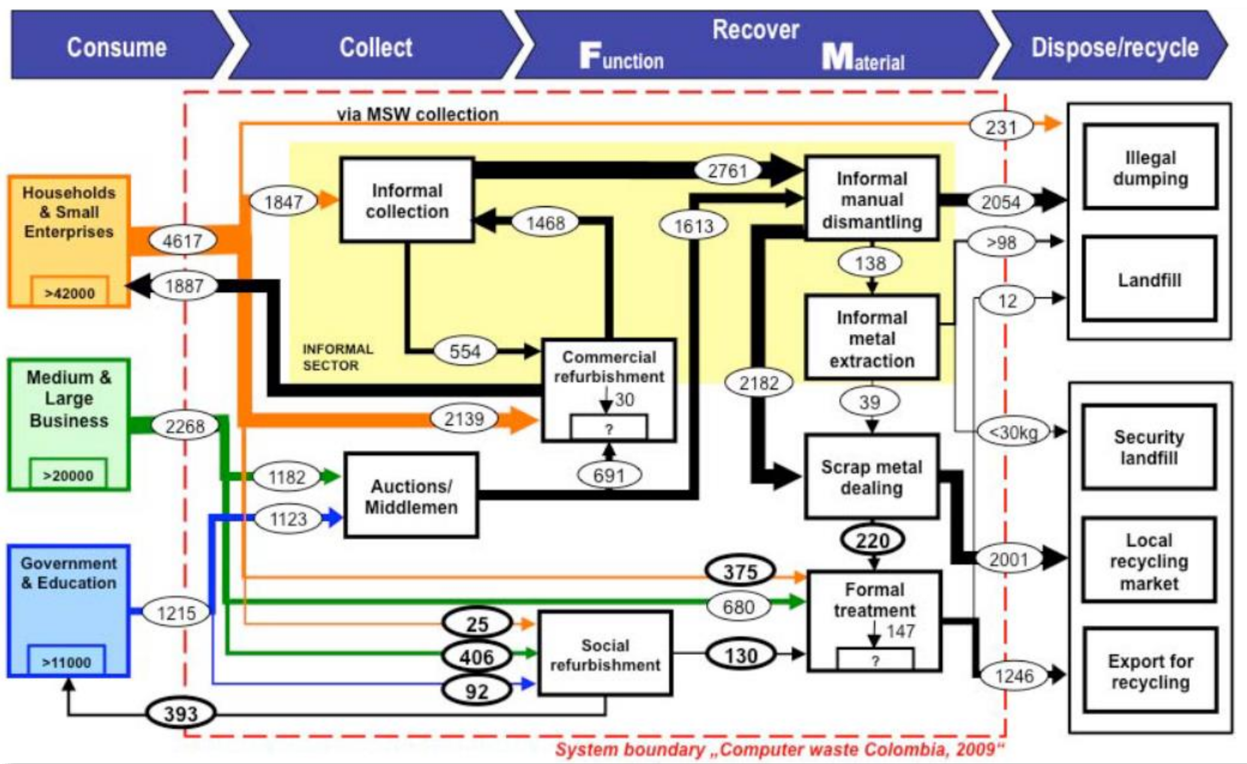

Figure 7: Total used computer flows (tons/year) in Colombia in 2009 (Leon 2010)

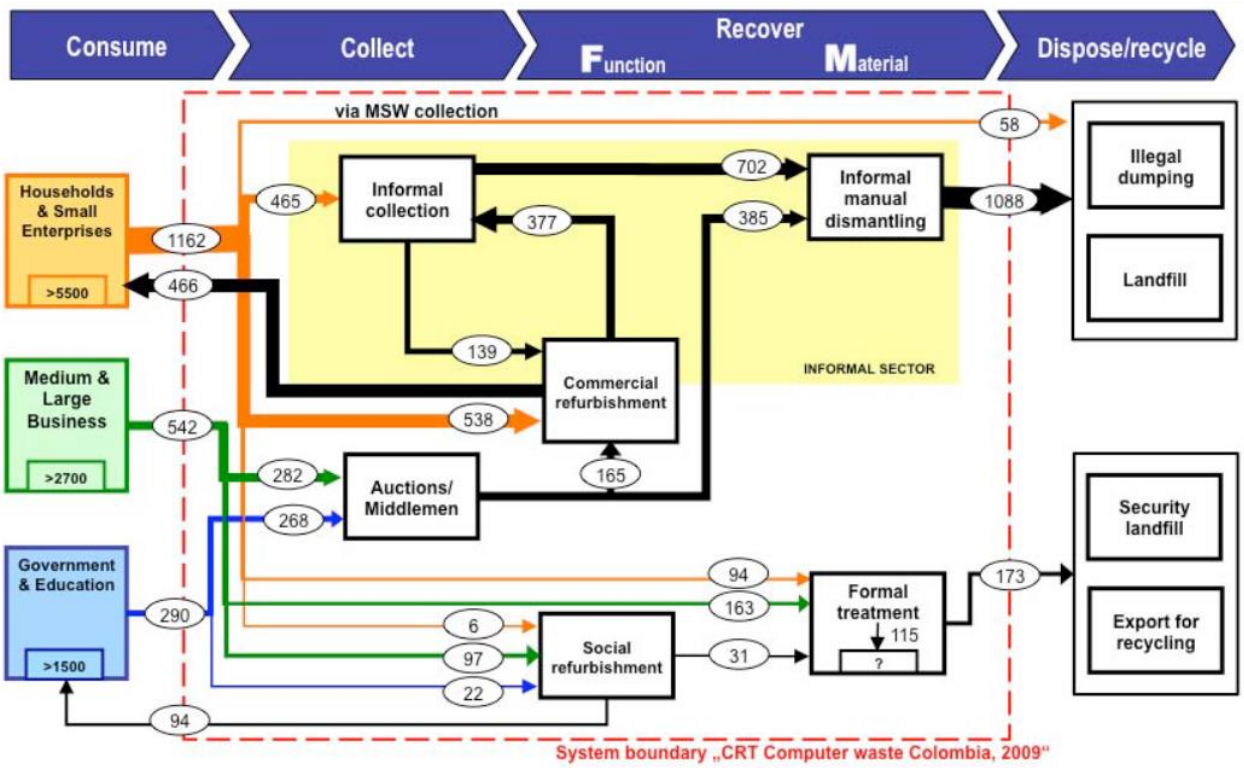

Figure 8: Total used CRT monitor flows (tons/year) in Colombia in 2009 (Leon 2010)

A recent report from GSMA describes how in 2007 members of the GSMA in Colombia anticipated legislation and voluntarily worked together to create a program called ""Recicla tu Móvil y Comunícate con la Tierra" (GSMA 2015). In two years, they collected 500,000 cell phones, 1,764,000 accessories, and 326,000 batteries managed by the processor Belmont. In 2013, Ley 1672 opened the door to other types of electronics being brought into the system. In 2014, Belmont introduced the first buy-back program for cell phones from over 80 different brands.

Authors' proposed system, inclusive of waste cooperatives

The authors of the 2010 study propose that a waste cooperative could buy used electronics from the informal collectors and pass it on to a formal treatment system, as shown in the figure below. They think that this will be beneficial especially for managing unwanted CRT monitors. They note that there would be a cost to producers under Extended Producer Responsibility in order to use price incentives to divert CRTs from being dismantled by the informal sector. Expected benefits of the cooperatives, based on experiences of Colombia of other waste cooperatives, include "The benefits for the *[informal collectors]* belonging to a cooperative are the increase of their revenue (cooperatives can negotiate better prices from bigger intermediaries or recycling companies), the amelioration of their working conditions (no more work on dumpsites, getting tools such as gloves, uniforms, etc.), and the access to credit, training and social programs."

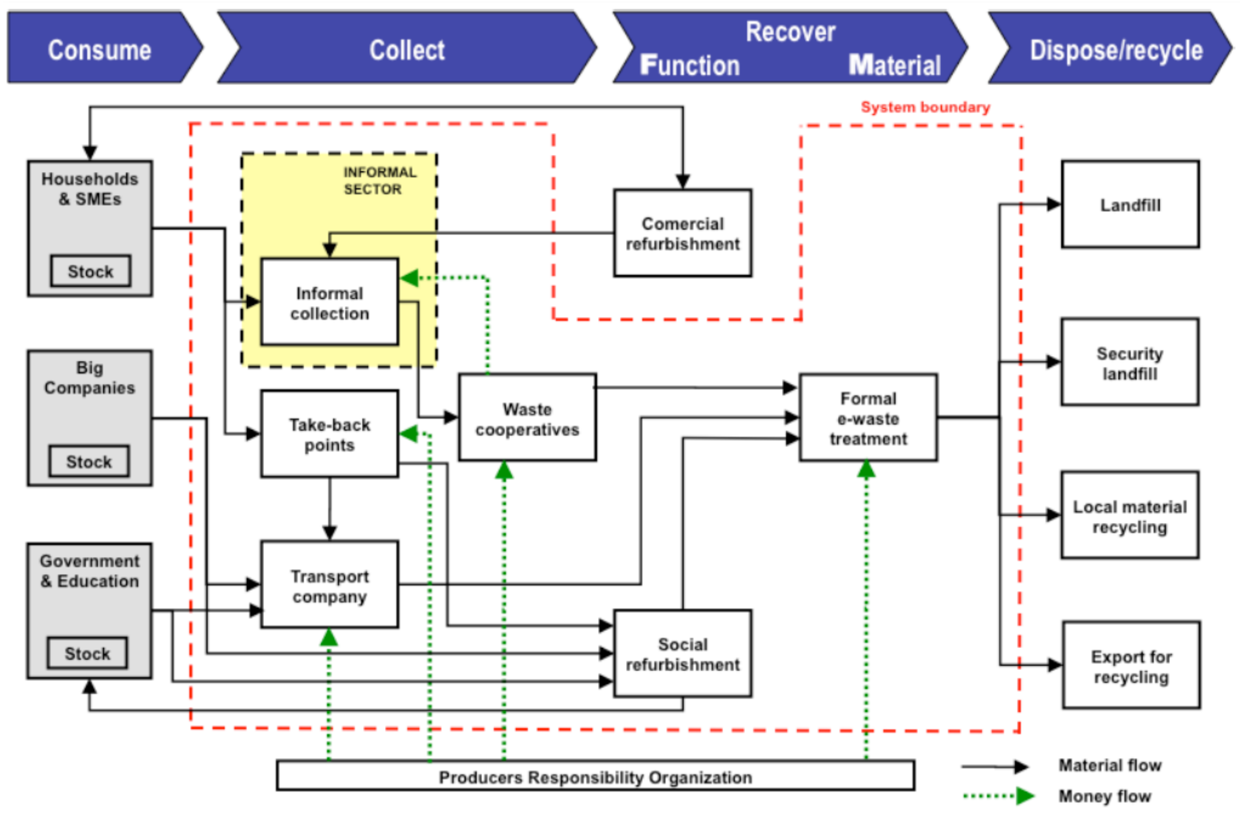

Figure 9: Proposed inclusion of waste cooperatives in the flow of used electronics in Colombia (Leon 2010)

Comparison of Colombia with Mexicali

Similarities

- The role of the informal collectors in Colombia in 2009 is very similar to that of Mexicali.

Differences

- There is a successful program of refurbishing donated computers to distribute in schools.
- Colombian institutions are required to sell their used equipment at public auction or donate it to the refurbishment program.
- The repair and refurbishment businesses tend to get their products from auctions.

Features to consider

- The donation and refurbishment program seems like a great way to extend the life of electronics while employing local refurbishers and enabling children to use computers at school.
- The proposed incorporation of a waste cooperative in the reverse supply chain seems promising from a number of angles. In particular, that "cooperatives can negotiate better prices from bigger intermediaries or recycling companies" implies that for the same work, informal collectors can earn more.

Santiago, Chile

According to Wolfensberger (2009), the electronics forward supply chain in Santiago, Chile begins with *fabricantes* that make, import or assemble branded or cloned products. Then *distribuidores,* such as new and used retail shops and charitable organizations, distribute the products to consumers. Three types of users are distinguished and the fraction of used electronics they generate are estimated at 35% from residential (*hogares*), 55% from private businesses (*empresas privadas*) and 10% from the public sector.

In most locations, residents store their used electronics or put them out with the trash. One of the five municipalities interviewed, Vitacura, had a collection plan for used electronics, but three others discussed the need to create a plan. Vitacura's *punto limpio* shown below received six times as much volume of used electronics in 2008 than when it opened in 2006. A few charitable organizations accept used electronics, of which a fraction are donated to schools and others are sold for recycling. Another group of charitable organizations accept donated computers that meet specifications and refurbish them for redistribution, on the order of 15,000 per year. Commercial refurbishers offer their service at a fee, and sell or put on the street excess materials. The formal used electronics processors work with large businesses (B2B). The informal sector fills a gap in residential used electronics collection in most communities, but only manages those which provide an income opportunity, including some which pose environmental and public health risks. Of the estimated 3,500 informal collectors in Santiago, about 500 collect used electronics. Each collects, sells or disassembles between 2 and 5 tons per year.

In terms of the disposition of materials from the used electronics, most plastics are thrown away because there are few plastic recycling businesses. However, there are many scrap metal dealers. There are also companies that buy printed circuit boards by the kilogram for processing. There is a single formal landfill in Chile authorized to receive used electronics at a cost around 500USD/ton. Its clients are mostly formal businesses, and only about 1% of the used electronics end up at the specified landfill. There are other landfills that charge around 20USD/ton, and around 63 illegal dumpsites as well

Comparison of Santiago, Chile with Mexicali

Similarities

- Many aspects of the system in Santiago, Chile resemble those of Mexicali. There are similar sets of actors, similar flows, and similar unwanted situations. These situations in Santiago as in Mexicali include insufficient recovery of materials by informal sector workers, selection of only desirable used electronics and associated inadequate disposal of undesired used electronics and components by recycling intermediaries.

Differences

- There is a *punto limpio* that provides a secure location for the proper disposition of unwanted used electronics. This is particularly beneficial for CRTs.
- There is a landfill authorized to receive used electronics, but do to contracts and cost, few go there.

Features to consider

- The *punto limpio* offers a sound option for residents to properly manage their used electronics.

Figure 10: Punto Limpio established in 2006 in Vitacura, Santiago, Chile. Used monitors and TVs have a dedicated bin.

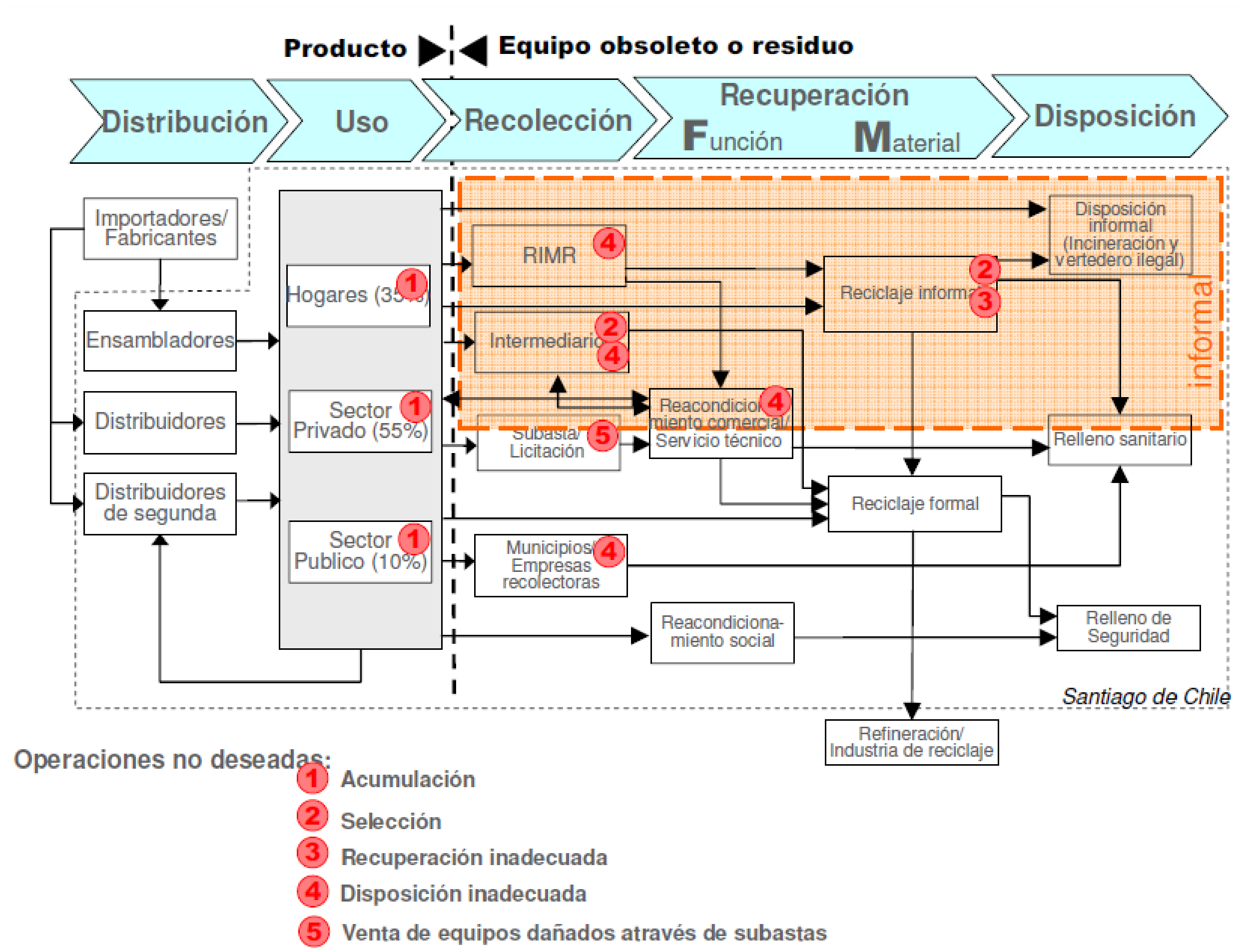

Figure 11: Unwanted situations in the used electronics reverse supply chain in Santiago, Chile 2009. RIMR are "Recolectores Informales de Materiales Reciclables", informal material collectors. (Wolfensberger 2009)

Dhaka, Bangladesh

Lepawsky and Billah (2011), geographers, describe the complex trading interactions amongst the actors in the Dhaka, Bangladesh used electronics market. In 2008 and 2009 they conducted lengthy interviews and surveys with various actors. They paid close attention to the value added as materials were transformed. "Rubbish electronics importers and resellers have profit margins of 100 per cent or more, but dismantlers' profits often exceed margins of 200 per cent". The diagram in Figure 12 demonstrates the added value along the supply chain. Focusing on the actors involved:

> "Importers, wholesalers and resellers are, in effect, trading on arbitrage opportunities that exist between jurisdictions where rubbish electronics can be sourced at low or no cost and imported into Bangladesh where they can be sold as working used electronics. Refurbishers engage in activities that bring non-working rubbish electronics back into working condition. This usually involves replacing non-working components with working ones scavenged from other stock. They also usually offer repair services as part of their business. Refurbishers often retain stocks of non-working rubbish electronics so long as some working components could be scavenged for refurbishing. […]Dismantlers break apart, sort, and clean rubbish electronics in order to separate out useable from non-useable components and materials."

The authors point out that intra-regional international trade dominates inter-regional trade. They do not discuss solid waste streams except to mention that some scavengers search in waste bins.

Comparison of Dhaka, Bangladesh with Mexicali

Similarities

- Similar set of actors: scavengers, collectors, refurbishers, remanufacturers and dismantlers

Differences

- In Dhaka, the industry is driven by intra-regional import of used electronics for domestic resale rather than management of domestic generation of used electronics
- The size of the industry in Dhaka is much larger. There are about 200,000 people employed in recovery, with about six large importers and over 1500 smaller related enterprises nearby.
- Outputs from used electronics dismantling are used in domestic manufacturing. "The sector is characterized by intense specialization of firms and myriad linkages to other sectors in terms of providing labor and material inputs into other production industries."
- The workers earn about 1USD per day, far less than the workers in Mexicali

Features to consider

- Linking outputs of the industry with domestic manufacturing (or maquilas in Mexicali) could enhance the financial viability of recovery.
- Higher profits achieved with further disaggregation of materials.
- Important to ensure living wages for workers; the wages in Bangladesh are too low.

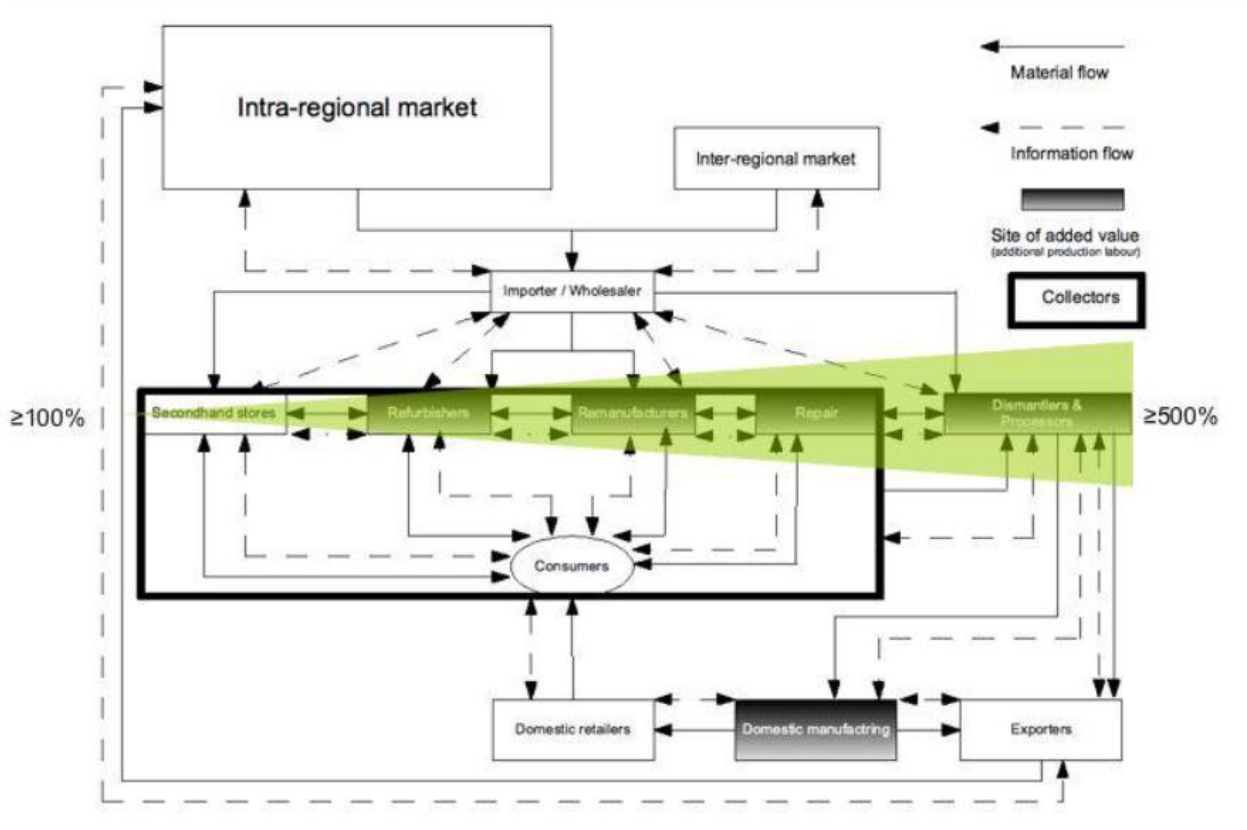

Figure 12: Rubbish electronics commodity chain in Dhaka, Bangladesh (Lepawsky and Billah 2011)

Tianjin, China

Xian Li (2012) describes that Tianjin is a pilot city designated to develop national recycling projects where a mix of informal and formal sectors manage used electronics. There are six large formal recyclers, and plenty of informal workers that manage used products, including those illegally exported from Japan. Informal collectors travel door to door, most commonly on an auto-tricycle. They display what they want to collect on sign boards. PCs in good condition for reuse are sought after, followed by large appliances due to the perception that they contain valuable components such as compressors and motors or at least plenty of materials. Small electronics are less sought after because there is very little expertise on how to extract value from them.

Electronics traders are located around shopping centers and enable customers to dispose of unwanted items with potential resale value when they purchase new ones. Unlike door-to-door collectors, they accept many mobile phones but do not accept appliances. There are also many regulated and unregulated repair shops.

Additionally there are also large collection and distribution centers which purchase used electronics from residents, businesses and institutions. These collection and distribution centers triage the products into those with reuse potential, large appliances for dismantling and others to be sold by weight. They sell PCs in the second-hand market, and sell monitors and appliances to wholesale customers. Monitors are repackaged as televisions and sold in poorer areas of the country.

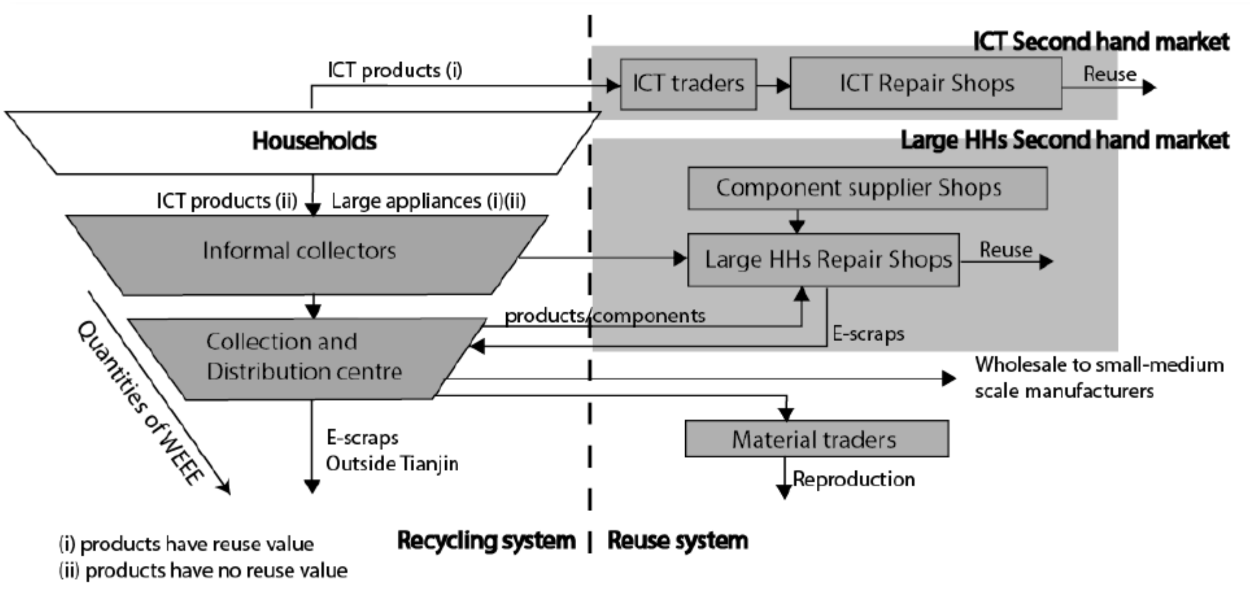

Figure 13: Flows of used electronics in Tiangin, China (Xian Li 2012)

Comparison of Tianjin, China with Mexicali

Similarities

- Both systems have door-to-door collectors, as well as repair shops and electronics traders near shopping centers.

Differences

- Large collection and distribution centers in Tianjin serve as a place for all sectors to sell their used electronics. Since the centers pay for the used electronics, they do not have an interest in sending them to a landfill, and instead sell the less desired products by the pound.
- They manage CRTs by converting them into televisions for poorer areas of the country.
- Informal collectors do not seek small electronics because of the perceived difficulty in extracting value.
- Illegal imports from Japan make up a large fraction of the used electronics managed by the informal sector.

Features to consider

- The large collection and distribution center seems like an efficient mechanism for capturing a variety of products from all sectors and enabling proper management.

Accra, Ghana

Unfortunately, the burning of wires at the Agbogbloshie scrap yard in Accra, Ghana has made this place internationally famous. An author of this report visited the site in January 2014 and was provided a tour by a young man who worked there. It appeared to him that the majority of the site was devoted to dismantling cars and appliances like refrigerators. A smaller section dealt with TVs, monitors and computers. Plastic casings were in a pile and circuit boards were sold to European recyclers. A small used computer retail shop was on site as well. Nearby, young men burned the plastic off of copper wires on the banks of a heavily polluted river and young women sold them packets of wire to put out the fires. Adjacent to the scrap yard was a privately (mis)managed dumpsite for municipal solid waste, serving as the destination for unwanted CRT monitors.

In response to international media spotlight on the subject, organizations worked together to create a new association and a small recycling center: “a joint project created The Agbogbloshie Scrap Dealers Cooperative, owned by GASDA, GreenAd and the National Youth Authority (NYA). The Agbogbloshie Scrap Dealers Cooperative is currently managing the new recycling facility and its staff. A management committee has been created and is composed of representatives from the three entities mentioned above as well as an operations manager, an environmental health and safety officer and an accountant, with oversight by the Ghana Environmental Protection Agency” (Pure Earth 2015). Whether the system put in place remains effective is unknown, as the funding for that project seems to have ended.

Figure 14: Children nearby wire burning in Agbogbloshie (source: PureEarth)

In 2011, researchers conducted an in-depth assessment of e-waste management practices in Ghana. Figure 15 below provides their estimates of the flows between stakeholders (shown in blue, tons/year).

In the figure, note how little of the material ends up in the official landfill (200 tons/year) relative to informal dumping and burning (99,000 tons/year), which exceeds even management by dealers and refineries (72,000 tons/year). As with Bangladesh, there is significant importation of used equipment. It may be that more of the used electronics entering Ghana are functional upon import (around 80%) compared to Bangladesh. The import is allowed in order to help residents bridge the digital divide.

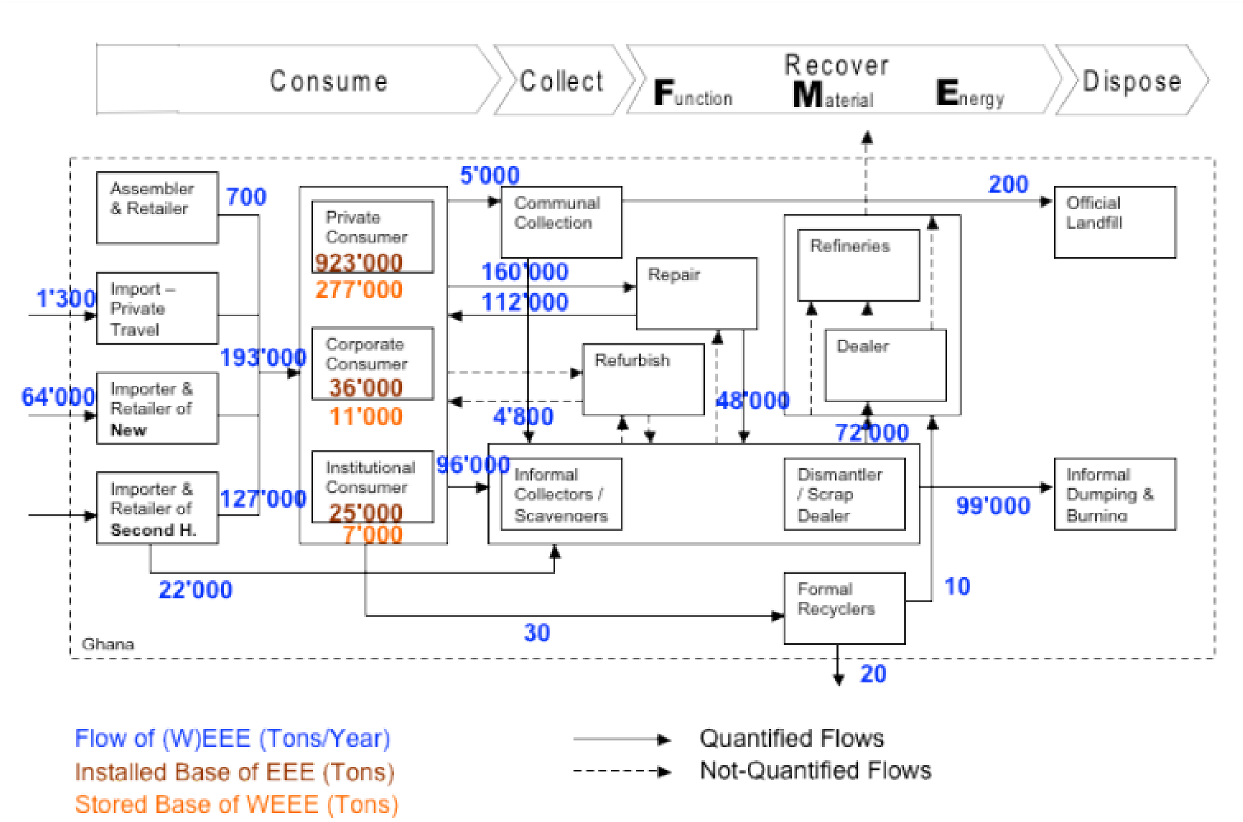

Figure 15: Stocks and flows of EEE in Accra, Ghana in 2009 (tons) (Amoyaw-Osei Y 2011)

Comparison of Accra, Ghana with Mexicali

Similarities

- Open burning is a common method used to extract copper from insulated copper wires (unless the newly implemented system is functional).
- Functional second-hand imports are a major source of electronics in households.

Differences

- Residents often require workers to purchase their used electronics from them, rather than leaving them out for the taking.
- Incessant open burning creates an enormous environmental and public health hazard.
- The workers earn far less than those in Mexicali "Despite the long working hours, most of the [roughly 10,000] people employed in the refurbishing and WEEE recycling sector continue to live in extreme poverty. Monthly incomes of collectors were between US$ 70 and 140, refurbishers between US$ 190 and 250, and recyclers US$ 175 to 285" Amoyaw-Osei Y, 2011).

Features to consider

- The Agbogbloshie Scrap Dealers Cooperative offers a potential model to ensure the sustainability of a new centralized used electronics recycling facility.

South Africa

Finlay and Liechti (2008) describe that in South Africa, informal collectors are well-established in the collection of recyclables, including used electronics from households, streets and landfills. Some dismantle the products to extract valuable materials, including breaking CRTs to get copper. Large used electronics recycling firms, some operating since the 1990s, have contracts with businesses and government and do not get involved in household recycling. Smaller electronics recyclers work alongside the larger firms for cash trade, and work on getting good deals with smaller businesses or municipal landfills. Sometimes the recyclers pay for the used electronics, other times the collection cost is deducted from the potential value and the disposer is simply eager for the removal to take place. There are also charitable organizations which refurbish and distribute computers.

In the years prior to 2008, the government and the private sector set up initiatives for systematic collection, which largely involved public drop off points. They steered away from collecting white goods or large household appliances since the scrap metal has value and the size of the items make storage difficult. Corporations were involved in the initiatives, which included periodic collection by large recycling firms; financial viability is determined by the ability to collect 400 kg of used electronics in one visit to a collection site. From the initial project results, 4.7 tons were collected in total across four sites in eight weeks; the recycler claims that 20 tons were lost to informal collectors during that time span. Fifteen percent of homeowners surveyed took their used electronics to the collection points, compared to 50% who put them in the trash, 36% who donated them, 33% who took them to a recycler, 13% who sold them, 8% who stored them at home and 8% who put them on the street for informal collectors. There are also informal and formal refurbishers, with some large companies that process tens of thousands of computers and monitors annually. White goods repairers often deal with warrantied products.

In the mass flow diagram from Liechti (2008) below, the green section represents the activities closely monitored and regulated by the government. "This includes importing, refineries and smelters, which require specific permits and are monitored and regulated, exporting, municipal landfills, which are mostly closely managed and monitored by local government, and hazardous waste facilities, which requires very specific permitting and controls." The yellow section represents the self-organizing private/formal sector which includes "vendors and manufacturers, retailers, consumers, second-hand and recycling businesses, and private sector formal collection initiatives." The orange zone includes the informal sector, "active in collection, in the second-hand market, manual dismantling, engaging with recyclers and scrap dealers, and on landfills."

The study found a few key challenge areas in terms of health and environment. These include: "Informal collectors are open to a range of threats, including health hazards, exploitation and violent crime. Environmentally unfriendly recycling also occurs. Environmentally unfriendly recycling activities are found. Health and safety precautions for workers are also not always adhered to. Hazardous disposal of e-waste fraction is minimal. Potentially hazardous e-waste is disposed in landfills." They also note opportunities for business development: "The scaling up of collection programmes, including logistics, is a business opportunity. Informal collectors can be organized. There are numerous business opportunities in the refurbishment and recycling sectors. New technology is needed. E-waste also has potential for small and micro-business development. Opportunities for business development exist in the secondary market (e.g. recycling plastics to produce a range of products)."

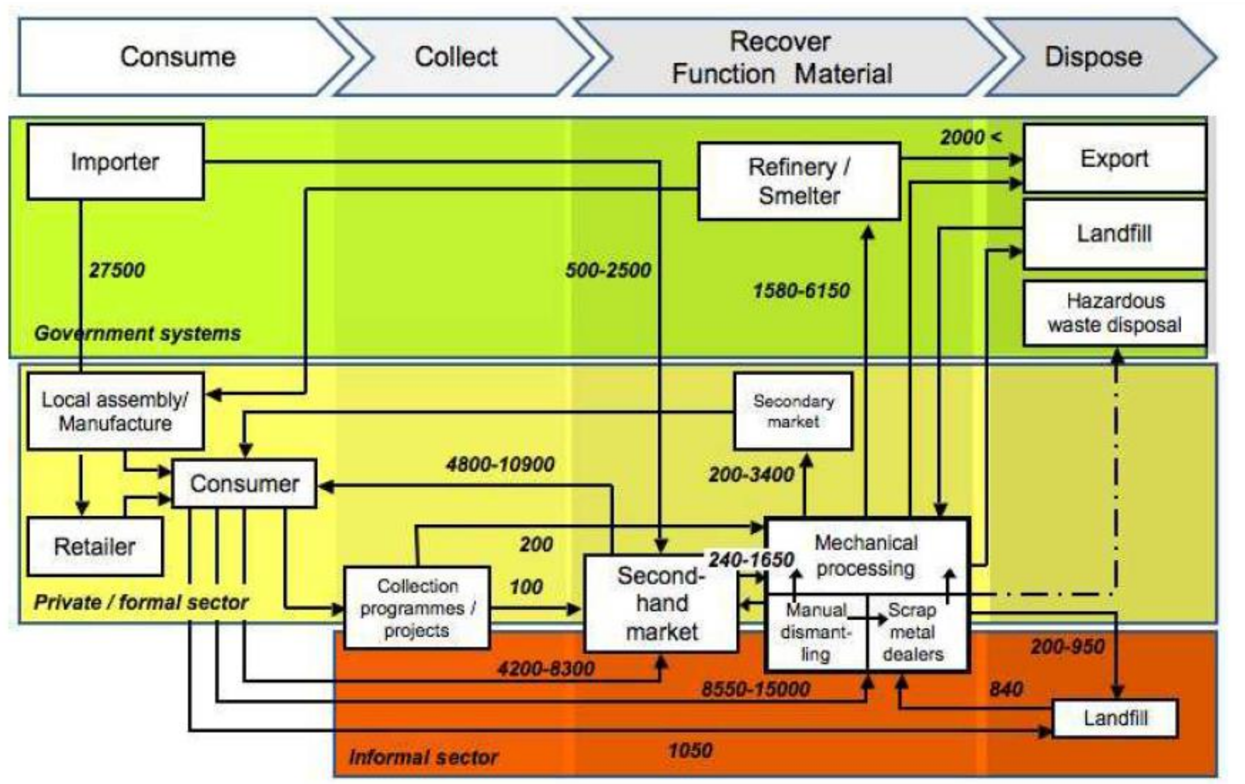

Figure 16: Flows of used PCs and PC parts in South Africa, tons (Liechti 2008)

Comparison of South Africa with Mexicali

Similarities

- Similarly have scavengers collection from households and landfills that sort and dismantle to add value.
- Similarly have refurbishers adding value to used goods.

Differences

- Existing large used electronics recycler firms.
- Have smaller recyclers that engage in contracts with small businesses to remove old used electronics as a service.
- Started drop off points in popular areas to collect used electronics from households in partnership with industry, which seems to be successful.

Features to consider

- The model of industry-funded drop-off sites in bustling areas that direct the collected products to a large recycler that can manage them properly.

Netherlands

The Netherlands has a much more regulated system than the other locations studied, including a producer responsibility program and compliance scheme. In Figure 18, 32% of the weight of generated waste electricals and electronics (WEEE) are managed under the compliance scheme, but another 28% arrive at the proper destination of national recyclers through complementary flows. Only 10% is estimated to be incinerated.

Huisman, van der Maesen et al. (2012) describe that households have the option of taking their used electronics to a municipal collection point, which also collects items like chemicals and furniture, since there is at least one required per municipality. Charitable organizations work alongside the municipalities to repurpose and sell collected items. Households can also give used electronics back to about 3,000 retailers, which are contracted to bring them to recyclers under compliance schemes. The municipal and retailer flows are sent to a regional sorting center under the compliance scheme, and then sent to specialized processors. The second-hand market includes individual internet-based transactions, resulting in reuse amongst households. Despite these options, up to 1,000 informal door-to-door collectors, driven by high metal prices, buy or receive used electronics directly. If a household puts used electronics in the trash, it will end up being incinerated. Between 100 and 200 regional metal scrap processors, waste processors and refurbishers accept used electronics from a variety of sources, and also send the recyclable portions to national recyclers.

Comparison of Netherlands with Mexicali

Similarities

- Informal door-to-door collectors gather electronics from households.
- The used electronics are sorted and sent to larger recyclers.

Differences

- Producer responsibility program to fund compliance scheme, which is enforced.
- Required municipal collection points, and regional sorting centers.
- Thousands of retailers contracted to participate in collection.
- Nine major electronics recyclers and specialized recyclers.
- 23.7 kg/ inhabitant in Netherlands, versus 8.4 kg/inhabitant in Mexico.

Features to consider

- Producer responsibility program.
- Required municipal collection points, which also gather chemicals, and associated regional sorting centers.
- Retailer take-back makes collection easy for consumers since there are so many options near where they shop, and businesses are already set up with drop-off locations and knowledgeable staff.

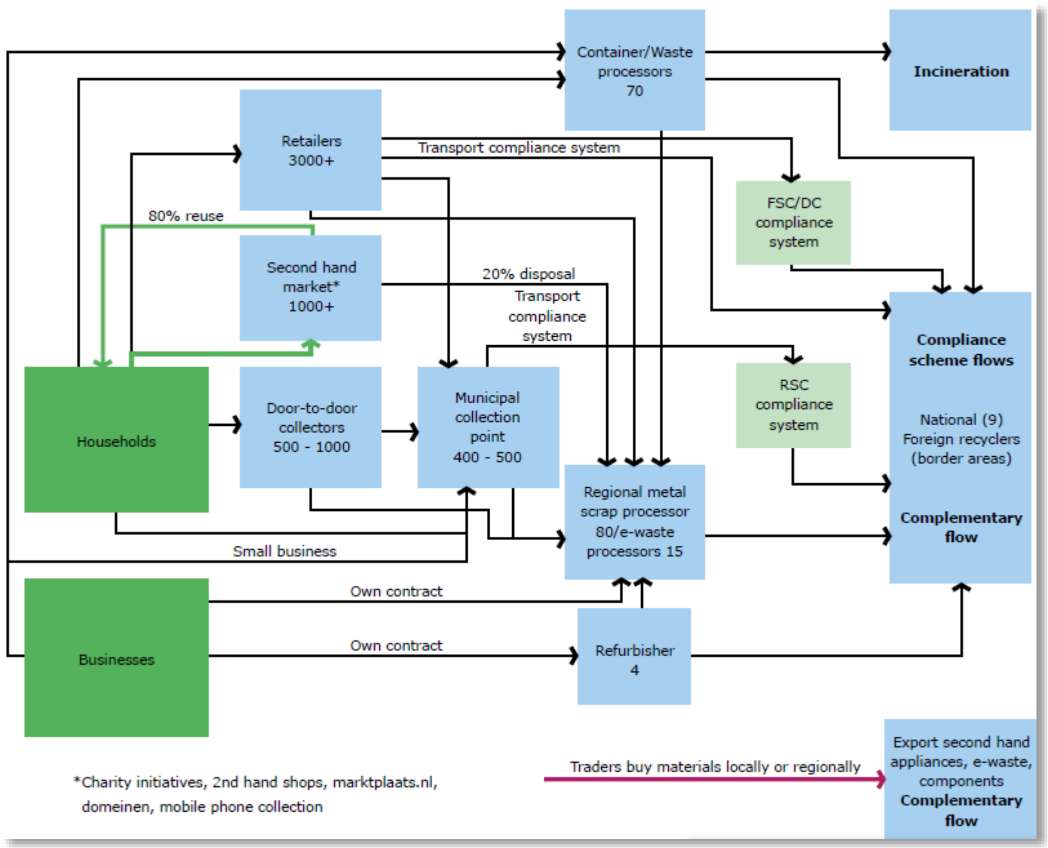

Figure 17: Flows of used electronics and number of actors in the Netherlands. RSC/FSC/DC means regional sorting & distribution center. (Huisman, van der Maesen et al. 2012).

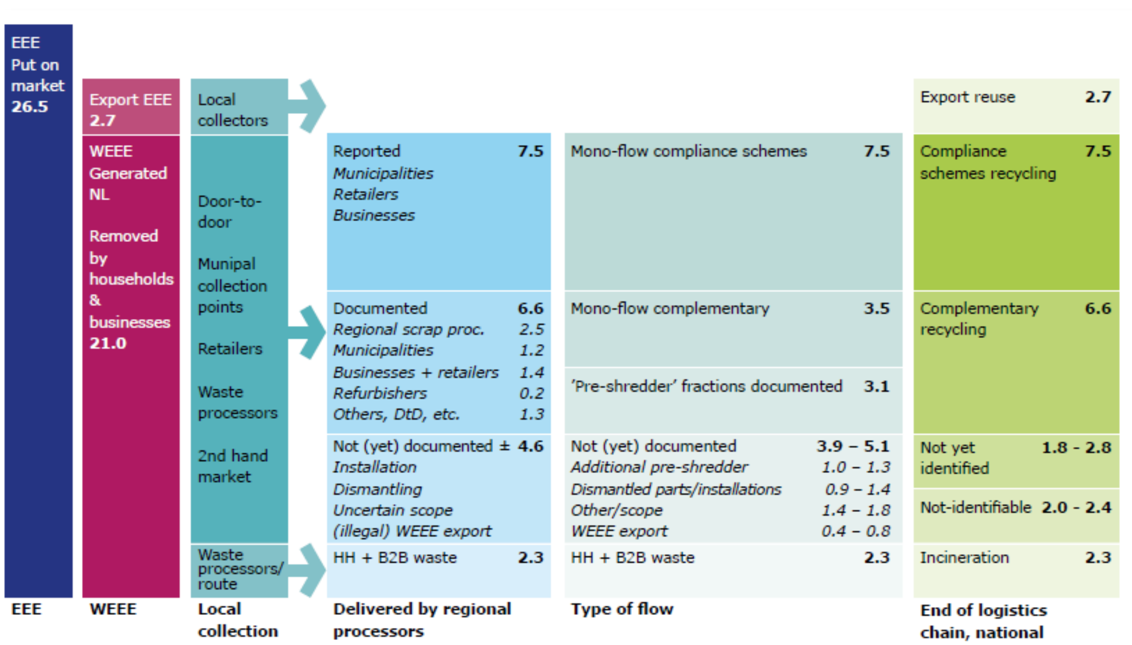

Figure 18: Dutch WEEE flows in 2010, kg/inhabitant (Huisman, van der Maesen et al. 2012)

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Regulations on used electronics around the world

The following chapter examines the regulation of Waste Electrical and Electronic Equipment (WEEE) in selected countries of Latin America and the world. In the case of Latin America, the corresponding WEEE regulations from Costa Rica, Colombia, and Peru are studied. These countries have shown significant progress in this area. In addition, the most important aspects of the regulatory schemes in Japan, the European Union and the United States are discussed. Finally, an overview of the Mexican regulatory system is included.

United States

In the US, there is not an overarching federal program to coordinate the collection and management of used electronics. Currently, half of the states have enacted some type of electronics recycling program legislation, as shown in Figure 19. These states accept a variety of products, potentially including: desktops, laptops, monitors, televisions, printers, tablets, e-readers, fax, scanners, keyboards/mice, media players, portable DVD, DVD/VCRs, servers, set top boxes, game systems and digital frames. Illinois has the most comprehensive list, accepting all but digital frames (ERCC 2015). These state programs also cover a variety of electronics users, potentially including: households, small businesses, medium-large businesses, government, non-profit/charity and schools. California covers all of these entities, while over half of the programs only cover households (ERCC 2015).

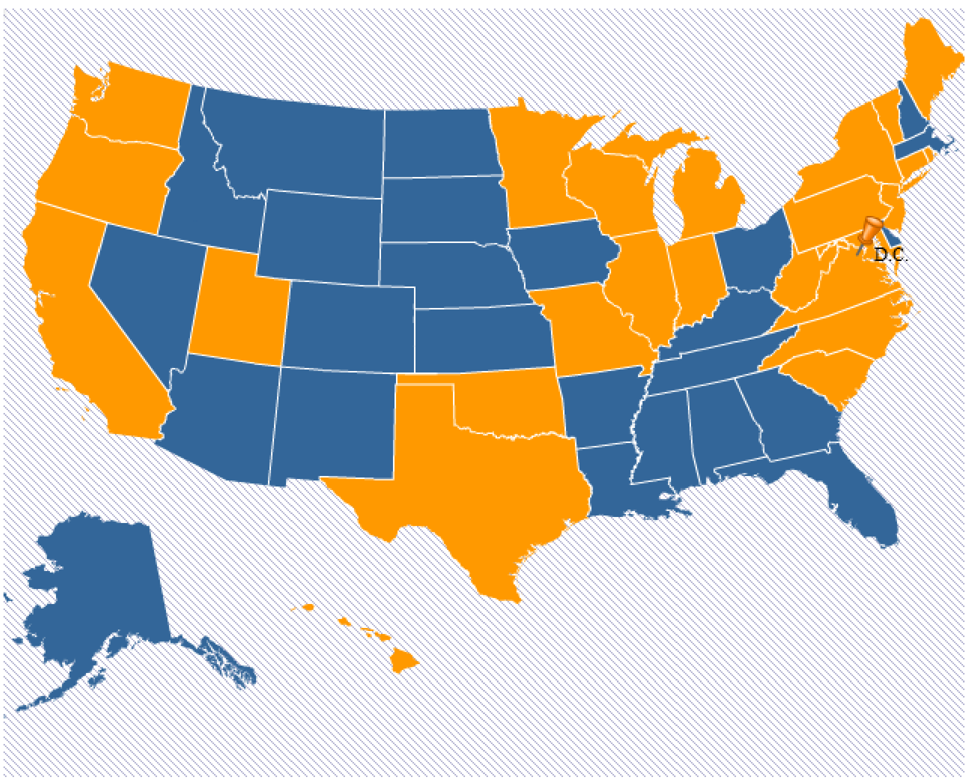

*Figure 19: States highlighted in **orange** have enacted some type of electronics recycling program legislation. Source: http://www.electronicsrecycling.org.*

In addition to these programs, twenty states have enacted landfill bans, which means that electronic products are not allowed to be disposed of through the traditional municipal solid waste collection system(ERCC 2015).

In 2011, a federal task force wrote a *National Strategy for Electronics Stewardship (Interagency Task Force on Electronics Stewardship 2011).* The four key components in the thirty-two-page report include:

1. Build Incentives for Design of Greener Electronics and Enhance Science, Research and Technology Development in the United States;
2. Ensure that the Federal Government Leads By Example;
3. Increase Safe and Effective Management and Handling of Used Electronics in the United States; and
4. Reduce Harm from US Exports of E-Waste and Improve Safe Handling of Used Electronics in Developing Countries.

Addressing the third point, which is of particular relevance to the development of the program in Mexico, they state:

> "There is a range of tools to help ensure used electronics are recycled in an environmentally sound manner, including accredited third-party certification programs, best practices, and increased knowledge and transparency of the companies and practices along the recycling chain. Quality electronics recycling certification programs not only advance best management practices, but also offer a way to assess the environmental, worker health and safety, and security practices of entities handling used electronics. Currently, there are two voluntary systems certifying electronics recyclers: R2 and e-Stewards. The electronics recycling industry has been quick to embrace the new certification programs."

They pledged to "Launch voluntary partnerships with the electronics industry to:

- Increase collection of used electronics that is safely managed by certified recyclers.
- Develop tools and materials that encourage the American public, businesses, states, and tribal nations to use certified recyclers.
- Increase consumer awareness about the importance of electronics recycling, as well as the tools and services available to do so.
- Involve States, tribal nations, NGOs and other stakeholders on the key elements of the voluntary initiative."

Some of the products that are collected by electronics recyclers and other firms are exported, which is a controversial issue, addressed by the fourth point of the Strategy. The USITC prepared a detailed report of the findings of its mandatory survey across the US electronics recycling value chain, including export (US International Trade Commission 2013). Several organizations have proposed federal legislation to limit the flow of exports, and the e-Stewards certification scheme strongly limits it. Currently, only CRTs and CRT cullet export is regulated. Key considerations tend to be the import restrictions in the receiving country and international law, whether exported products contains hazardous materials, whether it is working and/or whether it is a commodity grade material.

The National Director of the National Center for Electronics Recycling wrote an insightful article describing the evolution of the US used electronics landscape from 2005 to 2015. It is excerpted here:

> "Despite the lack of a federal agreement, there was another significant event on the national level in 2005. EPA hosted a national meeting on the key issues at the time, which involved months of planning ahead of time. The participants were asked to work on specific project areas, and NCER came away with a few data initiatives and a closer look at how a third-party group could operate. The biggest outcome of the meeting, however, was the identification of a need to develop a new certification for electronics processors that could be backed by a large group of stakeholders, including EPA. This led to many years of meeting and the ultimate R2 and e-Stewards split.
>
> Also in 2005, major changes in the markets for CRT glass were already being seen as domestic production was almost gone with the closing of plants run by Thomson, Corning-Asahi and Technglas in 2003 and 2004. Although these moves were not surprising with the transition to flat panel displays, it had an impact on the markets available and their distance to various key players.
>
> The IAER report in 2005 noted that computer equipment was the dominant type of equipment processed, and the majority of the volume came from business and government agencies. Meanwhile, on the consumer program front, the collection efforts undertaken by Minnesota's Hennepin County were seen as a model for high collection volumes – the county's 2004 per capita collection total was 3.4 pounds.
>
> In the policy world in 2005, the state laws in California and Maine would set the stage for a debate that would last several years and get played out in numerous state legislatures. California had ushered in a system based on a recycling fee paid by consumers of new products, while Maine's e-scrap law relied on producer responsibility (called "limited" at the time). Those two laws passed before 2005, but more than 20 other states would introduce legislation on electronics recycling that year, and six states completed or had ongoing study committees. Maryland was the only state to pass a law in 2005, and, interestingly, it was developed after a study committee recommended no state action.
>
> By 2010, the industry had experienced a flurry of legislative activity at the state level. In all, 21 states passed laws between 2007 and 2009, though in 2010 most of them had not been implemented yet or were in the very beginning stages.
>
> However, no two state laws were identical. There were groupings of similarity resulting from coordinated action, such as the upper Midwest group (Illinois, Indiana, Wisconsin) that followed the model passed in Minnesota in 2007.
>
> Additionally, computer manufacturers developed an approach for IT equipment that was first passed as law in Texas and later adopted in Oklahoma, Missouri and Virginia.

Meanwhile, in the Northeast, only one state (Connecticut) followed the model of producer responsibility set forth in Maine, while others passed a model based on Washington's approach (Rhode Island, Vermont) or were unsuccessful in passing any type of program law (Massachusetts, New Hampshire) even though they had landfill bans in place.

On the collection side, several states were reporting results from programs, and per capita rates were now over 6 pounds in Minnesota and Oregon.

The industry in 2010 was evolving as a whole. A survey that year was conducted for the Institute of Scrap Recycling Industries, which had acquired the assets of IAER, and it showed there were between 600 and 1,000 active e-scrap recycling companies at the time. The research noted mergers and consolidations were causing the overall number to decline.

At the same time, the project at an EPA national meeting to develop an industry certification plan had led to a series of meetings and, ultimately, the R2 document as well as a separate standard with e-Stewards. Both standards were launched in 2010 and would show rapid adoptions.

Several of the issues in front of us in 2015 were also talking points a decade ago. The first is the difficulty with properly managing CRT glass. Some observers boldly predicted that CRT glass would be gone from the recycling market by now, but the legacy of CRTs continues to present an enormous challenge to the industry due to the glut of glass appearing without new CRTs to produce. In addition, although many companies in the industry have come and gone, there are numerous smaller firms that are still active in 2015, and we haven't seen consolidation to the point where the industry is made up of just a handful of companies. There are certainly a number of companies handling larger volumes than in 2005.

The adoption of new state laws, on the other hand, has slowed to a trickle. Instead of a rush to get laws implemented in 40 to 50 states, as some may have expected 10 years ago, we now seem to be stuck on 25. Those 25 states are continually updating and amending their programs to attempt to deal with challenges, but no new state has passed a law in over three years.

However, those laws have had a definite impact in increasing the number of collection opportunities for consumers. The state programs, along with voluntary collection efforts from retailers and other entities, mean that many more collection points are available to consumers than a decade ago, and many of these outlets offer collection for free.

The certification effort that was kicked off on a large scale 10 years has evolved and greatly affected the industry. Gaining R2 or e-Stewards certification has become a near necessity for companies looking to work under state laws or for manufacturer programs. Both standards have released updated versions within the last two years." (Linnell 2015)

Extended producer responsibility (EPR) schemes

There are two basic types of electronics take back schemes operating in the US. The most widely used is a take-back scheme funded by producers. In the US, the approach is promoted by the Electronics Takeback Coalition among others. Under take-back laws, manufacturers are required to take financial responsibility for collecting and recycling used electronics. The amount paid by manufacturers is determined one of a few ways. In one approach, they pay in proportion with the volume that they currently sell on the market. In another, they pay in proportion with the volume of their product collected in the system, and share the cost of "orphan" products whose manufacturers are out of business. Some states set required collection amounts for the companies. The other main approach, used only in California, is the advanced recycling fee, or ARF (elsewhere ADP, advanced disposal fee). Under the ARF, consumers pay a fee at the purchase of products with video displays and portable DVD players. This fee goes into a recycling fund administered by the State which reimburses recyclers and collectors. A third option exists in Utah, where manufacturers simply must publicize recycling opportunities.

Figure 20 displays the types of policies in effect, presumably in OECD countries. Electronics make up over a third of those policies. Nearly three quarters of the policies follow the take-back form.

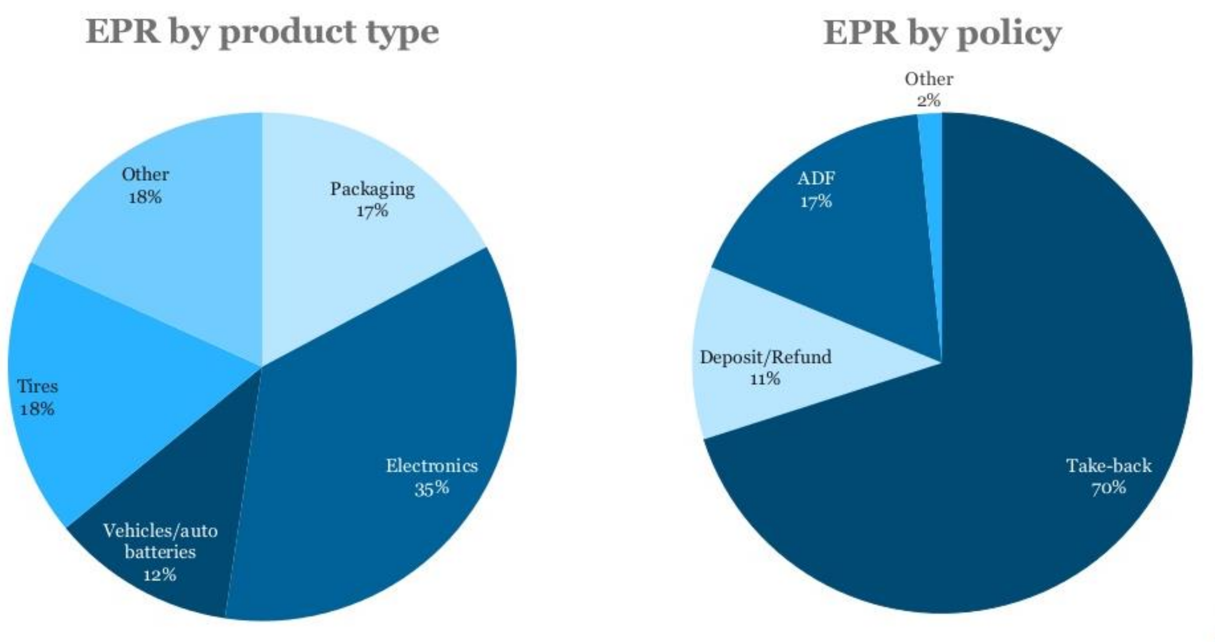

Figure 20: Types of extended producer responsibility programs in the OECD (Agrawala 2014)

The Product Stewardship Initiative tracks and promotes different programs across different product categories. They announce that EPR programs can be job creators as well as cost savers. A case study found benefits for a county, Hennepin County, Minnesota, around the size of Mexicali (Product Stewardship Initiative 2011):

"Hennepin County, Minnesota serves a population of more than 1.1 million people. Since 1992, Hennepin has offered a municipal collection program for the recycling of electronic waste. Under the Minnesota Electronics Recycling Act (May 2007), Minnesota became the fourth state in the country to require a producer-funded e-waste collection system. During the first year of the program, Hennepin County realized cost savings of more than $680,000, allowing the local government to allocate additional funds to other critical government functions. Similarly, St. Louis County in Minnesota serves a population of just under 200,000. The county operates 10 household electronic waste collection sites. During the first year of the manufacturer-financed program, St. Louis County saved approximately $90,000 in e-waste management costs."

Colombia

In Colombia there is specific legislation for WEEE management. Law N° 1672 establishes some "guidelines for the adoption of a public policy for an integrated WEEE management system". Enacted in July 2013, its main objective is the definition of guidelines for the integrated management of WEEE in the Colombian territory (Ley N°1672, 2013). Moreover, a regulatory decree for the law is being prepared (Camacho, 2016). The law contains a number of guiding principles, end-of-use processes for WEEE (i.e. refurbishment, reuse, recycling and disposal) and obligations for each one of the actors involved in the WEEE management system. Also, the national government is responsible for drafting the WEEE policy as well as for planning, coordination, implementation and monitoring. Policy aims to promote integrated management, encourage reuse and encourage the integration of the various actors for the development of strategies, plans and projects for the sustainable management of WEEE.

In addition, the Government of Colombia, before the enactment of Law No. 1672, developed legal instruments for three types of electrical and electronic appliances at the end of their lifecycle: batteries, lightbulbs and computers. Motivated by the significant consumption of these devices, the amount of e-waste that is disposed of in landfills or dumpsites, the need to preserve the environment and the desire to establish mechanisms to ensure that collection of e-waste is carried out separately from other domestic waste, Resolution N° 1297, N°1512 and N°1511 were enacted. The first one, N°1297, establishes the obligation for producers to implement a system of selective collection of batteries at the end of their useful life (Resolution N°1297, 2010). Moreover N° 1511 requires the implementation of a collection system and environmental management for waste lightbulbs (Resolution N°1511, 2010). Finally, N°1512 relates to computers and their peripherals (Resolution N°1512, 2010). These resolutions delineate actors involved in the system and their respective duties, demarcate collection goals according to established timetables and establish a series of prohibitions, such as; landfill bans, open burning and abandoning used electronics and appliances in public spaces. Currently a new resolution to increase the scope of regulated EEE is on the way (Camacho, 2016).

Costa Rica

In Costa Rica, Decree N° 35933-S titled "Regulations for Comprehensive Management of Electronic Waste" was promulgated in May 5, 2010. The main objectives of this decree was to: (1) Mitigate environmental negative impacts related to end-of-life electronics, (2) Establish the responsibilities for all actors involved in the system, (3) Promote appropriate mechanism for the monitoring of the system, (4) Minimize the amount of WEEE generated and (5) Inform the population about the WEEE management system (Decreto N°35933-S, 2010). Moreover, this law establishes a series of guiding definitions, including life cycle assessment, integrated waste management, involved stakeholders (e.g. producer, retailers, end users and compliance units) and recovery of waste. Also the legislation stipulates the creation of the National System for Comprehensive Management of Electronic Waste (SINAGIRE). SINAGIRE´s multi-sectoral committee is responsible for defining the framework for the integral WEEE management in Costa Rica. Moreover, some important functions include defining, reviewing and publishing, annually, collection goals: searching for solutions for orphan and historic equipment and promoting information and awareness campaigns of WEEE. Finally, the decree establishes the guidelines for the implementation of the compliance plan, its content, and the entity responsible for the verification process (Decree No. 35933-S, 2010).

Peru

Peru has a specific regulation for the management of WEEE. The decree D.S. N°001-2012-MINAM titled "Reglamento Nacional para la Gestión y Manejo de Residuos de Aparatos Eléctricos y Electrónicos" was enacted in June 27, 2012. This regulatory framework aims to establish a series of rights and obligations for the various actors involved in WEEE management during various stages of the reverse supply chain in order to mitigate negative impacts on the environment and on human health (Decreto Supremo N°001-2012-MINAM, 2012). This regulation has a number of definitions, indispensable for a proper implementation of the legal instrument. It also identifies the actors involved in the WEEE management system as well as their duties. Additionally, the regulation defines the management mechanisms for WEEE, incentives, violations and sanctions. Moreover, the regulation clarifies the basic documentation that EEE producers and WEEE operators must submit as part of their legal obligations.

The decree designates the Peruvian Ministry of Environment as the responsible entity and the "Organismo de Evaluación y Fiscalización Ambiental" (OEFA) as the agency in charge of the audit. Also, producers and operators are required to file annual reports about collected WEEE and the final destination of management of WEEE, respectively (Decreto Supremo N°001-2012-MINAM, 2012).

In addition, Peru has complementary legal instruments related to WEEE. For example, the Ministerial Resolution, N° 200-2015-MINAM relates to the submission, by producers, of management plans and annual goals. Electronics that are included are: large and small kitchen appliances, lighting equipment, electric and electronic tools, toys and other sport equipment, health equipment, control and monitoring instruments and vending machines. Initially, the goal established for consumer electronics is at least 4% of the amount of EEE defined as a baseline. This goal will increase annually. For the other categories the goal for the first year will be voluntary. In both cases, the baseline is determined by the average number of artifacts produced or imported during the last three years (R.M. N°200-2015-MINAM, 2012). Moreover, Resolution N° 027-2013/SBN is associated to end-of-life electronics generated by the Peruvian Public Administration and related end-of-use procedures (Resolution No. 027-2013 / SBN, 2013).

Finally, there are two Peruvian Technical Standards, NTP 900064 and NTP 900065. Both standards are related to the minimum required criteria for environmentally sound WEEE management (NTP 900,064, 2012; NTP 900: 065, 2012). The standard NTP 900:064 describes the overview of WEEE management stages. This standard has three informative annexes: (1) WEEE classification in accordance to its category; (2) WEEE classification based on its treatment, and (3) Components of WEEE containing hazardous substances (NTP 900064, 2012). The standard NTP 900:065 established precise practices for the appropriate handling of WEEE during the different stages, including one informative annex related to the processes of selective collection, mixed collection centers, and selective collection campaigns of WEEE (NTP 900: 065, 2012).

To summarize, the table below presents some similarities and differences in the WEEE regulations of these countries:

Table 1: Similarities and differences of WEEE regulations in Colombia, Costa Rica and Peru

Similarities	Differences
WEEE is a solid waste stream that needs to handled separately → Special regulations	Costa Rica includes the concept of product´s life-cycle management and waste recovery
A series of indispensable definitions related to the correct reading and interpretation of the respective legal instruments	Unlike Peru and Costa Rica, Colombia does not have a WEEE classification, but has legal instruments for certain types of waste such as batteries and accumulators, lightbulbs, and computers and their peripherals
Based on the Principle of Extended Producer Responsibility	Leading authorities: Peru → Ministry of Environment has the primary responsibility as the national environmental authority Costa Rica → Ministry of Health leads SINAGIRE Colombia → Ministry of Environment, Housing and Territorial Development leads the advisory body
The possibility for producers for selecting an individual or shared collection system	The Colombian legislation does not have a specific regime of sanctions
Establishment of the obligations of each actor involved in the management of WEEE	Colombian, unlike Peru and Costa Rica, does not specify anything about producer´s management plans

Japan and the European Union

Japan is the worldwide pioneer in the regulation of WEEE. In June 1998 Japan promulgated a law related to the end-of-life management of televisions, refrigerators, washing machines and air conditioning systems (Kahhat et al. 2008). This law, called Home Appliances Recycling Law (HARL), was enacted in April 2001, specifying that it is the final consumer who pays for the cost of recycling (Aoki et al 2012.). In addition, the law states that retailers are responsible for transportation of home appliances at the end of their lifecycle and producers for the corresponding recycling (Aoki et al. 2012). Currently, the recycling targets are 80%, 70%, 74% and 82% for air conditioners, refrigerators, televisions and washing machines, respectively (Aoki, 2016). In the past these goals were as follows, 70% for air conditioning systems, 60% for refrigerators, 55% for TVs and 65% for washing machines. This law has three important features. The first is that the consumer pays the costs of recycling, the second is that this law does not include collection goals but includes recycling goals, and the third is that it has a manifest system to track discarded household appliances (Forcada et al 2011; Global Environment Centre Foundation 2011).

In April 2013 the "Act on Promotion of Recycling of Small Waste Electrical and Electronic Equipment" was enacted, which includes about one-hundred electrical devices; such as, cell phones, video games consoles, digital cameras and other small electrical appliances. The municipal government is responsible for the collection of small WEEE and recyclers must be certified by the government (Ministry of Environment 2016, Aoki 2016).

Also in Japan there is a "Law for the Promotion of Effective Utilization of Resources," enacted in June 2000. This law seeks to integrate the initiatives of the 3Rs (reduce, reuse, and recycle) for the formation of a sustainable society. The law includes policies for the implementation of the 3Rs, from design through production, including segregation of waste and the creation of a system of voluntary collection by the producers (Ministry of Economy Trade and Industry 2007). Based on this law, initiatives for managing end-of-life computers in the residential and businesses sector have emerged (Kahhat et al. 2008). Currently, the association of manufacturers and importers of computers, through the PC 3R association, are responsible for the end-of-life system (PC 3R 2016).

In the European Community, Directive 2002/96/EC, known as the WEEE Directive, is motivated by the desire to diminish the use of natural resources by recycling electrical appliances and electronics (ESA) and the need for member countries to work together and not independently in this endeavor. The scope of this directive is focused on ten categories of EEE: large appliances, small appliances, computer equipment and telecommunications, electrical consumer appliances, lighting fixtures, electrical and electronic tools, toys and sports equipment, medical equipment, monitoring and control instruments and vending machines.

The directive establishes a set of definitions related to WEEE, as well as identifying treatment processes and actors involved. It also requires that devices are easy to disassemble for recovery, reuse and recycling, and that a selective collection system, different from the municipal solid waste system, needs to be established. On December 31, 2006 the directive went on to mandate that an average of four kilograms per year per inhabitant of WEEE were to be collected from private households. Moreover, the directive stipulates that a selected treatment process does not impact negatively on human health and the environment. Finally, member states are expected to ensure that end users know about the requirements regarding disposal of WEEE, separate from household waste, through the existing collection and return systems and human health and environmental impacts of dangerous substances found in WEEE (Directive 2002/96/EC 2003).

In addition, the directive 2012/19/EU, amending Directive 2002/96/EC, became effective on February 14th, 2014. One of the reasons for the change was the promotion of sustainable production and consumption, eco-design for ease of reuse and recycling, and selective collection of all WEEE containing nanomaterials in its composition (Directive 2012/19/EU, 2012).Furthermore, Directive 2002/95/EC, known as RoHS Directive, puts restrictions on the use of certain hazardous substances in electrical and electronic equipment. Put into effect in February 2003 it was motivated by the differences between the regulations of the member countries in terms of content of hazardous substances in electrical and electronic devices and the advantage of adopting rules at the Community level. The main driver for the directive was the adoption of the precautionary principle, i.e. the need for reduction of hazardous substances in waste, and the need for actions about the collection, treatment, recycling and disposal of WEEE to ensure no risk to human health and the environment. For this reason the directive instructs the reduction or elimination of heavy metals such as lead, mercury, cadmium, hexavalent chromium and hazardous organic substances; such as polybrominated diphenyl ethers (PBDE) and polybrominated biphenyl (PBB) and the removal of any substance that is scientifically proven to be harmful (Directive 2002/95 / EC, 2003).

Mexico

WEEE, or e-waste, is classified in the Mexican "General Law for the Prevention and Integral Management of Waste" (LGPGIR) as a type of waste that requires special handling (Article 19). The competent authority for this type of waste are state governments. The main considerations behind this classification are the content of toxic substances, valuable materials that could be recovered from these devices, and its growing share in the waste stream. However, some components such as CRT glass are classified as hazardous waste (Article 33). Hazardous waste is regulated by the Federal government {Bracho}.

The LGPGIR was originally published on October 8th 2003. The law was then modified several times. The last modification was published on May 22nd 2015[2]. Its main objective is to foster the prevention of the environmental impacts related to waste (Ley General para la Prevención y Gestión Integral de Residuos, 2015). In addition, a complementary rule was published on November 30th related to the implementation of LGPGIR (Reglamento de la Ley General para la Prevención y Gestión Integral de los Residuos, 2006). Moreover Standards NOM-161-SEMARNAT-2011 and NOM-052-SEMARNAT-2005 establish the required criteria to manage special and hazardous waste, respectively.

LGPGIR has several shortcomings that could limit the outcomes of a successful e-waste management system. Hence, a specific e-waste regulation is required and could have some benefits (Centro de Derecho Ambiental, 2010). For instance, it could improve conditions of the informal collection sector and the linkage of the previous with the formal sector, and it could establish clear rules and responsibilities for producers and other actors involved in the reverse supply chain.

[2] Updates to the LGPGIR, published on the Diario Oficial de la Nación (DOF)): 22-05-06, 19-06-07, 21-05-13, 07-06-13, 05-11-13, 19-03-14, 04-06-14, 05-12-14, 22-05-15, 30-05-12.

Unlike Mexico, the studied Latin American countries, Costa Rica (Decreto N°35933-S, 2010), Colombia (Ley N°1672, 2013) and Peru (Decreto Supremo N°001-2012-MINAM, 2012), have a specific WEEE regulation. These countries decided to establish a specific WEEE regulation to set a scope, suggest an integrated management system specific for WEEE, and assign responsibilities of all the actors involved in the reverse supply chain. However, the Mexican general waste framework also presents some similarities with the other countries. For example, it includes important general definitions (e.g. generator, integrated management of waste, recycling and reuse processes), states the importance of a management plan and the responsibility of stakeholders, and expresses the right of society to be well informed about solid waste generation.

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Organization of the used electronics informal sector

Globally waste pickers and informal recyclers are increasingly organizing to more efficiently and safely recover discarded materials, including used electronics, effectively diverting valuable resources for reuse and keeping them out of dump sites, landfills, landscapes, and watersheds. Today there is an estimated 20 million collecting and sorting waste material all over the world many of whom have effectively organized themselves into national and international associations, cooperatives, or unions. Red-LACRE (La Alianza Global de Recicladores), an affiliate of the Global Alliance of Waste Pickers, includes an association in Latin America, comprised of fifteen representative countries, including Mexico, and has more or less one million members (see link: http://globalrec.org/tag/latin-american-waste-pickers-network-red-lacre/ .

As e-waste is considered a subset of material collected by waste pickers, there are a few examples of informal recycling cooperatives effectively and safely participating in e-waste management systems in low and middle-income countries. This section attempts to provide examples of responsible efforts to include informal recyclers in the collection, aggregation, and dismantling of e-waste -- strategies that could potentially be incorporated into the model developed for Mexicali. Recycling cooperatives vary, but the strongest ones have the following features:

1.) Identification Cards:
The municipal government (or other entity) implements a formal registration process and issues identification cards, many of which include a photo. Identification cards are often renewed every ten years.
2.) Governmental Regulations:
Regulations for the separation and/or disposal of waste are defined, resulting in fines to residents and business owners for non-compliance, requiring, for instance, that residents and businesses dispose of all e-waste as mandated by the municipal government.
3.) Two-Years of Business Training:
To acquire the administrative and technical skills necessary for their organizations to thrive, many waste picking cooperatives receive one to two years of appropriate training.
4.) Strong Leadership
Cooperatives do better if leadership is well defined. Furthermore, leaders of recycling cooperatives have been shown to have a profound influence on the environmental strategies that their cooperatives adopt – leaders can effectively shape the culture of an e-waste recycling cooperative. Therefore, many leaders of waste picking cooperatives are provided leadership training.
5.) Branding:
Branding of the cooperative is important as both a factor in motivating compliance by residents as well as creating a sense of pride in cooperative members, which generates a desire to maintain careful and productive work habits.

Waste Pickers Working with Municipal Government

The goal of most recycling programs working directly with waste pickers is to incorporate them into the formal municipal waste management system. This has been achieved using a couple of strategies. Some waste picking cooperatives receive remuneration from the local or state government. In Brazil the Recycling Bonus law passed in 2012 provides funds to local waste pickers who meet the organizational requirements for receiving a monetary incentive. The payment is made at the end of each three-month period. The procedures that allow cooperatives to receive the funds include daily registration of volume collected by individual waste pickers; daily registration of buying and selling material; and daily registration of individual production (collecting, sorting, dismantling) by type of recyclable material. As the law requires that these procedures are regularly practiced, it means that new people and new practices have had to be introduced into the waste picking cooperatives, which may or may not decrease cooperative and individual earnings. The law established in Brazil represents one way waste pickers have been formally included in the management of solid waste. One waste picker from Belo Horizonte, Brazil quoted in the 2013 WIEGO publication "Informal Workers and Collective Bargaining":

"During 2012, at least 59 cooperatives and workers' associations in the metropolitan area of Belo Horizonte introduced changes in their administrative and management practices in order to meet the legal requirements for receiving the monetary incentive. According to the members, the changes are a real gain for the working conditions of the whole group in addition to the expected increase of income resulting from the monetary incentive."

Another option for creating a strategy that incorporates waste pickers into the municipal system is for a municipal government to offer a waste picking cooperative the opportunity to collect waste material, using a formally recognized collection route. Collection of material is established in a few different ways: 1.) A door-to-door system where a member of the cooperative either collects material on foot or by using a vehicle (note that this system sometimes uses smart phone apps to let the cooperative know that material is available for pick up); 2.) A stationary collection system where a member of the cooperative manages centers or hubs strategically placed throughout a city or town; and 3.) A mobile collection system where a vehicle serves as centrally located hub where people can easily dispose of e-waste.

Collection Routes and Hubs for Aggregating Material

Door-to-Door Systems

In Curitiba, Brazil and in El Rama, Nicaragua the local municipal government incorporated waste pickers into the formal system by offering them door-to-door collection routes. In Curitiba the municipal government provides a fee for service to the local cooperatives, while in El Rama they simply offer the waste picking organization the opportunity to legally collect material from individual households and businesses. Door-to-door collection is preferable for waste pickers as it offers them the opportunity to collect cleaner material than is available in dumpsites or landfills. This is an especially helpful strategy for municipal governments collecting waste in hard to reach neighborhoods where collection trucks cannot access homes. Globally waste pickers use all sorts of vehicles for door-to-door collection, including bicycles and motorcycles that pull small wagons, horse and cart, and small trucks.

Figure 21: Waste pickers, municipal workers, and students mapping collection routes in El Rama, Nicaragua – January 2013. Photo by Elli Blaine.

Stationary and Mobile Collection System

In terms of e-waste collection points, there are many examples where waste picking cooperatives have been given the opportunity to collect material at centrally located collection hubs. For instance in Nairobi, Kenya, Dell participated in the creation of an e-waste system that trained women on how to manage collection points throughout the city. Collection points were fashioned from shipping containers that function as independent small businesses. Once the shipping containers were filled, material was sold to a main hub where e-waste is responsibly dismantled. To launch the program, Dell provided micro-loans to twenty-seven women entrepreneurs who participated in the program. In addition to the Dell model, it is worthwhile noting that the waste picking cooperative Kagad Kach Patra Kashtakari Panchayat (KKPKP), which was established in Pune, India in 1993, manages small collection units that resemble miniature mobile homes which are periodically moved to strategic sites throughout the city and a cooperative scrap store in space provided free of charge by the Pimpri Chinchwad Municipal Corporation. Members who sell material at the store receive an annual bonus that has progressively increased from 5 to 10 percent.

Dismantling & Training

Dismantling e-waste can potentially expose informal recyclers to dangerous chemicals. Therefore many cooperatives and enterprises that choose to work in e-waste treatment are provided certified training. In this way at least some members of a cooperative or business can be included in a formalized e-waste treatment system that protects workers from potentially harmful chemicals. The opportunity of what some researchers call “deep disassembly” has been practiced in countries with low labor costs including Brazil, China, and India. Deep assembly allows for people to safely disassemble used electronics into smaller, purer fractions without having to invest in expensive equipment. The formalization of informal workers can allow for: 1.) Opportunities to learn additional skills, 2.) Prospects for greater social standing, 3.) Safe handling of e-waste, and 4.) Additional small business creation opportunities. There are a few examples of recycling cooperatives that responsibly dismantle e-waste. Professor Tereza Cristina M.B. Carvalho at University of Sao Paulo (USP) created one notable program in 2008. At a lab within USP Professor Cristina designed a step-by-step process for safely dismantling e-waste in short increments of time. Once she understood the step-by-step process for safely dismantling particular categories of e-waste, Instituto GEA (http://www.institutogea.org.br/) was brought on to provide workshops that taught safe handling and dismantling procedures for waste pickers all over Brazil. Since that time, e-waste centers, both for collecting and dismantling electronics, have been established within existing cooperatives. A publication documenting the process and curriculum they used for training waste pickers to safely dismantle e-waste can be found at: http://ecoeletrofase2.com.br/ecoeletro2/wp-content/uploads/2016/01/2016.01.06_LIVRO_GEA_FINAL_ISBN.pdf.

Health and Safety Practices for Recyclers Working With E-Waste

Informal recyclers working with e-waste can potentially be exposed to health hazards, which require e-waste workers to take a number of necessary steps to protect themselves. Hazards include cuts or eye injuries from sharp objects, hearing loss, and exposure to toxic metals that can result in long-term health effects. The most notable chemical hazards found in e-waste are: 1.) Lead from Cathode ray tub (CRT) glass, batteries, and old printed circuit boards that, with long-term exposure, can cause nerve and brain damage, kidney damage, birth defects, anemia and high blood pressure; 2.) Flame-retardant dust from plastic cases, which has been known to result in thyroid problems; 3.) Mercury vapor from batteries, switches, thermostats, fluorescent tubes and thermometers, which has been associated with nerve and brain damage as well as birth defects; and 4.) Cadmium dust from nickel-cadmium batteries, printed circuit boards, and phosphor coating on CRT glass, which has been associated with kidney disease, issues with bones, and lung cancer.[3] Dismantling materials as well as glass breakage (CRT screens) releases dust, which, even in small amounts, when breathed in or swallowed can harm a workers’ health. Therefore e-waste dismantling centers must be kept clean with a wet mop or a HEPA vacuum as opposed to a broom, which can further spread the hazardous dust. Additionally, material should be dismantled before shredding. Uniforms should be provided and they should be left at the recycling site, rather than taken home where they can expose hazardous dust to other members of the family. In addition, work boots should also stay at the site. If workers are not provided lockers, uniforms and boots

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[3] HAZARD EVALUATION SYSTEM & INFORMATION SERVICE

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Occupational Health Branch
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should be kept in plastic bags at the facility when workers leave at night. If a CRT screen is broken, anyone cleaning the area should wear a respirator while using a wet mop or HEPA vacuum. As parts of material may come dislodged while workers are engaged in disassembling e-waste, it is important that cut-resistant gloves (e.g. Kevlar) and safety glasses are worn at all times.

Suggested Strategies from an Award-Winning Model

Chintan is a well-regarded organization that works with waste pickers in New Delhi. In 2015 they were awarded the United Nations Momentum for Change Award in the Urban Poor Category for their initiative to train e-waste pickers to collect and dispose of electronic waste. Nokia funded and partnered with Chintan to provide training, space, and sponsored a public awareness campaign. The following is a list of key strategies outlined by the organization in a report published this year.

- Establish a partnership with a company producing electronics (Chintan partnered with Nokia).
- Create a partnership with a local NGO that can effectively support the informal sector with appropriate and effective capacity building in collection and disassembly methods as well as leadership and business management.
- Attain the most current data on the informal sector (they often have a keen understanding of the supply chain).
- Identify leadership capabilities within your informal group.
- Provide capacity building (Nokia paid Chintan to do workshops for the informal sector)
- Complete a comprehensive market study
- Roll out an e-waste awareness campaign (Nokia paid for the campaign).
- Establish a door-to-door system to not only collect e-waste but to continue to create awareness among residents, regarding the importance of properly disposing of e-waste.
- Identify space for storage and dismantling of e-waste (although Nokia provided the space, in many cases, for instance in Pune, the municipal government offers space to establish an e-waste recycling hub).

Although, as described above, efforts to create environmentally sound e-waste management systems that incorporate the work of the informal sector exist, organizations working with waste pickers are eager to learn about new strategies for creating safe and effective systems. Therefore the system created in the Mexicali program has the potential to fill a real need, establishing innovative strategies that are not only environmentally sound but provide a living wage income to people living in poverty. In this way the program has the opportunity to pave the way forward by providing an example of a system that includes waste pickers in the creation of an effective used electronics management system.

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Articles on Chintan: http://www.igep.in/e48745/e49028/e56537/index_eng.html; http://www.thebetterindia.com/41177/waste-picking-a-respectable-green-job-in-delhi/.

Current system structure and flows

Fieldwork conducted in Mexicali noted the dynamism of reverse electronic supply chain in the city. Formal and informal actors interact to channel the process of recycling all materials or parts from electronic equipment that have an established market. If the material or part has a reported value among the agents that make up the system, collection for recycling is predictable (Estrada-Ayub and Kahhat, 2014). For example, printed circuit boards have a known value by the actors, thus, a recycling route is clearly defined in the system. Similarly is the case of other parts from the different electronic waste.

Figure 22 shows the current system for managing electronic waste in Mexicali. The system includes main actors, informal waste pickers or scavengers (pepenadores), municipal waste pickers, collectors and recyclers. Scavengers are informal actors involved in the selection and collection of recyclables from different parts of the city. They are a very important player in the system. According to Ojeda and colleagues, in Mexicali, many individuals are engaged in scavenging activities (Ojeda et al. 2016). Their work ensures an increase in the recycling rate in the area. According to its area of operation, the waste pickers of Mexicali are divided into three groups: walking scavengers (Sw), on-site scavengers in the ETIR transfer station (Sos) and landfill scavengers (Sos). Also, trash truck scavengers (St) are hired by the municipality and linked to the collection of municipal solid waste. Both actors, waste pickers and municipal waste pickers, collect recyclables, including obsolete electronic equipment, and trade them in the reverse supply chain. For the specific case of obsolete electronic equipment, if the equipment or its parts have the potential to be reused, they are channeled into the second-hand market. Otherwise, they go through a process of dismantling and subsequent trade of parts and materials that have a market value. In a context such as that found in Mexicali, a system that ignores these informal actors is a system doomed to failure.

The role of "middleman" of the system takes place with the “acopiador” of collectors. This actor, formal or informal, collects recyclables from the different actors in the system, including the walking scavengers, trash truck scavengers, residential sector, commercial sector and industrial sector. Based mainly on the collected volume and the market price, the accumulated material is sold to different recycling companies located in Mexicali, Mexico or the United States.

A future management system of end-of-life for electronics, in Mexicali, should definitely consider environmental problems and public health mentioned in the next section. However, it should not disrupt the positive aspects found. The authors recommend an intervention to strengthen the current flows and good relationships of the current system and simultaneously mitigate negative impacts.

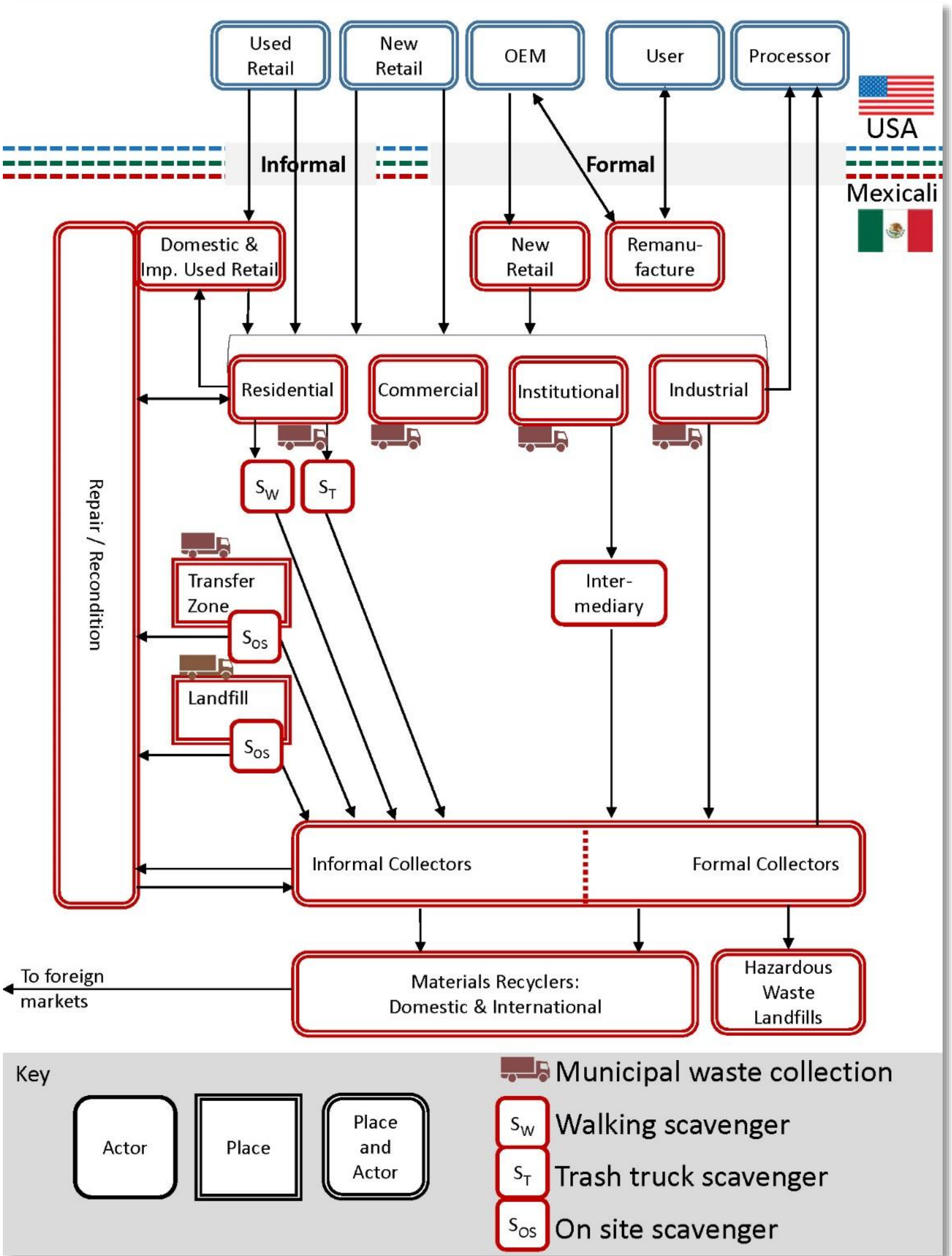

Figure 22: Current system of e-waste flows in Mexicali

Environmental problems and potential solutions

Environmental and public health problems

According to the Partnership for Action on Computing Equipment (PACE) Working Group of the Basel Convention, some of the many materials in computing equipment are hazardous, while others are valuable:

> Computing equipment contains more than 60 types of metals and other materials, some in large amounts, "primary constituents" such as steel, some in small amounts, "minor constituents" such as silver, and some in very minute amounts, "micro or trace constituents" such as gold. Of course, the exact materials are different for each manufacturer, for each piece of equipment, and they are always changing as the technology changes. Facilities that recover material from end-of-life computing equipment must be prepared for new and old equipment, with new and old technology.
>
> Some of these materials present little or no special hazard or concern, e.g., steel. Certain other materials may present a hazard when they are broken, crushed, shredded or melted, unless environmentally sound management practices are employed (PACE, 2011).

The appendix contains tables which list for selected electronics the chemical substances of concern, and relevant standards, certification schemes, and legislation that list those substances. Dozens of used electronics items were noted to contain one or more of the chemical substances of concern {miller 2013}. A single cell phone, for example, is comprised of more than forty elements and cadmium from one mobile phone battery can potentially pollute 600 m of water (Trick, 2002). Discarded refrigerators and air conditioners contain Chlorofluorocarbons CFCs) that eventually destroy the ozone layer and plastic housings of electronic products contain brominated flame-retardants, which are known hormone mimickers.

The electronic reverse supply chain in Mexicali presents some problems that endanger the environment and public health. These should be mitigated and there are several global efforts dedicated to this effect, some with a focus on the Latin America region. The team has identified the following main problems:

(1) inadequate removal of glass with lead content from the cathode ray tube (CRT) monitors and televisions,
(2) inadequate removal of batteries,
(3) open burning of insulated copper cables,
(4) landfilling of e-waste
(5) working conditions of waste pickers or scavengers are poor and must be improved. Several authors have noted the potential health problems related to work performed by some scavengers, in the streets, transfer stations and landfills.

Cathode ray tubes (CRT) of monitors and televisions

Background of problem

The second strategy includes improper removal of glasses containing lead from cathode ray tubes (CRT) of monitors and televisions. For more than 70 years, CRTs have been the main component of television sets, desktop computers and oscilloscopes; due to the maturity of its technology, reliability and low price (Lairaksa, Moon, & Makul, 2013). With the emergence of flat screen TV receivers (LCD and PDP), CRTs have begun to lose market in the world, to a very low market share (IHS, 2016). It is expected that CRT sales will disappear in the coming years.

The analog blackout that is been implemented in Mexico, the obsolescence of electronic equipment that have a CRT, and difficulties related to the end-of-life management of CRT represent a critical situation for Mexicali. This situation escalates because the Mexican standards cataloged this solid waste as a hazardous waste due to its content of lead in the glass, making it difficult, and hampering their management at the end of life stage. Similarly, United States of America (USA) classifies the glass of CRTs as a hazardous material when it is sent to a landfill; however, an exclusion of this classification, which allows recycling or reuse, is feasible (EPA, 2016 Title 40 - Protection of Environment). Therefore, it is recommended to adapt Mexico to the legislative example of USA. Thus, authorize the exclusion of the classification of CRTs as hazardous waste if they are processed following an environmental-friendly end-of-life management plan. This regulatory change will streamline the proper management of CRTs and will benefit an eventual electronic waste management system in Mexicali, or anywhere else in Mexico. Additionally, based on the current context, it is recommended that the future electronic waste management system generates a fund to encourage the drop-off of these devices. This fund will be used to provide an economic incentive to those actors who deliver it completely and therefore, ensure a proper end-of-life management. In this way, environmental damages resulting from a selective recycling, where devalued materials; such as CRT glass, end-up in informal dumps; as in the case of Peru, Mexico and the Philippine, would be avoided (Kahhat 2012, Yoshida et al. 2016).

Glass recycling of CRTs, at the moment, is the most expensive operation compared to other materials present in these devices, such as metals and plastics (Xu et al. 2012). Moreover, it is a bulky component (about 60% of the weight of a monitor or television), difficult to transport and is not degradable (Mueller et al. 2012). There are two main types of recycling systems for obsolete CRTs. The first type is the open system, or open-loop recycling systems; where recovered lead, copper and other sub-products may be reused in a different application (Singh, Li, & Zeng, 2016). The second, closed type system, closed-loop, or glass-to-glass, uses the recycled material for production of new CRTs. However, the decay rate on the production of new CRTs is a major obstacle in this system. The last facility left that recycles this material (clean glass of the screen and funnel of the CRTS) to make new CRTs, VIDEOCON, still accepts it, but is not sure whether it will continue with this policy in the future (Resource Recycling, 2016). The company “TDM” located in Mexicali is the branch of VIDEOCON and has received for many years the used CRTs from USA.

CRTs are composed of two main types of glass. The first type of glass is located in the display of the device and contains mainly, apart from the essential components of the glass (i.e. silicon oxide), barium oxide (between 1.9 and 14%) and strontium oxide (between 0 and 12%) (ICER, 2014). The lead content in this part is nonexistent or low (maximum 3.3%). Furthermore, the conical section of the CRT (funnel or cone) contains between 11 and 25% of lead oxide. The total weight of lead oxide in a CRT can be up to 3 kg in the case of a 32-inch CRT (ICER, 2014). Considering that lead is an element that hinders the recycling of a CRT, the separation of the components of a CRT (i.e. screen and funnel) is a critical step in the recycling processes. Dismantling of obsolete CRTs could use conventional methods; such as, the hot wire method, laser cutting, or acid leaching (Gong et al. 2016). Once separated, the glass from the CRT screen has a greater number of uses. Furthermore, in the case of the CRT funnel an option is the pyro-metallurgical process. This energy intensive melts the CRT funnel to separate and recover lead (Gong et al. 2016).

Potential solutions

Currently there are several options for the usage of the CRTs glass. For example, the use of CRT as a fluxing agent in copper and lead smelting processes (Xu et al. 2012) is an alternative , especially for foundries that have an optimum supply of this "new raw material". CRTs have a high percentage of silicon oxide, which makes them suitable for such processes; but should determine the effect of the addition of this residue into the produced slag to determine if it can be used for other purposes. In Mexico, at the request of "Retroworks of Mexico," "Grupo Mexico" has experimented in the use of unused CRTs as a fluxing agent in copper refining. Despite obtaining satisfactory results, the classification of obsolete CRTs as "hazardous material" is a great disincentive for the Mexican business group (Ingenthron, 2016).

Furthermore, in respect of the recovery of lead from the glass containing lead, there is a process patented in China, called “Oxygen bottom blowing furnace technology” (SKS), wherein glass with a high lead content can be added to this kind of ovens. First, the glass is grounded and then is mixed with other lead concentrates and fluxes. At the end of the process lead and residues are obtained. The latter contains less than 5% of lead and could be used as raw material for cement (Xie et al. 2012). Additionally, Mostaghel and colleagues have investigated the effects, of adding to the residues from the oven, percentages of CRT glass. The study determined that the addition of used CRTs up to 10% by weight does not affect the crystalline phase and that the leachability of certain minor elements, are within the allowed range for applications linked to the construction sector (Mostaghel et al. 2011). Mingfei and colleagues have studied the possibility to remove lead by simultaneous production of glass microspheres, which could be used as fillers for polymers and abrasive materials (Mingfei et al. 2016). The particular properties of lead (i.e. density, corrosion resistance and malleability) make it be an important material in various industries/applications, such as; production of ammunition, protection systems against X rays, solders, battery manufacturing, and among others. Its use and finite reserves makes recycling an important activity (Gong et al. 2016).

In addition, there are various processes that obsolete CRTs can be used as raw material for producing another product with different uses than the original. For example, studies show the possibility of using the glass of CRT screens as a substitute for feldspar in the manufacture of stoneware (high temperature ceramic). The study compared a standard sample of stoneware with 35% in weight of sodium feldspar and samples with different contents of CRT glass (2.5, 5, and 10% in weight). The results showed that using up to 5% in weight as a replacement of the fluxing agent, can improve the densification process of ceramics and its mechanical properties (Andreola et al. 2008). Also, the use of CRT glass as fine aggregate for the production of concrete sett has also been investigated by Ling and Poon (2014). After an acid wash process, the CRT glass is used in the manufacturing process of concrete sett, replacing fine aggregate. The results show that concrete sett, with a composition of aggregates of 100% CRT glass, have satisfactory mechanical properties, alkali resistance, and water absorption; however, they recommend limiting its use to a replacement of fine aggregate not greater than 25%. The main reason is related to the lead leachates found in the *Toxicity Characteristic Leaching Procedur*e, TCLP, test, which indicates that the limit of 5 mg/L is exceeded in those blocks with replacement rates higher than 50% (Ling & Poon, 2014). Another satisfactory alternative to the use of obsolete CRT glass is in the manufacturing industry of foam glass. This process involves heating the glass, finely grinded; at temperatures ranging from 650 to 750 °C, and the addition of foaming agents, such as; egg shells, calcite and dolomite (Fernandez et al. 2014). Furthermore, Yoshida and colleagues have reported the use of CRT glass from the informal sector in road construction in Indonesia; however, the environmental impacts from a possible leaching of lead have not been studied (Yoshida et al. 2016).

In addition, another option for handling end-of-life of CRTs is the use of exclusive and temporary landfills for this type of waste (Kahhat and Kavazanjian 2010) or disposal in hazardous waste landfills.

Batteries

Background of problem

Batteries are a common complement of various electrical and electronic equipment, vehicles and other devices. There are various types of batteries, which could be classified by two major types, disposable and rechargeable. Disposable batteries include zinc-carbon, alkaline-manganese and lithium batteries. The second type of batteries, rechargeable batteries, includes nickel-cadmium, nickel-metal hydride, lithium, lead and acid ion batteries. These devices are essential to many human activities; however, the environmental risk associated with their end-of-life could be significant.

In the absence of integrated environmental policies related to its end-of-life; one of the most important concerns is related to its final disposal in landfills and dumpsites, and the environmental impacts resulting from the leaching of heavy metals they contain; such as cadmium, chromium, mercury and lead. Karchanawong and Limpiteerprakan (2009) have used the TCLP test of the US Environmental Protection Agency (EPA), and found that the final disposal of batteries in landfills affect leachate characteristics by increasing concentrations of heavy metals. However, other studies show that in well-managed landfills the risk of an environmental impact, product of the leaching of heavy metals, is low (SWANA 2004).

Potential solutions

There are several methods that can be used for recycling batteries. These technologies, able to recover valuable resources, can be grouped into pyro- metallurgical, hydrometallurgical, or physical treatments (Tanong et al 2014). For example, for carbon-zinc, alkaline-manganese, nickel-cadmium, and lithium batteries; or a mixture of them, the BATENUS process; based on a hydrometallurgical process, could be used (Frohlich and Sewing 1995 Bernardes et al . 2004). Other available technologies (or companies that have developed these technologies) are as follows: NIREC, NMM-Sedema , AED , WAELZ, RECYTEC , SUMINOTO , BATREC , ACCUREC, and among others (Bernardes et al., 2004).

However, in the world, battery recycling rates are quite low. Two of the main reasons are the shortage of recycling programs and the high costs associated with the reverse supply chain of these devices (Gies , 2015). However, there are exceptions, as the case of lead and acid batteries; where global regulations and the widespread use of lead in various industries have helped achieve high recycling rates: over 90% in developed countries (Gies, 2015). On the other hand, recycling lithium ion batteries is low and is motivated mainly by the recovery of the materials constituting the cathode of the battery, such as cobalt (Gies , 2015). Important to note that a significant growth of these batteries is expected, especially for use in electric vehicles (Richa et al. 2014).

While there are technologies for the recycling of batteries, a common practice in developing countries (including Mexico) is disposal in landfills or dumps (Delgado et al. 2007). In the case of Mexicali, the precariousness of the only landfill dedicated to municipal solid waste: "Hipólito Rentería", practices in the residential sector in relation to the disposal of batteries, and the lack of a plan for the end-of-life batteries; increases the environmental concern mentioned above. Then, based on the environmental risk posed by batteries, little economic incentive related to recycling, and conditions of municipal landfills, it is suggested to incorporate a parallel system of batteries at its end-of-life. A challenge is that a Mexican company which recycles batteries aside from lead acid is at a distance in central Mexico.

Open burning of insulated copper cables

Background of the problem

The price of copper on the market and the preference of the "acopiador" for the purchase of uninsulated wires, encourage the scavenger to burn the insulated copper wires outdoor (Kahhat and Williams, 2009; Estrada- Ayub and Kahhat, 2014). This process has significant environmental and public health consequences, mainly because of Dibenzo-p-dioxins and dibenzofurans polychlorinated (PCDDs / PCDFs) emissions, or dioxins and furans (Williams et al 2008, Leung et al. 2007). Dioxins and furans are chlorinated, aromatic, and organic components, highly persistent and bio-accumulative in the environment, which have different dangerous effects for living beings, including skin and cancer effects (ATSDR 2016; Gullett 2007). The emission of dioxins and furans to the environment is linked to various anthropogenic activities, such as incineration of municipal and industrial solid waste (ATSDR 2016).

Gullet and colleagues y Leung and colleagues, have reported high amounts of PCDD/PCDFs as a product of the electronic waste informal recycling activities, especially the open burning of insulated copper cables (Gullett et al 2007, Leung et al 2007). While this practice is common in Mexicali-Mexico and other countries of the world; such as Peru, Ghana, Nigeria, India, China; the solution to the problem could be very simple (Asange et al. 2012, Kahhat and Williams 2009, Kahhat 2012). A Strategy to mitigate environmental damages, promoted by Williams (2005), Kahhat and Williams (2009), and Williams and colleagues (2013), is the use of economic incentives. The authors propose the use of economic incentives to ensure direct purchase of insulated copper wires, from the certified center. This intervention will not affect the dynamism of the real system, their actors and connections. Once purchased, these cables will be processed with technologies capable to mechanically separate both materials: plastic and copper, for subsequent recycling of both materials. Currently, there are several companies offering this type of technology (chopper machine), including the Italian Guidetti S.R.L. and their series "Sincro EKO" capable of processing between 50 kg /hr and 1,000 kg/hr of electric cables (Guidetti 2016). The weight of the five products of the "Sincro EKO" line ranges between 350 and 3400 kg, its power between 3.6 and 46 kW, and the dimensions between 1.06 and 3.38 m long, 0.81 and 1.78 m wide, and 1.15 and 3.75 m high (Guidetti SRL, 2016). The cost of this equipments oscilate between 12,999 and 39,999 euros (Guidetti). For example, the "Sincro 315EKO" has a price of 17,409 euros (please see Appendix for the detail of the price and specifications). The authors propose the use of economic incentives to ensure direct purchase of insulated copper wires, from the certified center." Funding for these economic incentives could come from the system´s revenue or government subsidy.

Proposed solutions

Figure 22 shows the current system and the proposed one. In both cases, the insulating copper cable is collected informally by various types of scavengers, however, the proposed scheme will create a mechanism for the purchase of insulated copper wire at a slightly higher price than the price offered by the market for cables without covering. This incentive and the cost reduction of informal processing of copper cables, before assumed by collectors/separators, will progressively eliminate open burning of insulated copper cables and an environmental friendly processing will be ensured through the certified centers, which could include some "acopiadores".

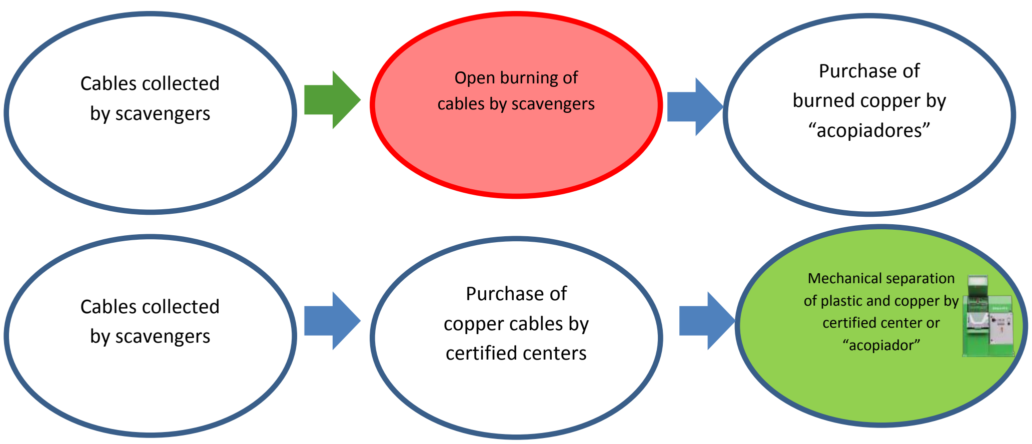

Figure 22: Current situation (above) and proposed system of collection and separation of cables (below).

Landfilling E-Waste

Background of problem

Electronic waste is made up of mix of harmful and valuable chemical elements and compounds. Therefore when e-waste ends up in dumpsites and sanitary landfills toxins including lead, cadmium, mercury, beryllium, polyvinyl chlorides (PVCs), brominated flame retardants and pthalates, many of which are neurotoxins or hormone mimickers, may seep into the environment.

When waste breaks down and water filters through the refuse, leachate occurs, creating a highly toxic liquid that can potentially pollute soil, waterways and plant life. Long term exposure to these toxins have been known to impact the brain, nervous system, endocrine system and bones. They also can cause birth defects. Babies in utero and children are especially vulnerable. At key moments in their development neurotoxins, including lead and mercury, can cause life-long damage. Therefore appropriate infrastructure for keeping electronic waste out of final disposal sites is crucial.

"The introduction of industrial and municipal solid waste into our environment has contributed greatly to the increase in levels of heavy metals in soil and vegetation grown in dumpsites. The soil and plants on these dumpsites will constitute a serious threat to the health of people living around such areas." (Adefemi and Awokunmi, 2009).

Some of the elements that are released into the ground, water, and air in final disposal sites include the following (see complete table in the appendix):

Mercury	Fluorescent tubes, flat screen monitors
Cadmium	Rechargeable batteries, chip resistors, infrared detectors, semiconductors
Lead	Lead batteries, cathode ray monitors
Nickel	Nickel batteries, alloying metal in steel

A study of heavy metal contamination around the Alaba International Market Dumpsite in Nigeria was conducted in 2013 to measure water, soil and plant life up to 200 meters from the dumpsite and at a depth of up to 30 centimeters. Although the study determined that there were high concentrations of cadmium, chromium, zinc, lead and nickel, which vary according to change in season, soil depth and plant part, concentrations of lead and nickel were particularly high. These heavy metals were also found in well and tap water at homes near the dumpsite, exceeding permissible levels defined by the World Health Organization (WHO). Lead, which showed the highest concentration in soil and water, was also found in the roots of vegetables grown in the vicinity of the Alaba International Market. When ingested, heavy metals in food bioaccumulate, becoming more toxic as they move up the food chain. Researchers surmised that high concentrations of lead may be a result of the disposal of cathode ray tubes, computer monitor glass, printed wiring boards and lead-acid batteries. Concentrations of cadmium were the lowest for all the heavy metals included in the study, which researchers indicate is most likely a result of the fact that Cd-Ni batteries were banned in many of the countries that manufacture electronics.

Mexicali's Hipolito Renteria Final Disposal Site

Mexicali's Hipolito Renteria Final Disposal Site, which is improperly lined making adjacent neighborhoods particulary vulnerable to toxic leachate, is expected to be useful until the year 2020. The dump site is situated over a deposit of floodplain material consisting of sand and gravel, making it more likely that toxic leachate is seeping into waterways, affecting water quality and wildlife habitats. As you can see from the aerial photo below Hipolito Renteria is located near agricultural activity, which, as described above, can be harmful due to leaching of heavy metals, most significantly lead, which is a known neurotoxin.

With a lack of funds to effectively manage the landfill, air quality in the vicinity of the site is significantly compromised by dust and particles and the generation of methane can potentially result in spontaneous fires. In October of 2015 fire in the landfill spread to the extent that it took a dispatch of police and firefighters five hours to get waste pickers working at the site to safety and control the flames. Not only does methane contribute to the dumpsite catching on fire, but a 2011 study published on bioclimatic shifts associated with the Mexicali landfill showed that there is a one to two degree Fahrenheit increase in temperature in and around the garbage dump. The study determines that a change in land use from native soil to a garbage dump significantly changes the surrounding atmospheric behavior because of the heat generated.

Mapa de calles de EJIDO HIPÓLITO RENTERÍA

Disassembly at Mexicali's Hipolito Renteria Final Disposal Site

The program's baseline study shows that there are an estimated one hundred and fifty wastepickers collecting electronic waste at Mexicali's Hipolito Renteria final disposal site. Although most of the waste pickers at the site sell electronic waste by weight, it was found that 20% use potentially harmful techniques to dismantle devices (for instance, in some low-income countries, informal recyclers practice leaching of precious metals with the help of acids or burn cables to secure copper wire, which produces known carcinogens called dioxins). These methods for dismantling e-waste could result in adverse health conditions and environmental degradation. Although the waste pickers interviewed did not admit to burning cables in their dismantling efforts, evidence was apparent at the final disposal site (see image from baseline study below).

Figure 23: Evidence of burning (credit UABC)

Strategies for Keeping Electronic Waste out of Final Disposal Sites

Some of the strategies developed to keep e-waste out of dumpsites include collection systems, take-back programs, and aggressive legislation. E-waste collection systems for example have been shown to have a dramatic effect on the percentage of electronic waste that goes to landfill, particularly for large appliances like fridges, air conditioners and washing machines. Take-back programs have also proven to be beneficial. One example of a successful take-back program was initiated by the Chinese Government in August 2009. The program allowed residents a 10% discount on new home appliances when they returned e-waste to formal collection sites. The product types accepted by the program were TVs, fridges, washing machines, air conditioners and computers; and any of the aforementioned electronics could be applied toward any new electronic product. From 2009 to 2011 57,609,000 large appliances had been collected as a result of the program. The initiative shows that trade-in programs can divert the flow of e-waste from final disposal sites. Legislation is another strategy used to keep e-waste out of dumpsites (see section on *Regulations*).

As e-waste in final disposal sites has been known to be particularly detrimental to the health of informal recyclers and local residents as well as the environment, one goal of an effective management system is to deter used electronics from dumps and landfills. Although a few affordable leachate management strategies exist, for instance gravel filtration, keeping electronics out of final disposal sites is the most effective means for ensuring public and environmental health. Through the implementation of many of the strategies discussed in this document, e-waste can be effectively diverted and appropriately recycled.

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Material Flow Analysis

The goal of the material flow analysis (MFA) is to estimate the quantity of several used products that are generated each year, and of those, how many are thrown out. By generated, we mean ready for end-of-life management. For example, if a used product is given to a friend, put in a closet, or sold to a neighbor, it *is* not considered to be generated. If instead it is brought to a recycler, shop, or thrown out, it *is* considered generated. The distinction is important, because we do not seek to interrupt reuse opportunities, but only to make sure that used products at the end of their lives are managed properly. Additionally, we look at the international import and export flows through the Mexicali border crossing.

Overall used electronics generation approach

We performed separate analyses for the residential and commercial sector, and then combined the totals. To do so, responses to surveys about electronics ownership and end–of-life habits were scaled to the population and number of employees in Mexicali.

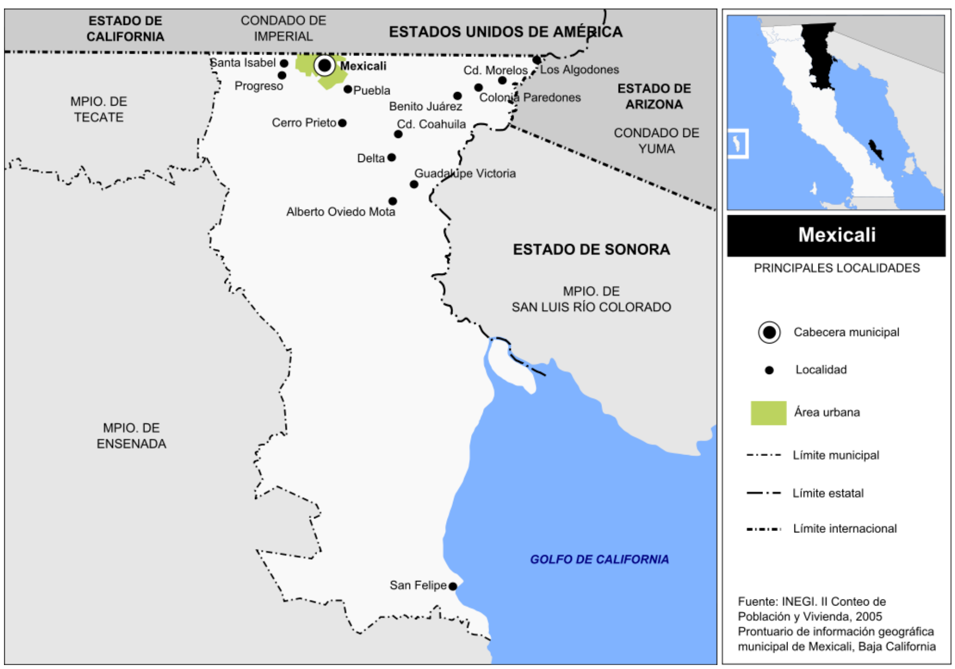


Figure 24: Municipality and urban area of Mexicali (INEGI)

In order to scale the survey results to the city level, the number of residences in the city of Mexicali[4] was estimated. It is important to distinguish the city from the larger municipality in this regard, as shown in Figure 24. In 2010, the municipality population was estimated at 938.7 thousand with 265.7 residences and on average 3.52 people per residence, while the city population was 698.8 thousand. The city population grew to about 737 thousand in 2015. From an analysis of the 2015 INEGI ENDUTIH survey microdata, there are an average of 3.42 people per residence in the urban area of Mexicali in. We can estimate that there were 202 thousand urban households in 2010.

[4] Note that INEGI has produced a useful tool for visualizing the number of households at the neighborhood level, along with other demographic information: http://www.beta.inegi.org.mx/app/mapa/inv/

Since the surveys were conducted in 2015 and insights are sought for future years, we used historic population data[5] to project forward the current and future population. As shown in Figure 25, Census data is available through 2010, and forecasts are made onwards based on population growth rates. Assuming a constant rate of people per household, we can estimate number of residences based on the population estimate. We could scale the survey results based on population alone, but some products like refrigerators and washing machines are better represented on a per-residence basis. Table 2 lists the population and residence forecasts. We estimate that there were 215 thousand residences in 2015, which grew to 218 thousand in 2016 and could grow to 228 thousand in 2020 at current growth rates.

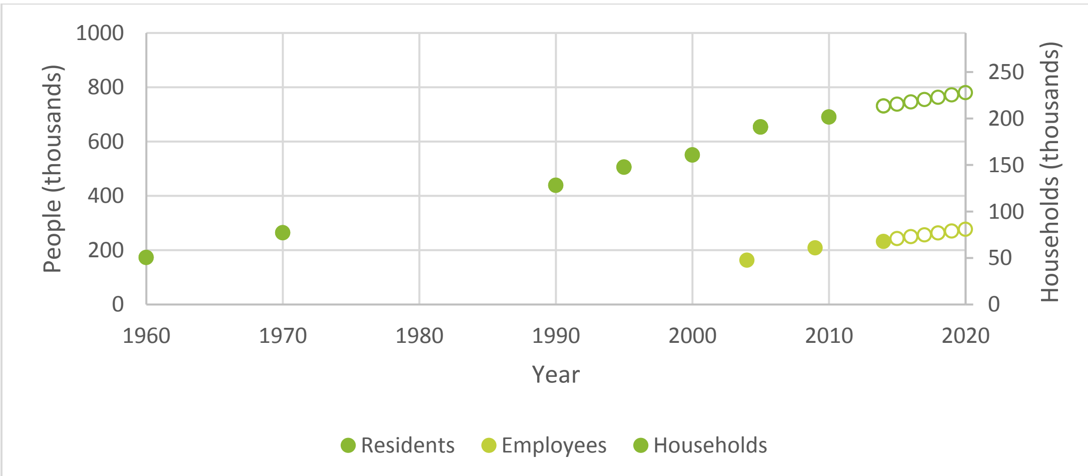


Figure 25: Historic urban population and employees of Mexicali (left axis) and households (right axis). Estimate in 2014. Forecast through 2020 based on 2000-2014 estimates.

Table 2: Forecast population and households and employees[6] in urban Mexicali

Type of estimate	Year	Population (thousands)	Households (thousands)	Employees (thousands)
Economic Census	2009			208.1
Census	2010	689.8	201.7	
Estimate / Economic Census	2014	730.8	213.7	231.7
Forecast	2015	737	215	242.2
Forecast	2016	746	218	249.2
Forecast	2017	754	221	256.1
Forecast	2018	763	223	263.0
Forecast	2019	771	226	269.9
Forecast	2020	780	228	276.8

[5] Source: http://population.city/mexico/mexicali/

[6] Source: http://www.inegi.org.mx/est/contenidos/proyectos/ce/ce2014/
Employees= Personal ocupado renumerado + Propietarios, familiares y otros trabajadores no renumerados + no dependientes de la razón social

Residential estimates

Surveys conducted in the fall of 2015 by UABC enabled Camanoe Associates to make estimates of the stock (number of items in the home, working or not) and end-of-life disposition of electronics (gift, reuse, throw out, etc.) in Mexicali. UABC surveyed 400 people; 398 responses representing 1617 inhabitants were included in the analysis (two responses lacked number of people in households). The per-household or per-person rates of ownership were calculated from the survey respondents, and scaled to the city population as shown in Figure 27. We selected a set of tracer products for study.

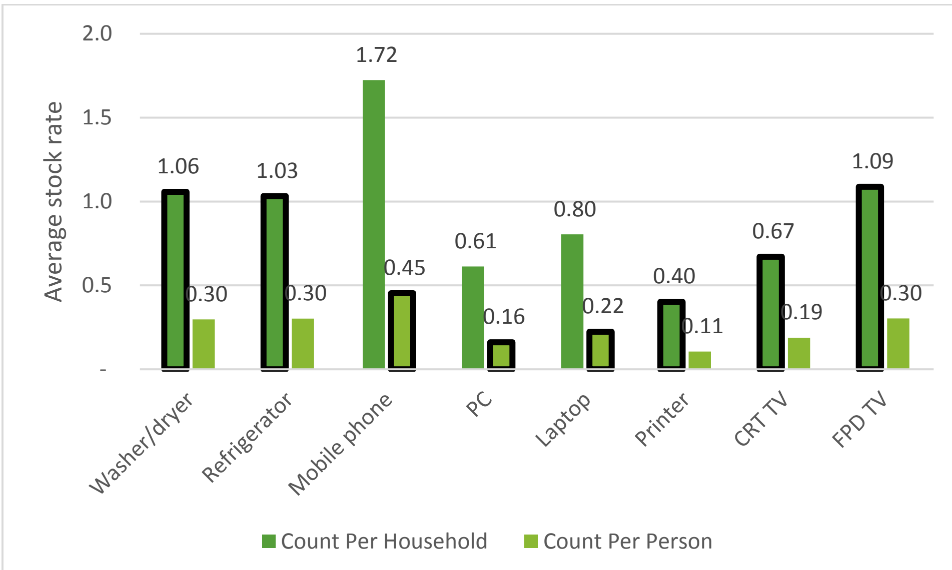


Figure 26: Count of electronics currently in homes in Mexicali, per household and per person. Black outline indicates the rate that was used in the analysis for that product.

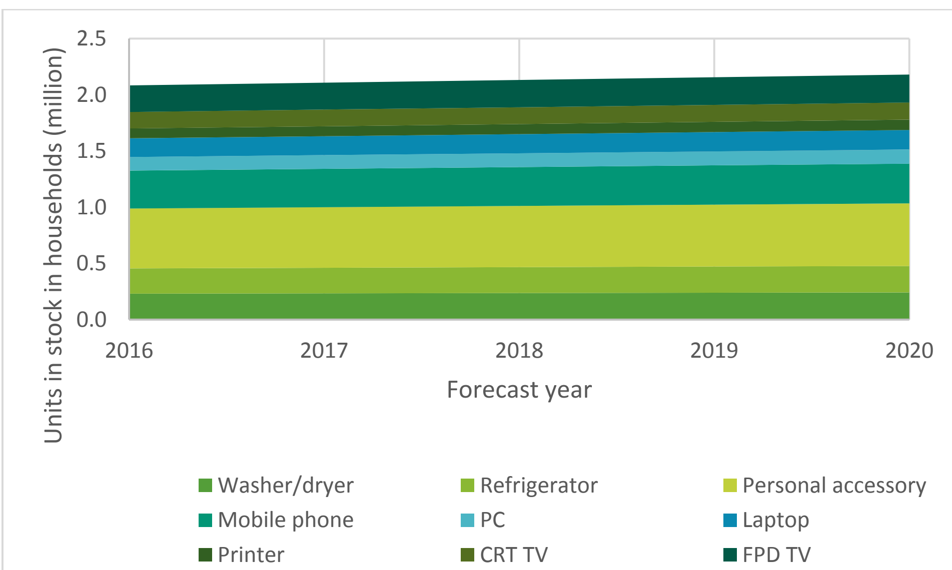


Figure 27: Estimate of number of units working or not in households, or stock, in Mexicali through 2020.

Additional information on flows was taken from national surveys conducted in 2011 and again in 2013 for a related project with the Commission for Environmental Cooperation (CEC). The 2013 survey included 1245 households, 42 of which were from Baja California. The questions focused on computers and monitors, and asked details about each one the house had ever owned.

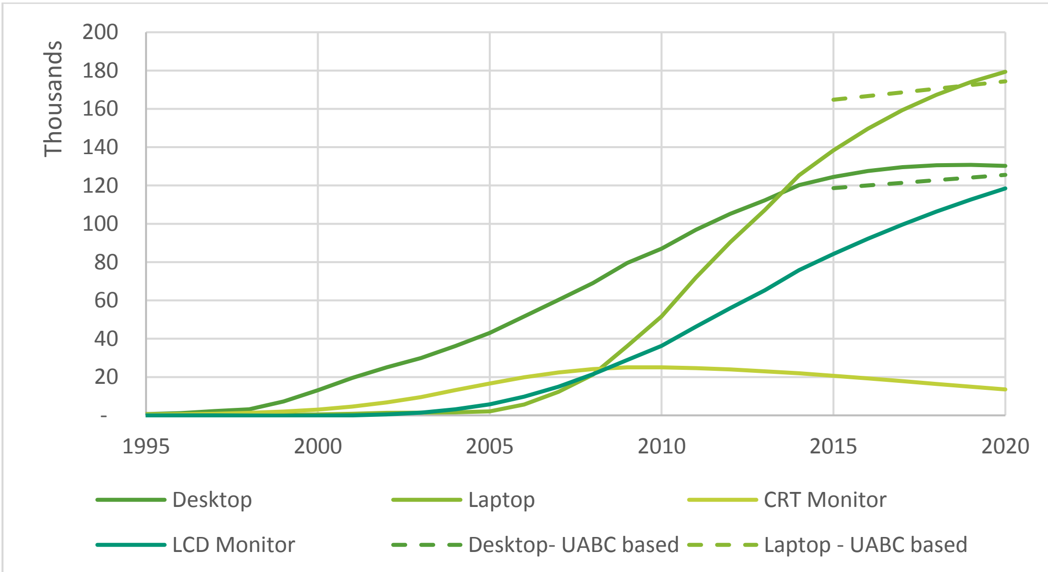


Figure 28: Estimation of computer and monitor stock using the sales-lifespan approach with national survey data scaled to Mexicali (solid lines), compared to the stock of computers estimated from UABC surveys.

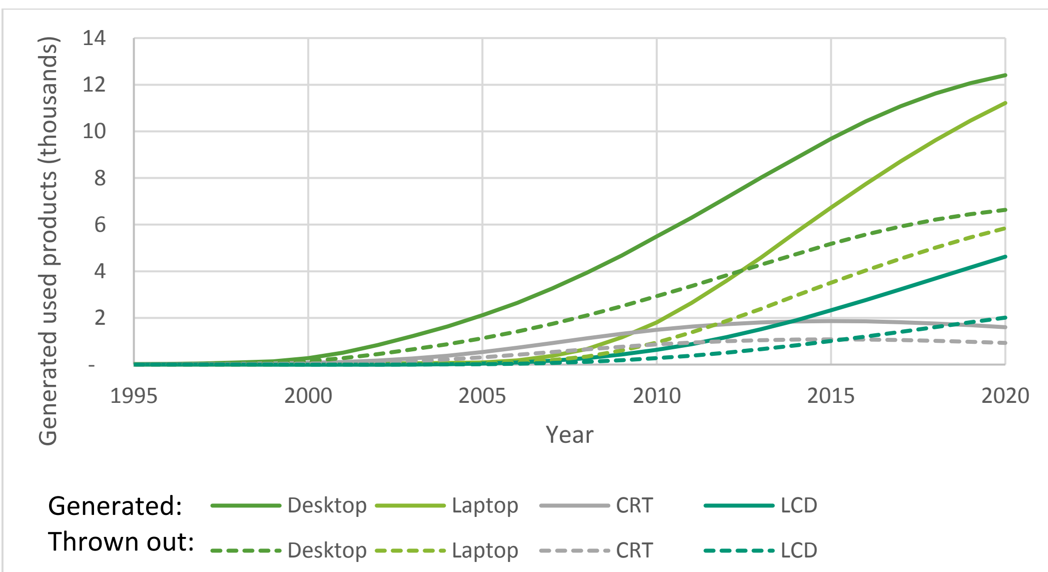


Figure 29: Estimates and forecasts of generated residential used computer and monitor products in urban Mexicali. Solid lines represent total generated, while dashed lines represent those that were "thrown out".

Using the survey responses, we estimated the lifespan of these products with the Sales Obsolescence Method described in (Miller, Duan et al. 2016). We scaled estimates and forecasts of Mexican sales of these products to the Mexicali population. While this model is intended to estimate the generation of electronics by combining lifespans and sales data, it can also estimate the stock, shown in Figure 28. The national parameters in the model were calibrated to approximate the stock in Mexicali based on the UABC survey estimates. In Figure 29, the quantity of computer and monitor products generated each year is presented in the solid lines. The dashed lines indicate those which are expected to be "thrown out" versus sold to a shop.

It also asked how many other types of electronics and electricals had been generated in the past year and how they were dispositioned. We use the Survey Scale Up Method described in (Miller, Duan et al. 2016), developed by (Kahhat R 2012), to estimate the quantities undergoing various end of life dispositions. The survey results about generated products per households are scaled to the number of households in Mexicali.

The Mexican agency INEGI also does an annual survey of technology use in households; the most comprehensive version is for the year 2015. The questions posed in that survey, however, ask yes/no presence of functioning equipment, which does not enable estimating stock since many households have multiples of the same product, or products that are not functioning.

In Figure 30, we forecast the quantity of units that will be thrown out through 2020. In Figure 31, we estimate the total weight of these units by multiplying by the unit weights found shown in **Error! Reference source not found.**. While the quantity of mobile phones dominates, since they are light, the heavier devices dominate the weight. Hardcopy devices like printers and scanners are notably high. This is likely because there exist fewer reuse and recycle channels for printers as compared to other products.

Considering that there are three sets of pepenadores seeking to pick valuable items from the trash thrown out by residences, it is quite likely that not all of the items thrown out are lost in the landfill. The authors observed that the pepenadores tended to collect one type of item at a time (eg. paper, plastic, metal, etc.) so they may prefer to collect one type of e-waste at a time, or just select higher value items. This is unknown, so we assume equal rates of removal from the trash. For this study, we estimate roughly half of what is thrown out is currently picked by pepenadores while the other half is lost in the landfill. This latter fraction is the highest priority for this project. The charts below reflect the total estimates of the items thrown out.

Note that while we've modeled refrigerators here, it is quite unlikely that they will end up in the landfill. According to research by Dra. Ojeda, the municipal waste workers will only collect refrigerators on sporadic special days. On other days, they will likely end up at a scrap metal dealer. There is a center in the city for recycling items with refrigerants, including air conditioners, apparently the economics are less attractive.

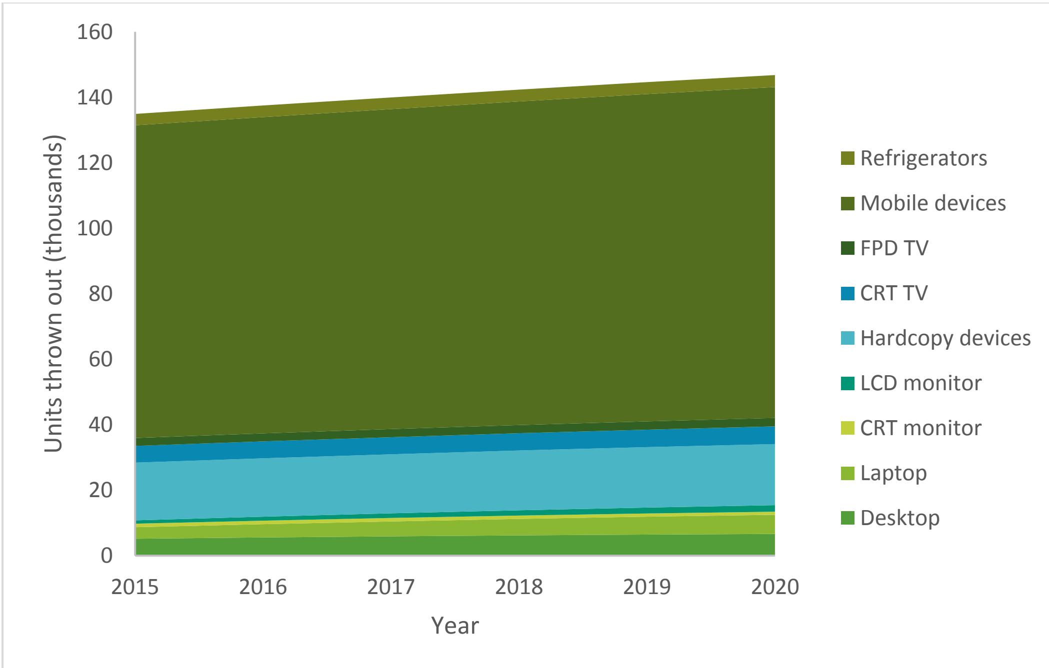


Figure 30: Estimates of residential units thrown out, quantity in thousands, by year 2015 to 2020

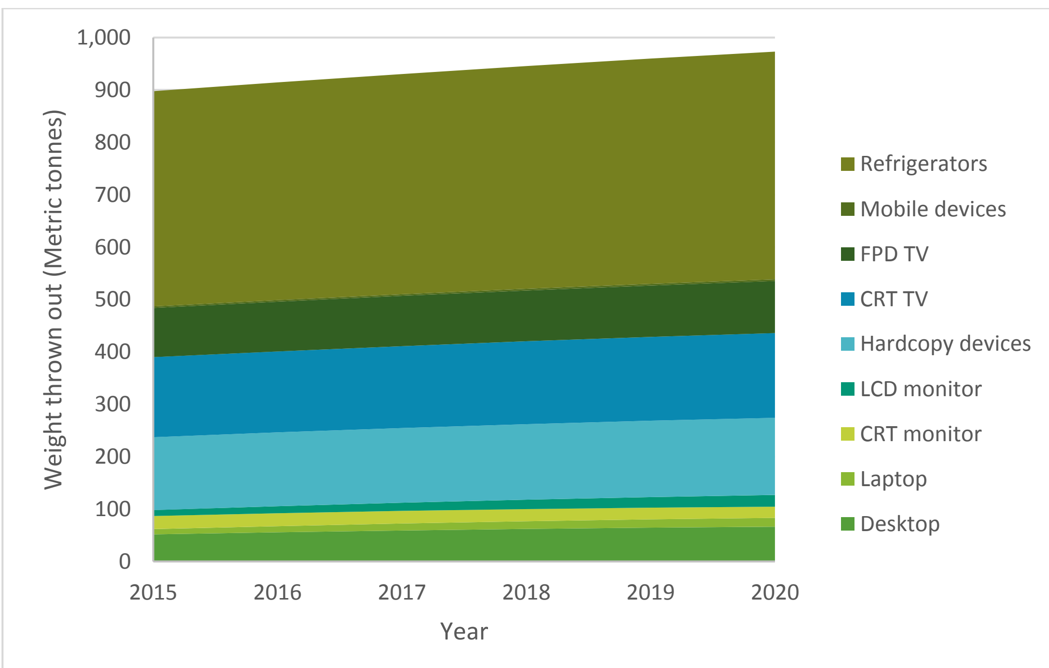


Figure 31: Estimates of residential units thrown out, weight in metric tonnes, by year 2015 to 2020

Table 3: Residential data sources available for products of interest and the geographic scope. Bold indicates use.

Product	UABC 2015 stock & EOL type	CEC 2013, time series (purchase, stock, lifespan, EOL type)	CEC 2013: discard in last 12 months, type	INEGI 2015 Microdata: Working stock	Pew Research, Deloitte, COFETEL
Laptops	**Mexicali**	**Mexico / BC**		Mexico/Mexicali	
Desktops	**Mexicali**	**Mexico / BC**		Mexico/Mexicali	
CRT Monitors		**Mexico / BC**			
Flat Screen Monitors		**Mexico / BC**			
TV: CRT	**Mexicali**		**Mexico / BC**	Mexico/Mexicali	
TV: Flat Panel	**Mexicali**		**Mexico / BC**	Mexico/Mexicali	
Printers	**Mexicali**		**Mexico / BC**		
Refrigerators	**Mexicali**		**Mexico / BC**	Mexico/Mexicali	
Washer/Dryer	**Mexicali**		**Mexico / BC**	Mexico/Mexicali	
Cell phone	**Mexicali**				Mexico

Table 4: Product unit weights assumed in this project.

Equipment	Weight (Pounds)	Weight (kg)

Desktop	22.0	10.0
Laptop	6.4	2.9
CRT Monitor	50.5	22.9
LCD Monitor	24.6	11.2
CRT TV (weighted average)	66.0	29.9
CRT TV 19"	41.0	18.6
CRT TV > 19"	73.0	33.1
LCD TV	85.3	38.7
Mobile Device	0.200	0.09
Refrigerators*	260	117.93
Hard copy devices	17.4	7.89

Source for all products except refrigerator: (US EPA ORCR 2011)

**Source for refrigerator: http://www.doityourself.com/stry/what-is-the-average-refrigerator-weight#b*

Commercial estimates

The approach used to calculate the generation of selected end-of-life electronics will be explained in the following paragraphs. First, the stock of computers and monitors (in use by commercial entities) was determined using national surveys conducted in 2011 and again in 2013 for a (yet unpublished) related project with the Commission for Environmental Cooperation (CEC). Ownership per employee for each sector, obtained from the surveys, and data related to number of employees per sector, obtained from the 2014 Mexican Economic Census were used to predict the stock of computers and monitors in the municipality of Mexicali. Table 5 presents the number of employees for the Municipality of Mexicali for the years 2004, 2009, and 2014.

Table 5: Employees in the Municipality of Mexicali (Mexican Economic Census, 2014)

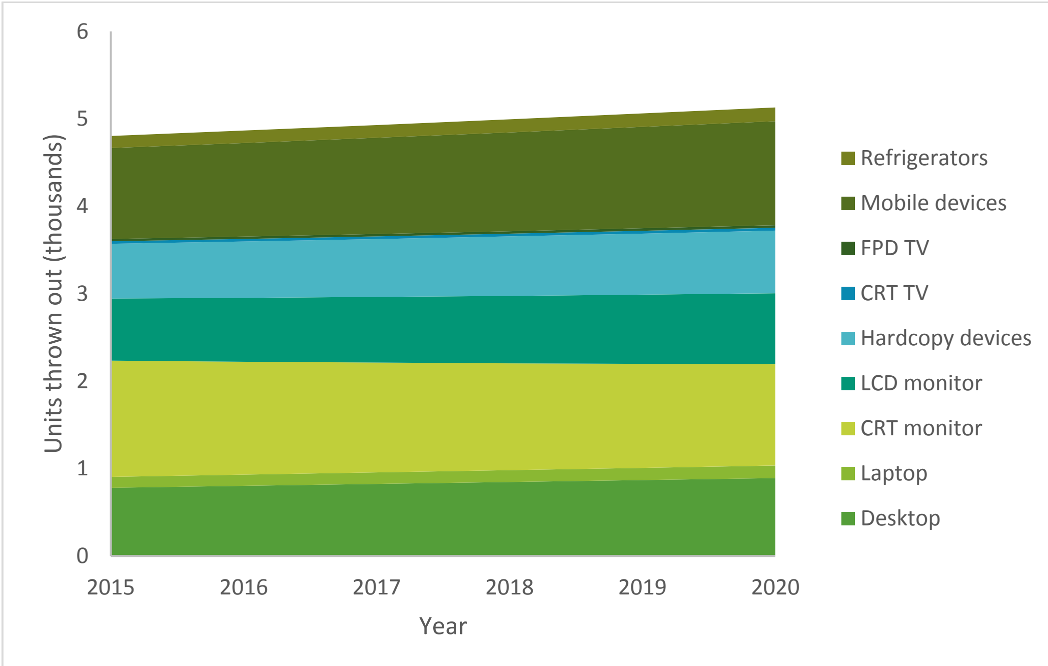
Sector	2004	2009	2014
Agriculture, Forestry, Fishing and Hunting	927	992	1,561
Mining	247	209	78
Utilities	4,901	6,213	1,510
Construction	7,246	8,357	6,384
Manufacturing	62,015	72,854	73,763
Wholesale Trade	7,058	10,384	12,199
Retail Trade	31,728	37,618	39,465
Transportation and Warehousing	5,034	5,683	5,063
Information and Cultural Industries	1,232	1,791	946
Finance and Insurance	609	1,245	1,311
Real State and Rental and Leasing	1,789	3,160	3,107
Professional, Scientific and Technical Services	2,500	4,397	4,254
Enterprises	94	0	16
Administrative and Support, Waste Management and Remediation Services	4,555	7,778	19,851
Educational Services	3,070	4,475	5,481
Health Care and Social Assistance	3,068	6,249	7,337
Art, Entertainment and Recreation	920	1,780	2,939
Accommodation and Food Services	9,631	13,652	15,412
Other services – except Public Administration	8,413	11,570	20,262
Public Administration (Estimated)	7,544	9,654	10,750

Then, the flows of the selected equipment at the end-of-use phase was calculated based in national surveys conducted in 2011 and end-of-life scenarios developed and validated by Kahhat and colleagues in 2012 and Miller and colleagues in 2013. Also, generated EOL electronics per employee and preferred management option were calculated based on the surveys. Important to mention that these surveys requested information related to the end-of-use action taken by the business sector, as shown in Table 6. Finally, data for the baseline year, 2014, was extrapolated to 2020 based on the estimated growth of employees in Mexicali. In addition, the forecast relied on the Mexican Economic Census, developed in 2004, 2009, and 2014 (presented in Table 2).

Table 6: End-of-use management options and scenarios

End-of-use management option	Reuse	Recycle	Landfill	Exports
Returned to leasing company	0.7	0.3		
Refurbished under contract to private service provider	0.7	0.3		
Recycled under contract to private service provider		1		
Disposal under contract to private service provider		0.2	0.8	
Returned to manufacturer		1		
Storage off-site				
Sold	0.7	0.3		
Donated	0.6	0.4		
Disposal via curbside garbage collection		0.2	0.8	
Recycled via curbside recycling program		1		
Returned to municipality during a special collection event		1		
Returned to collection depot for recycling/refurbishing		1		
Other				1

In Figure 32, we estimate the quantity of units and in Figure 33 the weight thrown out by all businesses, and then by small businesses. We are interested in separating small businesses, those with under 50 employees, because they are less likely to have the resources to properly manage their used electronics. Since they are unlikely to be properly managing their used electronics, they should be included in the new program along with residents. Based on INEGI data, we estimate small businesses to have 16% of the employees and thus are estimated to generate 16% of the used electronics.



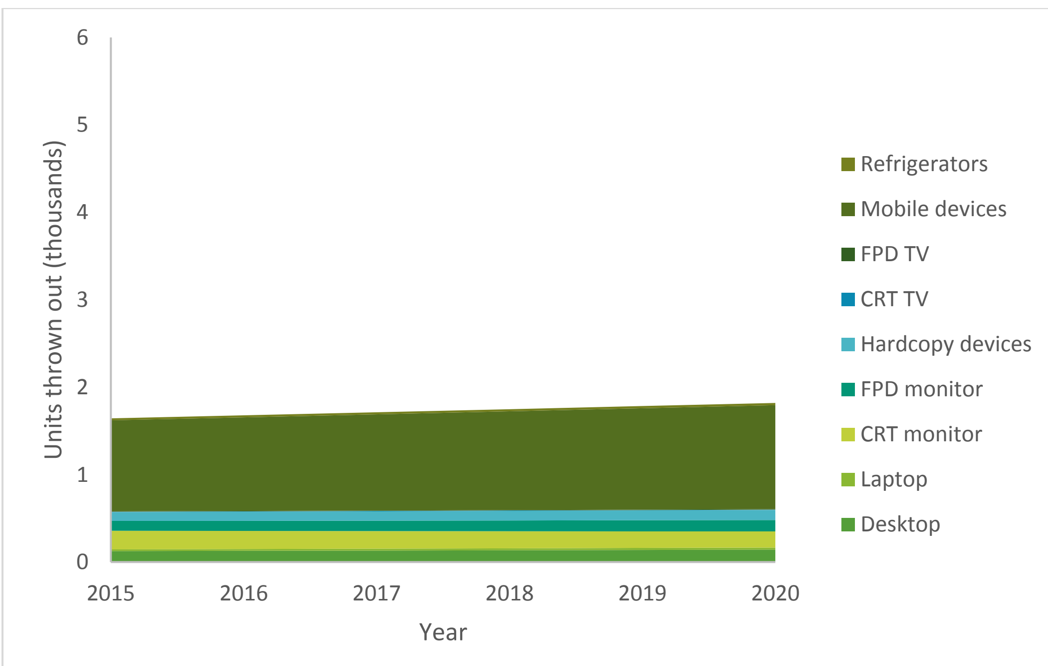
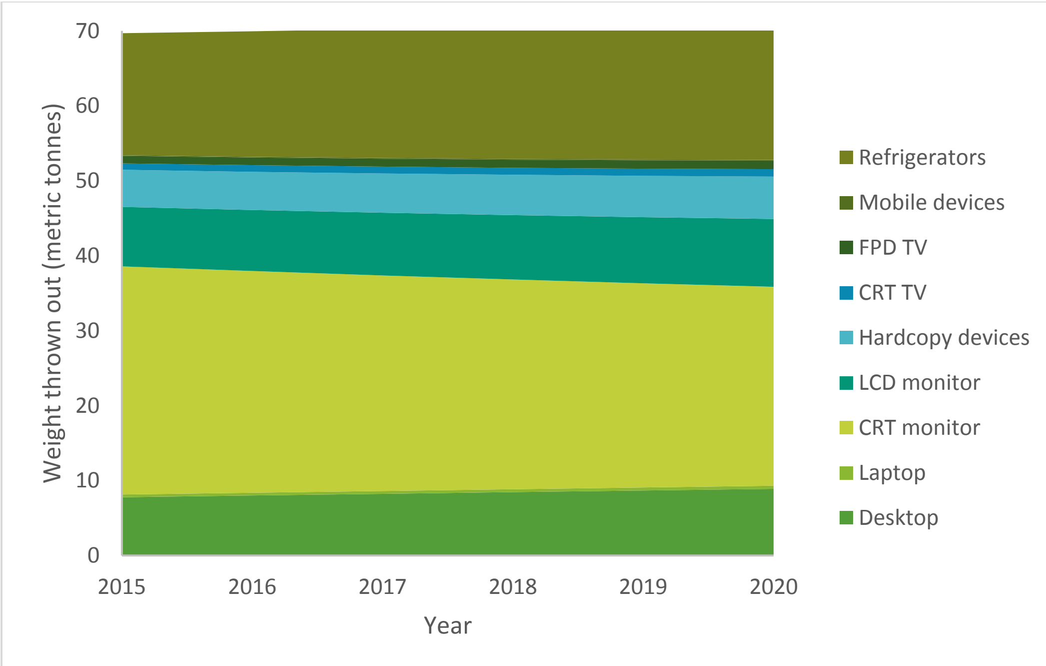


Figure 32: Estimates of commercial units thrown out, quantity in thousands, by year 2015 to 2020. All businesses (upper), small businesses (lower).



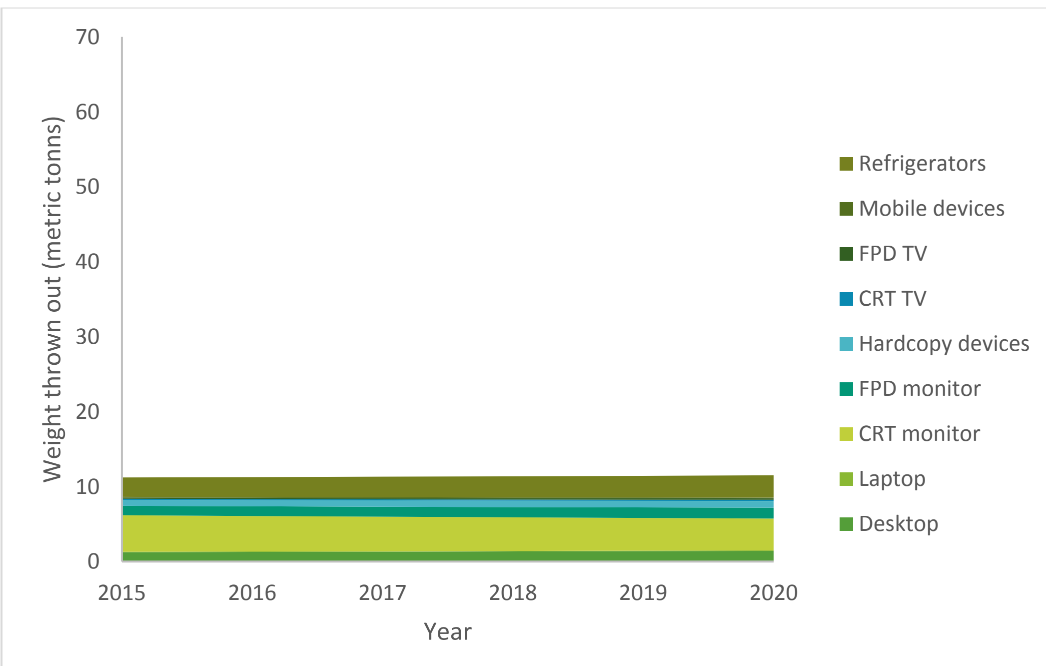


Figure 33: Estimates of commercial units thrown out, weight in metric tonnes, by year 2015 to 2020. All businesses (upper), small businesses (lower).

Combined Residential and Commercial Estimates

In Figure 34 and Figure 35, we combine the quantity and weight estimates, respectively, of residential and small business generated products being thrown out. The fraction of this not currently collected by pepenadores should be managed. The bulk of the quantity derives from residential users, compared to small businesses. Thus efforts should be targeted at gathering electronics from residential users.

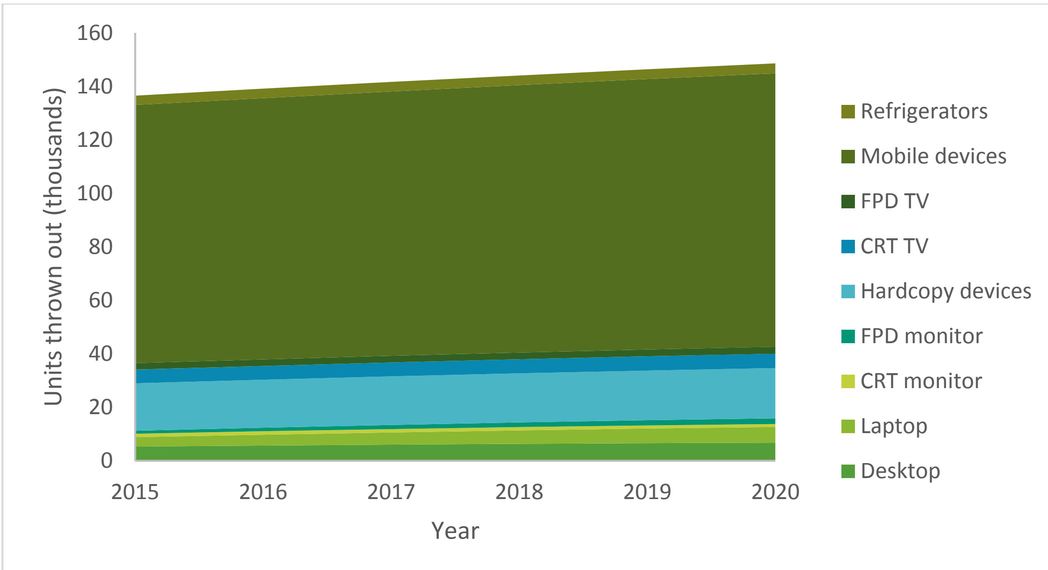


Figure 34: Estimates of combined residential and small business units thrown out, quantity in thousands, by year 2015 to 2020.

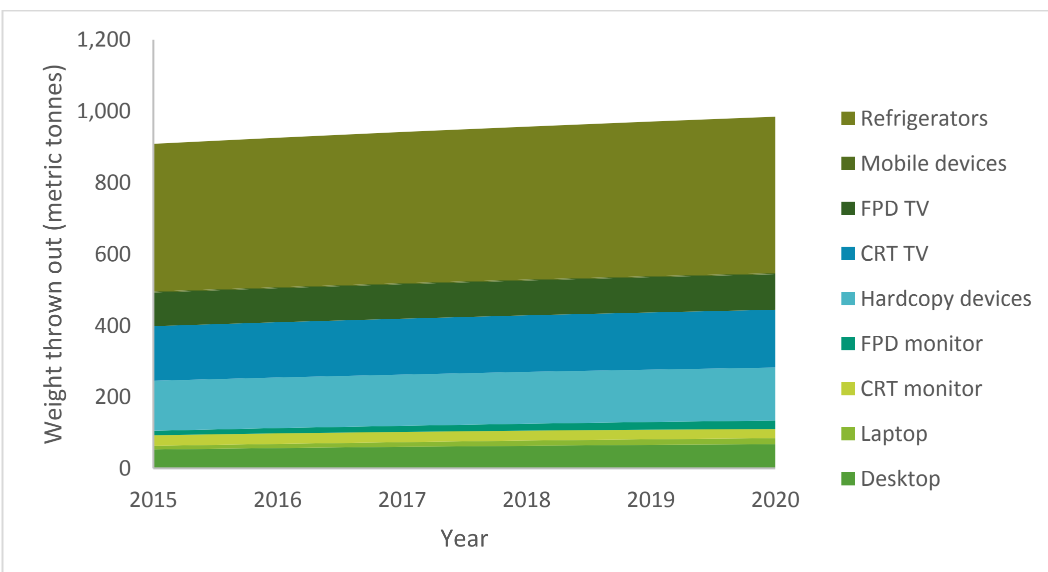


Figure 35: Estimates of combined residential and small business units thrown out, weight in metric tonnes, by year 2015 to 2020.

Import and export trade flows across Mexicali border crossing

As Mexicali is situated on the border of Mexico and California, hence the name, we sought to investigate the flow of new and used electronics across the border in recent years. Where possible, the trends were compared with the source of purchased electronics reported by survey participants.

Overall approach

Detailed trade data was purchased from Quintero Hermanos, a Columbian-based company which operates a database on SICEX.com. The data was assessed for years 2013-2015, as they represent the most recent trends. This data source was also used in a prior project with the CEC, and the data was found to be reliable. The following detailed data fields are available for imports and exports:

- Date yyyy-mm-dd
- Country of Origin / Destination
- Product Schedule B Code
- Product Description by Schedule B Code
- Product Description by Schedule B Code Country
- Harmonized Code Product English
- Harmonized Code Description English
- TOTAL Quantity
- Measure Unit Quantity
- TOTAL FOB Value US
- FOB Value per Unit US
- TOTAL Gross Weight Kg
- Type of Transport
- Custom

One objective of using detailed trade data is to distinguish the traded products that are likely new compared to those that are likely in a used state. A method developed by (Duan, Miller et al. 2014) provides a complex means to do so; in this study, we follow a slightly less complex approach. As shown in Figure 28, the detailed trade data is arranged by the export (or import) unit value and the export (or import) quantity. Since the used products tend to be less expensive than the new products, we find an appropriate Used-New threshold. The products that are lower than the threshold are classified as "used" while those greater are classified as "new".

For this study, we approximated the Used-New threshold by analyzing prices found on the interpersonal goods exchange website, *Mercado Libre*. Noting that products come and go on the website, we recognize that this analysis is a snapshot of July 2016 that is hopefully representative of the typical distribution of products at any given time. We exported the price details for all items for sale within a category, defined by the product type, Baja California location, and used versus new designation. Prices were converted to USD to be consistent with the currency in the trade data. We then found the frequency distribution of the prices of these categories of items, and compared used and new.

Some products are assumed to be all-new or all-used. Printers have very limited reuse potential, and therefore all traded products are assumed to be new; scrap printers would likely be traded as scrap, which we cannot separate out in the data. CRTs are no longer in production regionally, and therefore all CRT monitors and TVs are assumed to be used.

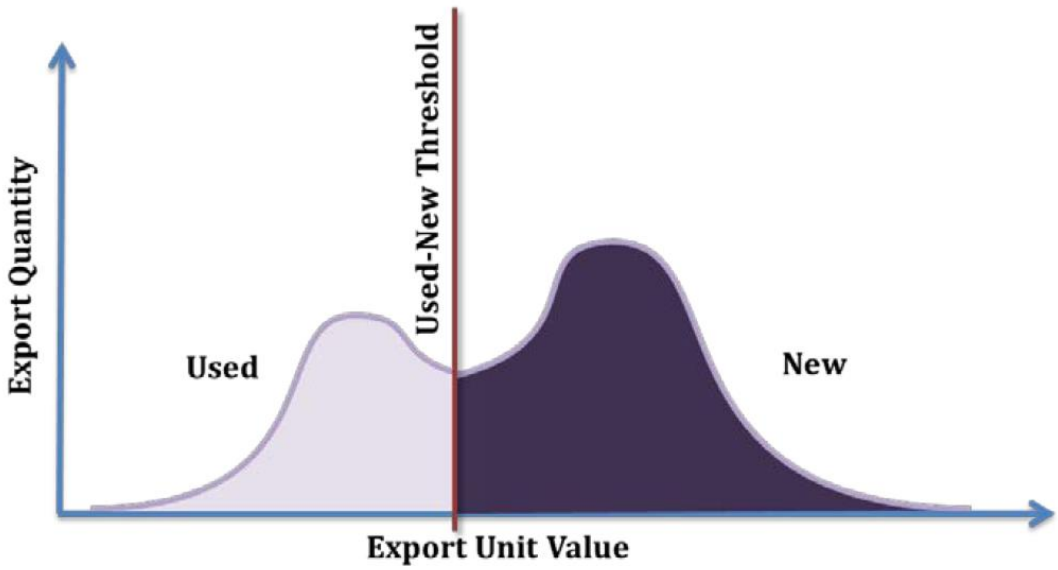


Figure 36: Illustration of sum of Used and New export quantities from disaggregated trade data with Used-New threshold differentiating underlying used and new distributions

Product prices on *Mercado Libre*

Figure 37 presents the price distribution for computers, used and new, found on *Mercado Libre* in July 2016. While the PC/desktop graph more clearly distinguishes used from new, there is a shift in distributions for laptops as well. US$225 was used as the Used-New threshold for both products.

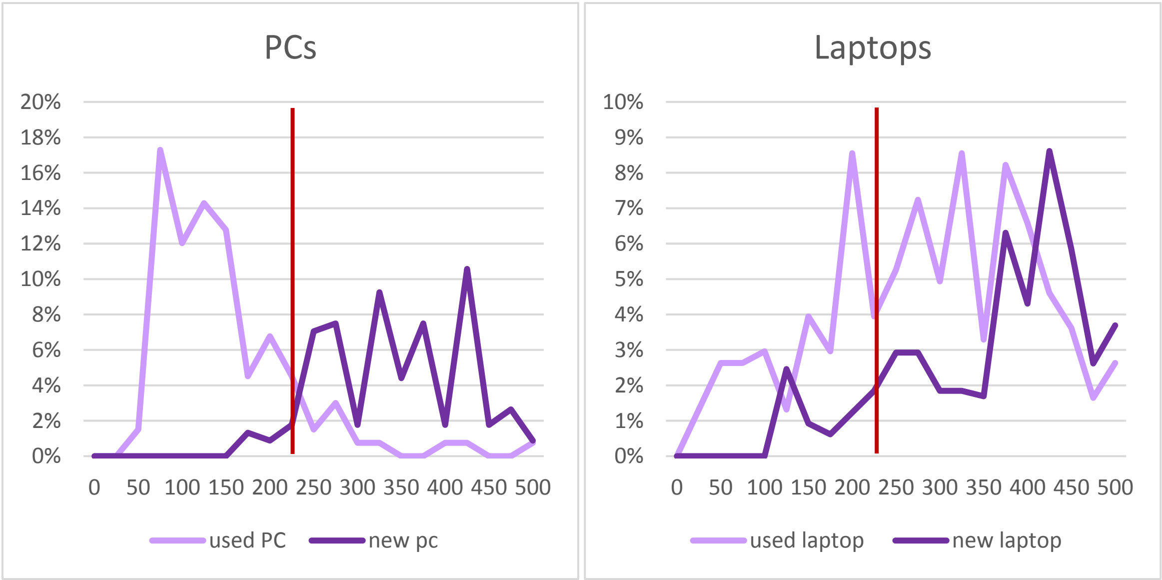


Figure 37: Price distribution of computers on Mercado Libre in Baja California in summer 2016; PCs / desktops (left), laptops (right). Price in USD. Sample sizes: used PC = 133, new PC =227, used laptop = 304, new laptop = 650.

In the case of flat panel display (FPD) devices, US$200 was chosen as a reasonable threshold. Prices from *Estado de Mexico* supplemented the few used FPD TVs available in Baja California.

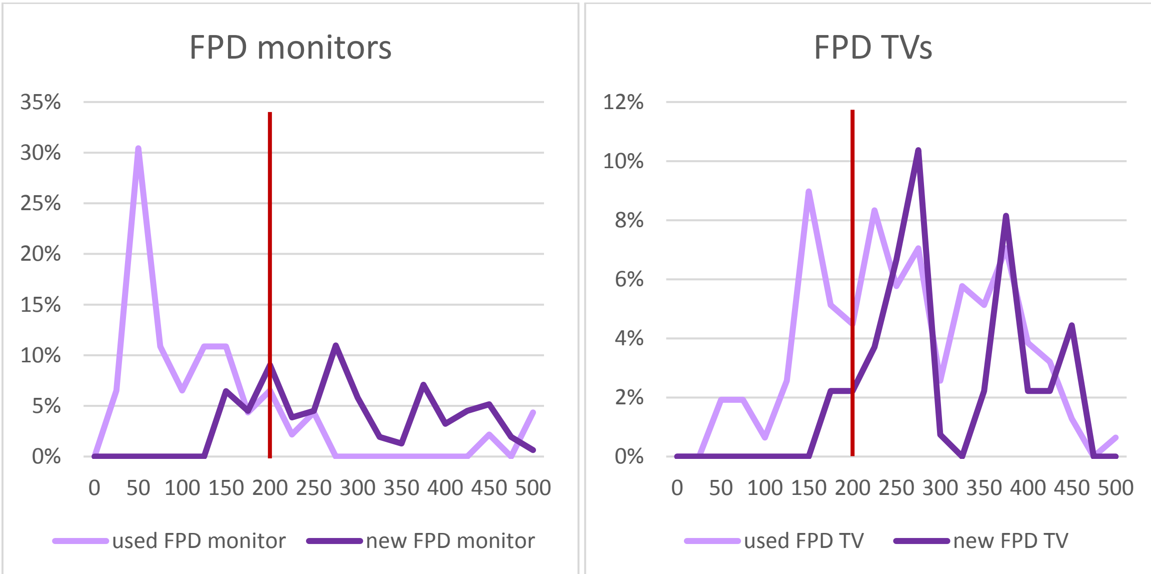


Figure 38: Price distribution of flat panel display (FPD) devices on Mercado Libre in Baja California in summer 2016; FPD monitors (left), FPD TVs (right). Price in USD. Sample size: used FPD monitor=46, new FPD monitor=155, used FPD TV = 156, new FPD TV = 135.

The threshold for cell phones was set at US$150, though we note considerable overlap in the distributions. In the case of refrigerators, on the site there was a wide price gap in used and new refrigerators; US$1000 was set as the threshold.

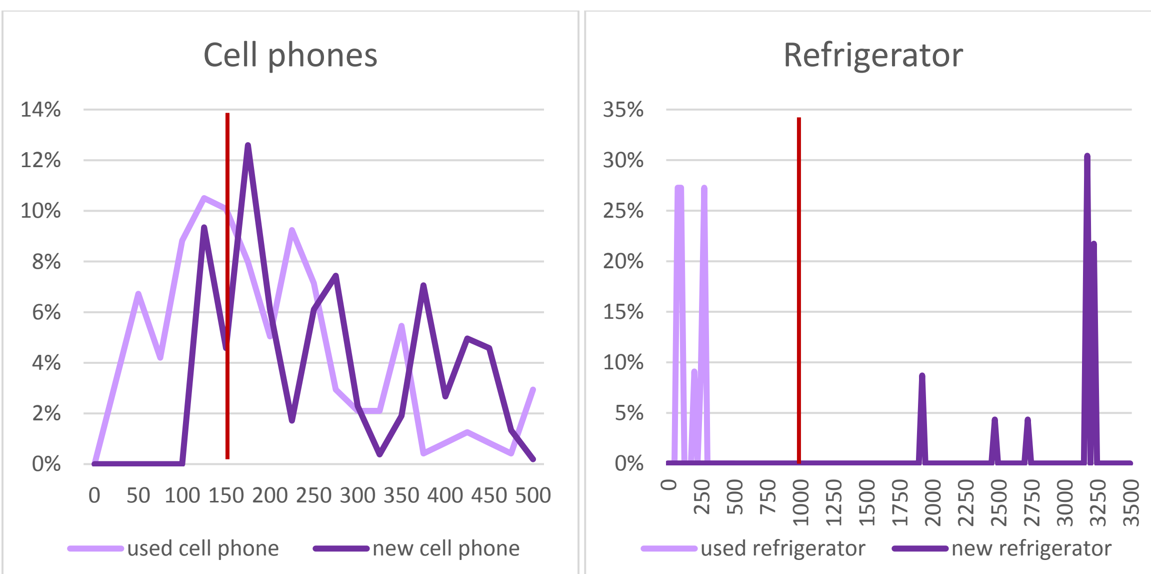


Figure 39: Price distribution on Mercado Libre in Baja California in summer 2016; cell phones including smartphones (left), refrigerators (right). Price in USD. Sample size: used cell phone = 238, new cell phone = 524, used refrigerator=11, new refrigerator=23.

Trade codes

We focused on trade data related to the tracer products of interest, and found corresponding trade codes, shown in Table 7.[7] The data source is described above in *Overall Approach*.

Table 7: Trade codes corresponding to tracer products of interest

Product description	Trade code
Fridges (incl. combi-fridges)	841821
Cathode Ray Tube Monitors	852821
Cathode Ray Tube Monitors	852822
Cathode Ray Tube Monitors	852841
Cathode Ray Tube Monitors	852849
Cathode Ray Tube TVs	852873
Desktop PCs (excl. monitors, accessories)	847141
Desktop PCs (excl. monitors, accessories)	847149
Desktop PCs (excl. monitors, accessories)	847150
Flat Display Panel Monitors (LCD, LED)	852851
Flat Display Panel Monitors (LCD, LED)	852859
Flat Display Panel Monitors (LCD, LED)	853120
Flat Display Panel TVs (LCD, LED, Plasma)	852872
Fridges (incl. combi-fridges)	841822
Fridges (incl. combi-fridges)	841829
Laptops (incl. tablets)	847130
Mobile Phones (incl. smartphones, pagers)	851712
Printers (f.i. scanners, multifunctionals, faxes)	844331
Printers (f.i. scanners, multifunctionals, faxes)	844332

[7] Note that we excluded 852812and 852813 for Cathode Ray Tube TVs, but those codes may be appropriate. Few CRT TVs were recorded using the trade code 852873.

Trade data results

From the analyses, we summed the quantity, gross weight, and free on board (FOB) value of the imported and exported used and new products. Beginning with imports, Figure 40 compares the quantity, Figure 41 compares the weight, and Figure 42 compares the value.

Note that in general, mobile phones dominates the quantity of items traded, but due to the relatively very low weight, they account for little of the total weight. Still, they increasingly dominate the value. This was the same trend observed for weight and quantity with the generation of products in Mexicali. Monitors and TVs made up a big share of the weight of the items imported, followed by printers.

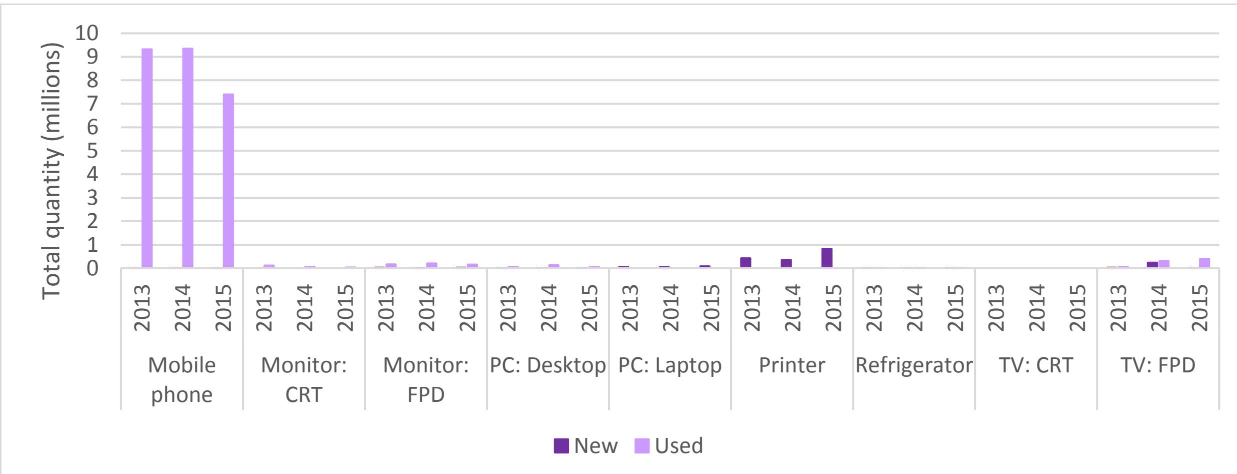


Figure 40: Quantity (millions) of new and used products imported through the Mexicali border crossing in 2013-2015

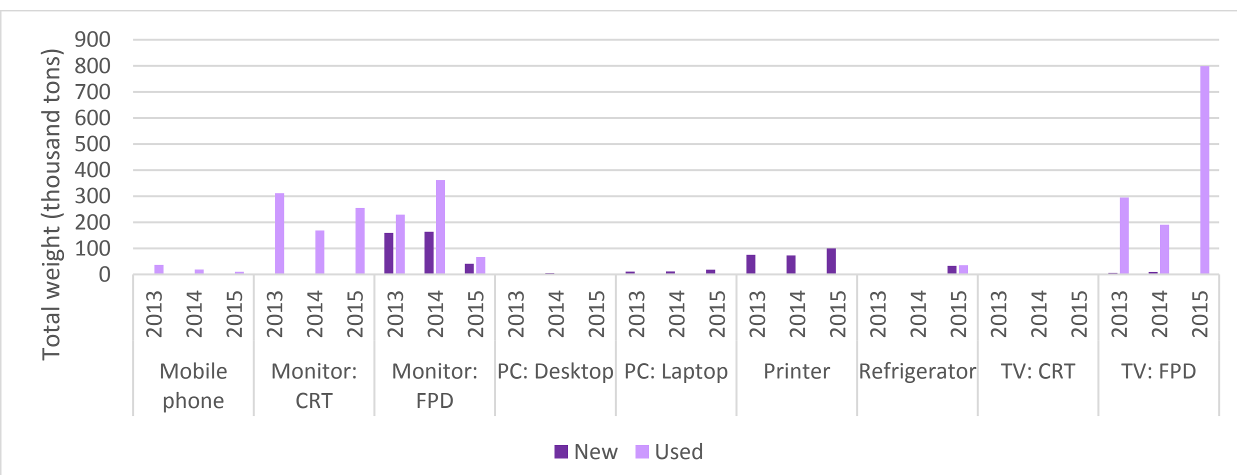


Figure 41: Gross weight (thousand tons) of new and used products imported through the Mexicali border crossing in 2013-2015

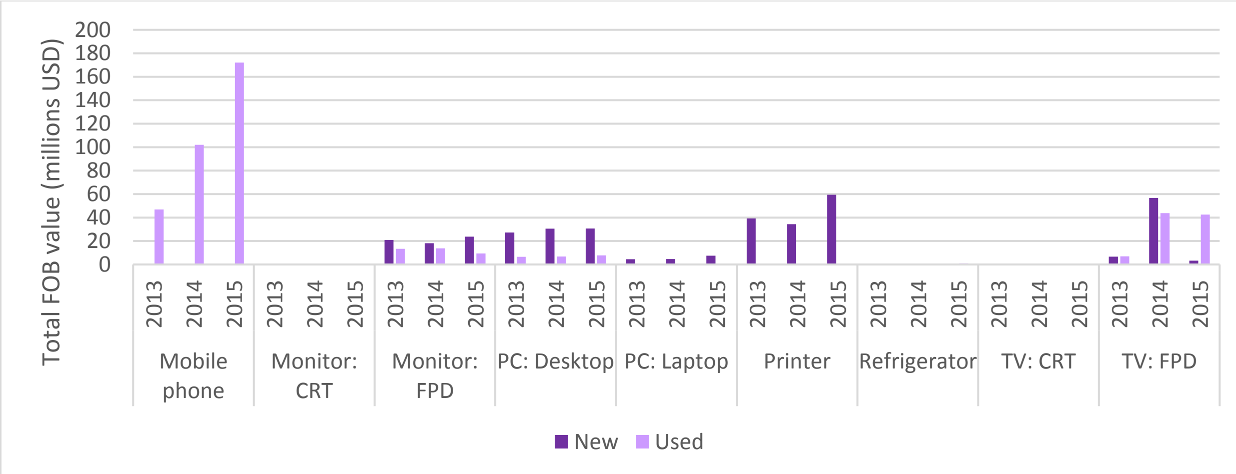


Figure 42: FOB value (millions USD) of new and used products imported through the Mexicali border crossing in 2013-2015

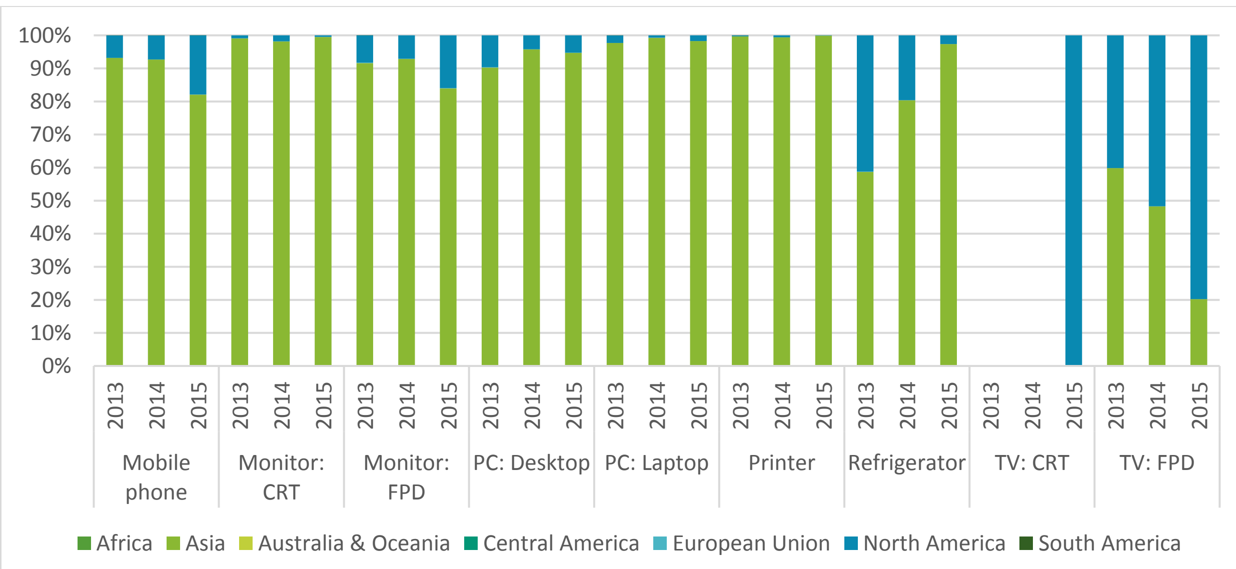


Figure 43: World region of origin for the imported products, by quantity

Looking at the countries and regions where these products came from, the vast majority originated in Asia. China was the main exporter, followed by Taiwan and South Korea. TVs and refrigerators were the only products with a higher North American origin. This may be due to the shipping weight of these products. Given that most products originated from Asia, it could be that some of the products previously assumed to by "used" were instead very low cost new products.

Turning our attention to exports, nearly 100% of the exports were destined for the US. Since this is a border with the US, that makes sense. However, some of these products may be re-exported for other countries. This is a challenge with trade data; the actual original country of origin is reported by the importer, hence why Asian countries are listed as the country of origin on imports, but the exporter only records the first stop on the journey. We can find import data from other countries that list Mexico as the origin, but without manifest data, we wouldn't be able to track that shipment back to the Mexicali border crossing.

Examining the quantity in Figure 44, weight in Figure 45, and value of the exports in Figure 46, we find the same trends with mobile phones as with imports. They have low weight, high quantity and high value. FPD TVs, have the highest value overall, while FPD monitors, and printers also have considerable presence.

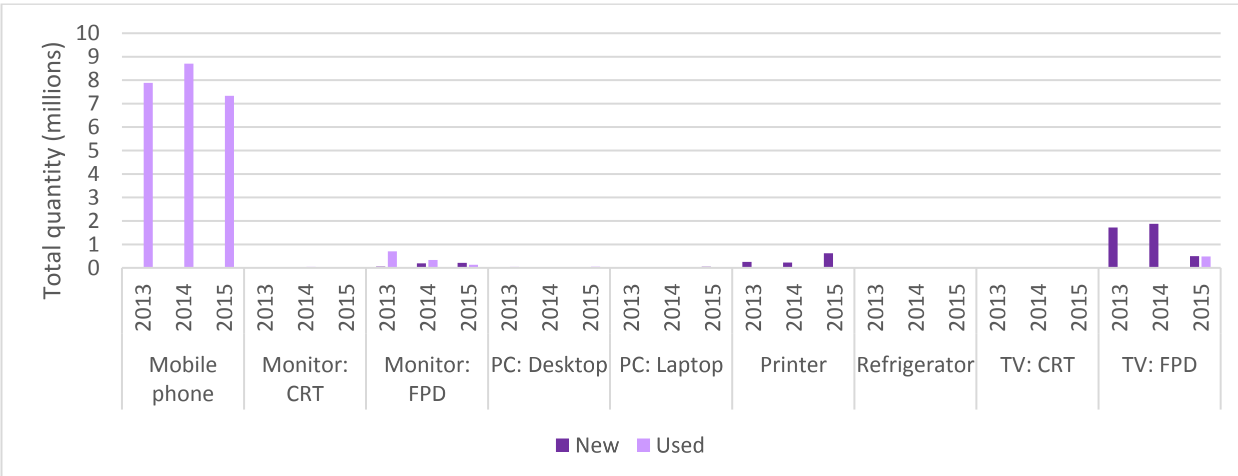


Figure 44: Quantity (millions) of new and used products exported through the Mexicali border crossing in 2013-2015

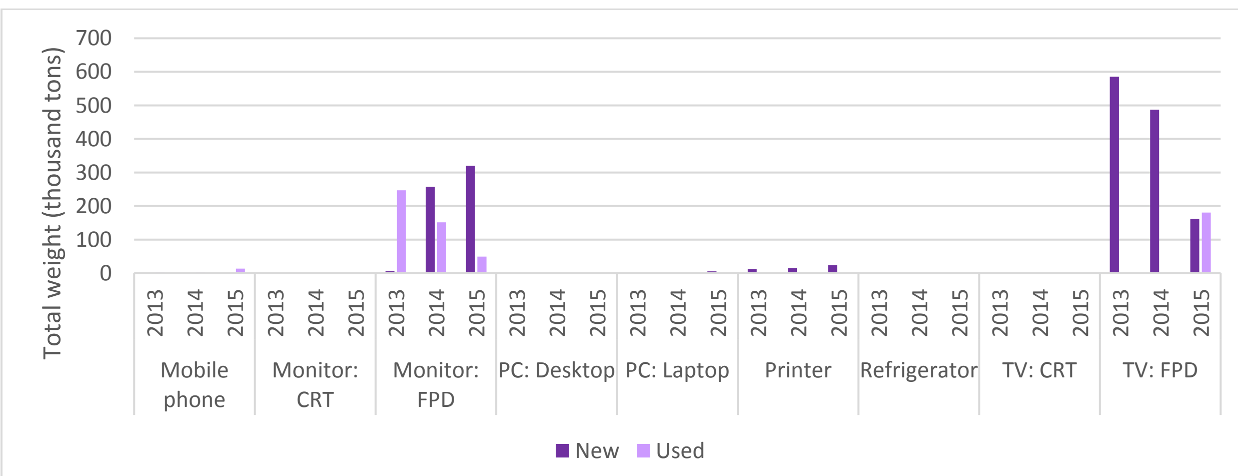


Figure 45: Gross weight (thousand tons) of new and used products exported through the Mexicali border crossing in 2013-2015

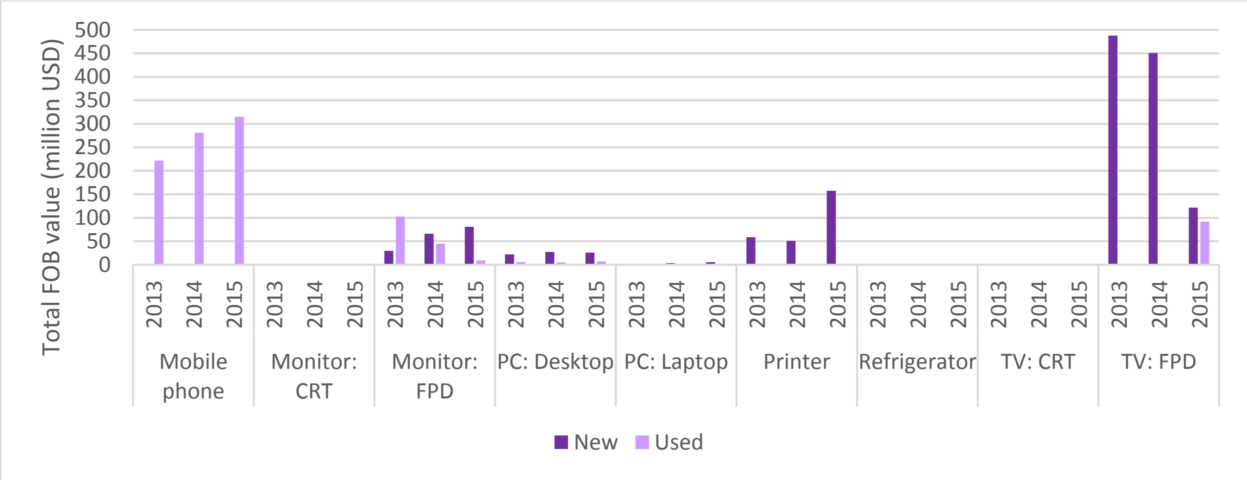


Figure 46: FOB value (millions USD) of new and used products exported through the Mexicali border crossing in 2013-2015

References and annex: Material flow analysis

Duan, H., T. R. Miller, et al. (2014). "Quantifying Export Flows of Used Electronics: Advanced Methods to Resolve Used Goods within Trade Data." Environmental Science & Technology **48**(6): 3263-3271.

Kahhat R, W. E. (2012). "Materials flow analysis of e-waste: Domestic flows and exports of used computers from the United States." Resources, Conservation and Recycling **67**: 67 - 74.

Miller, T. R., H. Duan, et al. (2016). "Quantifying Domestic Used Electronics Flows using a Combination of Material Flow Methodologies: A US Case Study." Environmental Science & Technology **50**(11): 5711-5719.

StEP (2016). Business Plan Calculation Tool for Manual Dismantling Facilities.

US EPA ORCR (2011). Electronics Waste Management in the United States Through 2009.

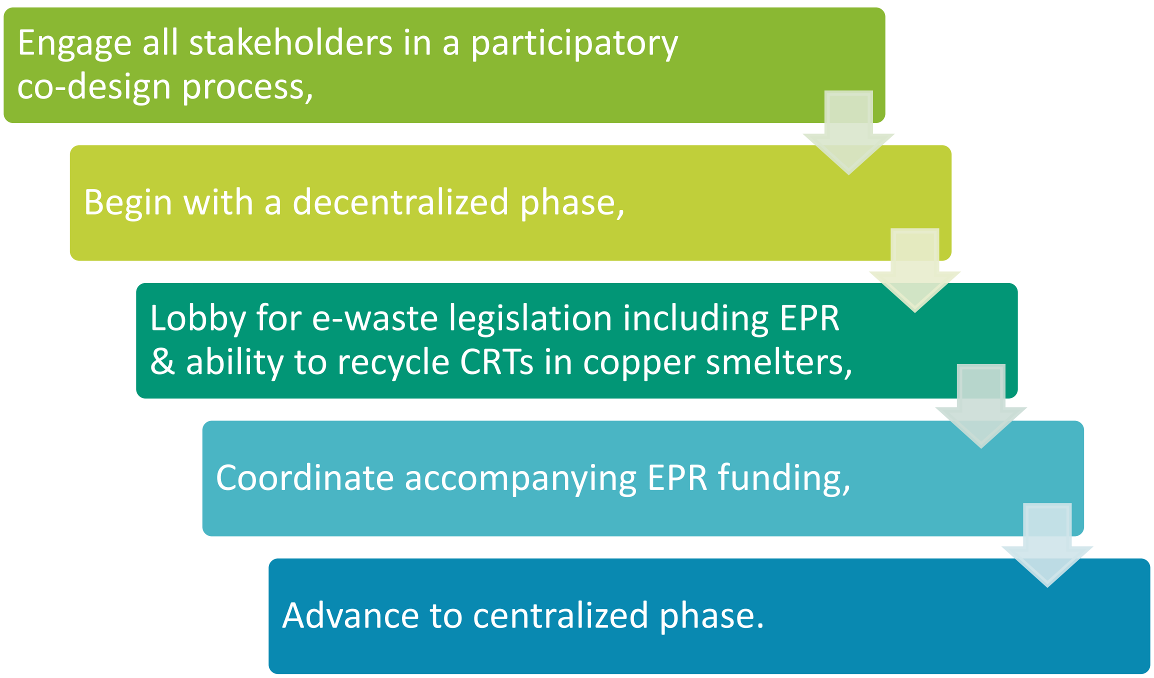
Proposed system structure and flows

We evaluated a variety of options, borrowing from the practices observed in used electronics reverse supply chains around the world, and came up with potential solutions, which are outlined below based on our understanding of Mexicali's specific situation at this time.

The effectiveness of a proposed system should be measured against these four main objectives:

1. *Mitigate environmental and public health impacts found in the current system of managing end of life electronics.*
2. *Preserve and enhance the main actors involved in the current system.*
3. *Increase the collection and recycling of electronics at its end-of-life stage.*
4. *Be financially sustainable*.

To achieve these objectives with available resources, we propose that the program[8]:



In this section, we first discuss features of the decentralized phase. We then estimate financial feasibility of the centralized plan without EPR funding and find it to be infeasible. Ultimately, whether or not the program includes a regional dismantling facility, it is our hope that the Mexicali e-waste management scheme will serve as a successful model for systemic change in e-waste management, inspiring other towns in Mexico as well as throughout Latin America to adopt effective e-waste systems.

[8] We have learned from stakeholders working on e-waste issues in Africa that legislation and a third party Producer Responsibility Organization (PRO) is a prerequisite for producer buy-in and sustained participation in a system. (Reed Miller conversation with Gina Killikelly, Dell Ireland in August 2016)

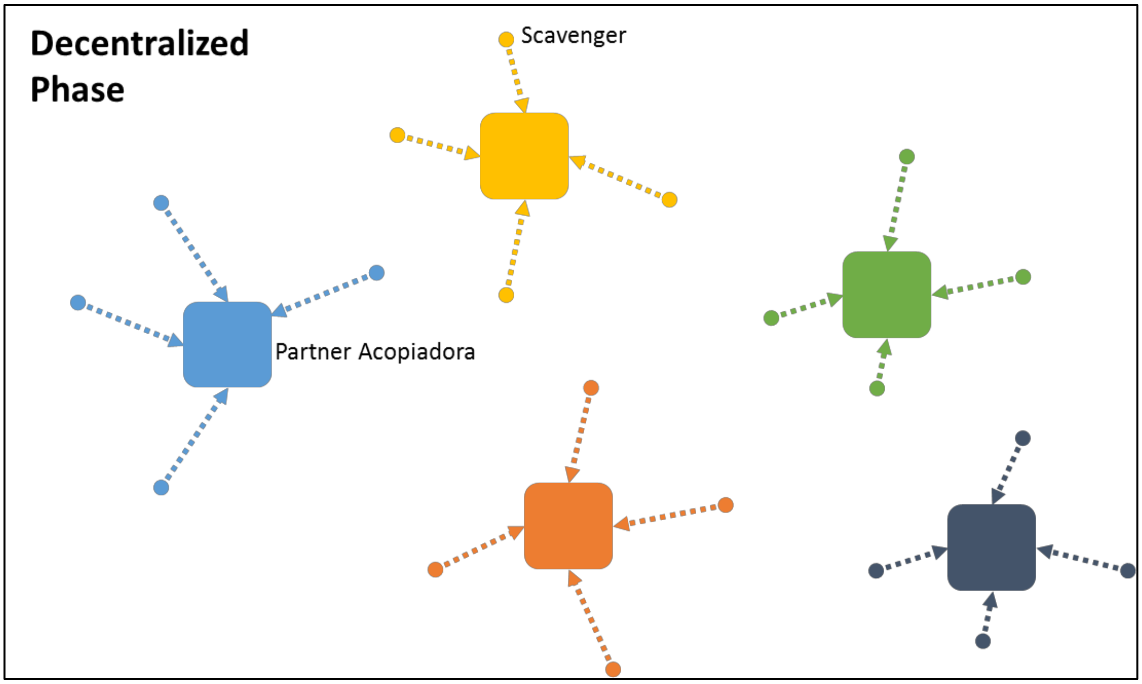


Figure 47: Depiction of certified partner acopiadoras and the certified scavengers affiliated with them collecting e-waste and bringing it back for dismantling and sale in decentralized phase

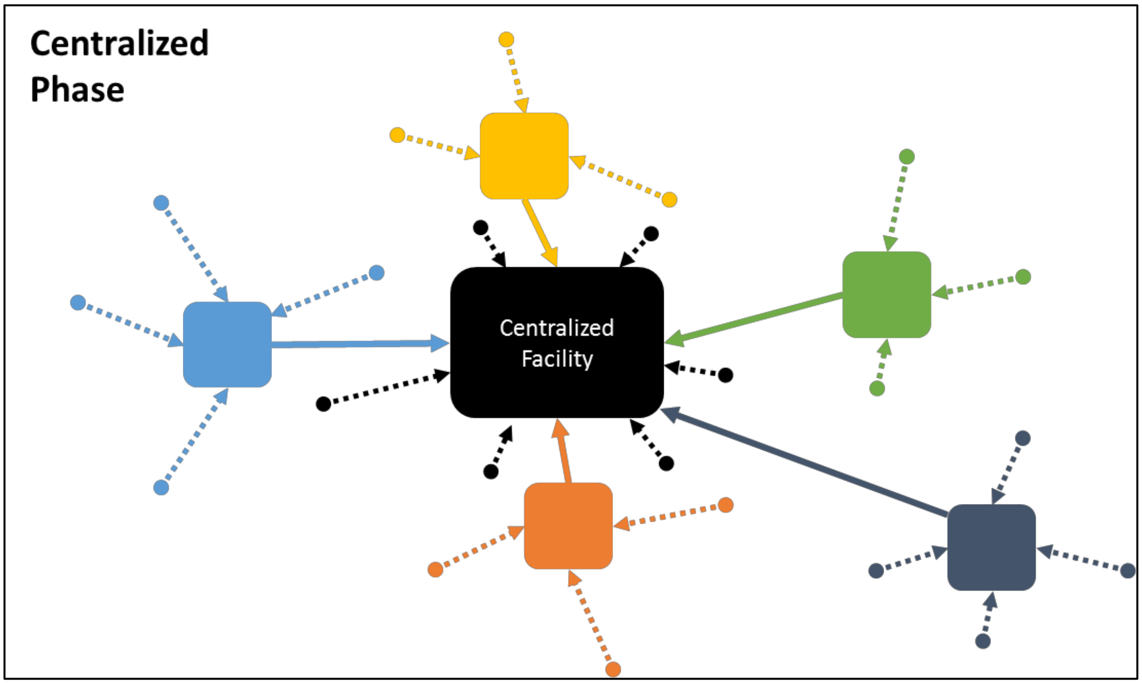


Figure 48: Depiction of centralized dismantling facility and nearby certified scavengers along with certified partner acopiadoras and the certified scavengers affiliated with them collecting e-waste and bringing it back for dismantling and sale in centralized phase.

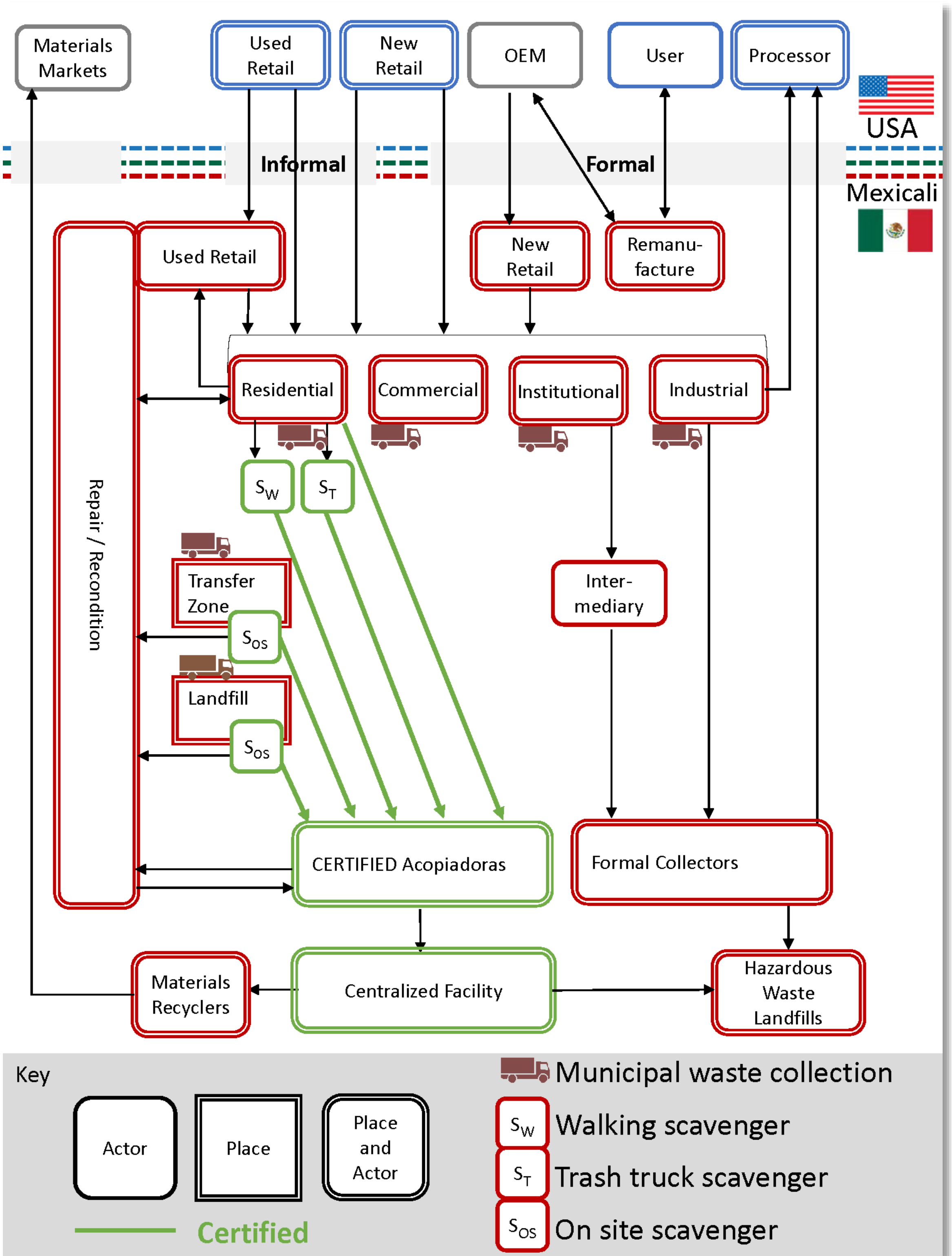


Figure 49: Proposal of the e-waste management system in Mexicali in the centralized phase.

Participatory Co-Design Process for Establishing Program Design

Incorporating a participatory, co-design process for creating systems that meet the needs of all stakeholders traditionally ensures greater sustainability of waste management programs. Therefore, in anticipation of implementing the decentralized and centralized phases of the Mexicali e-waste program outlined below, participating partners (acopiadoras, wastepickers, residents, the municipal government, etc.) need to be identified and invited to attend well-coordinated e-waste management co-design workshops. Co-design workshops should be organized in such a way that all participants have the opportunity to be heard and engage in the creative process, either adapting the models suggested below or generating additional key innovations.

Features of Decentralized Phase

The decentralized phase at the start of the project does not have sustained funding, so the interventions involve minimal capital investment and emphasize partnership building and certification to achieve the program goals in a twelve-month period. The four objectives listed again below are:

1. *Mitigate environmental and public health impacts found in the current system of managing end of life electronics.*
    - Improved dismantling workspaces for certified scavengers located at partner acopiadoras
    - Reduced copper cable burning due to incentivized chopper machine at one partner
2. *Preserve and enhance the main actors involved in the current system.*
    - A few dozen walking scavengers are certified and engaged in an enhanced, decentralized dismantling system
    - Around ten acopiadoras already collecting electronic scrap are certified and engaged as partners
3. *Increase the collection and recycling of electronics at its end-of-life stage.*
    - Simple text message system connects homes with electronics to scavengers
4. *Be financially sustainable.*
    - Minimal capital investment in dismantling tables, storage lockers, and tricycles
    - Some investment in complimentary public awareness campaign
    - Keep cost burden of proper CRT management with acopiadoras
    - Capital investment in insulated copper cable chopper machine and sustained market intervention to incentivize chopping

Engage and improve existing small recycling enterprises (Acopiadoras)

Small informal recycling companies (acopiadoras) currently working in the city of Mexicali could be selected to participate in the program, using the following criteria: a.) Large enough to accommodate 2-3 sorting tables for certified collectors/dismantlers to use to safely and responsibly disassemble e-waste; b.) Large enough to accommodate a locked cage or locker where certified collectors/dismantlers can aggregate material; c.) A proven track record of handling electronic waste, including cell phones, laptops, and printers; d.) A proven track record of fair and adept financial management; and e.) Situated in an appropriate geographical location so that they can participate in a network of strategically located collection points.

The program's certified acopiadoras would not only receive training on the safe handling of e-waste but they could be provided a sticker, green branding their establishment as an official e-waste collection point accredited by the program. Each participating acopiadora could also be provided tables, tools, tricycles for collection, and, as a result of implementation of the program, a more readily available supply of used electronics. Two to five certified collectors/dismantlers could be assigned to each participating acopiadora for a total of 20-50 formalized jobs created by the program.

Establish collection points

In addition, the acopiadoras would act as collection points providing an opportunity for the residential sector and the small and medium size business sector to drop off their used electronics.

Procure simple collection vehicles

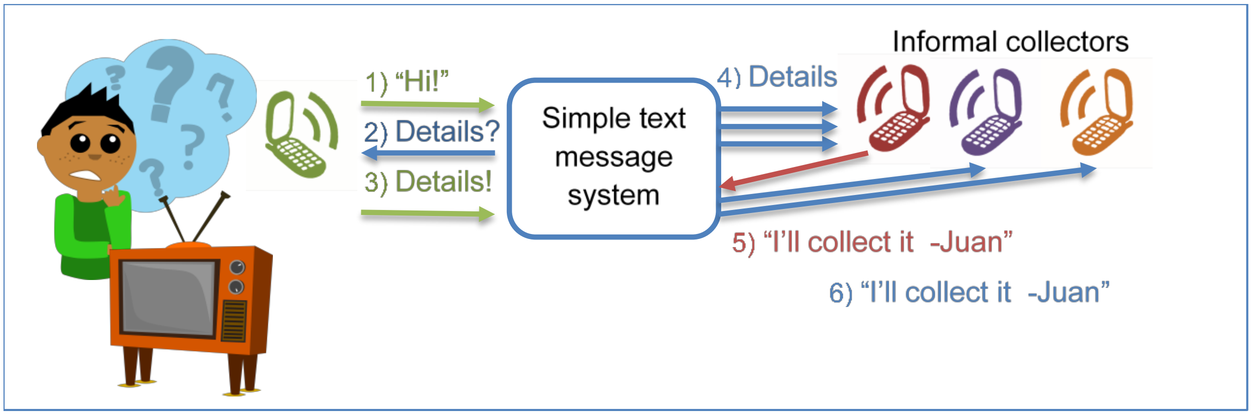
Participating certified acopiadoras could also be provided tricycle carts to haul e-waste, branded with the program logo and a phone number for residents to send a text to participating certified collectors/dismantlers, letting them know what material they would like picked up and the address from which it needed to be collected. For an example of person-powered tricycle carts see an example here (left): http://www.worksmancycles.com/shopsite_sc/store/html/frontload.html, or electric tricycle carts here (right): https://www.alibaba.com/product-detail/high-quality-Strong-power-1000W-60V_60433317660.html?spm=a2700.7724857.0.0.BfhRHH.

Establish text message for on-demand collection

Through TV ads, signage, and radio spots, residents could learn how to use text message set up by the program to alert participating certified collectors/dismantlers of their need for pick-up of e-waste. A catchy phone number could be provided on all signage and on the carts themselves, instructing residents on how to send a text message.

As depicted below, first the resident sends an initial text (1). They would then receive an autoreply (2) that asks for details such as: "Tell us what item you have and what address", and they would text back the details (3). The auto-responses will be forwarded to the group of certified informal collectors/dismantlers (4). One of the collectors would claim it by sending a reply text (5), which is forwarded to other collectors (6) so they know not to bother.

The only costs for text messaging system would be setting up an SMS Shortcode and local text messaging rates, which are around $0.04 to send and $0.01 to receive. One possibility is the free software Frontline SMS: http://www.frontlinesms.com/technologies/frontlinesms-overview/. They offer consulting services for a custom use of the tool.



Include the informal sector (pepenedores)

As the walking waste pickers (waste pickers working outside of the existing unions located at the transfer station and the municipal dump site) are already aware of the best locations throughout the city to collect e-waste, the authors recommend that the program target this particular group of informal collectors/dismantlers. This group of waste pickers would be provided training and become certified on how to safely collect and disassemble e-waste. Additionally, they would be offered safety equipment, including steel-toed boots, safety goggles, and a smock which, to limit the transfer of hazardous dust to their homes, would be left behind at the end of their work day at the specific small recycling facility where they are working. Rather than being organized into an additional union, each certified collector/dismantler would work directly with a participating small recycling company (acopiadora).

Train, certify, and provide green branding

The program would train and certify the participating acopiadoras and waste pickers so that they could safely collect and disassemble e-waste. Insituto GEA is a Sao-Paulo-based organization that, in partnership with University of Sao Paulo (USP), has developed and implemented a successful e-waste collection and disassembly curriculum at waste picker cooperatives throughout Brazil. The curriculum starts with a discussion of the environmental and health hazards of e-waste and then uses a hands-on approach to teach informal recyclers how to responsibly and safely collect and disassemble e-waste. Their curriculum (or similar curriculum) would then be provided to any walking waste picker who chooses to participate and to the network of participating acopiadoras strategically placed throughout the city. (Go to: http://ecoeletrofase2.com.br/ecoeletro2/onde-levar-seu-lixo-eletronico/and http://www.institutogea.org.br/).

Regularly provide assessments and establish a network of participating acopiadoras

All participating acopiadoras would be assessed every semester based on system performance indicators. Performance indicators might include the following: a.) An average of three certified collectors/dismantlers per day that use the disassembly tables provided by the program; b.) A minimum amount of X treated CRT glass (units) per X kg of printed circuit boards collected each month; and c.) X kg of plastic from insulated copper cables per X kg of recovered copper from e-waste collected each month. If acopiadoras failed to achieve these goals, the program manager might decide to remove them from the list of certified and green branded acopiadoras. Certified collectors/dismantlers and acopiadoras could be potentially united into a network (the branded network could be comprised of one collector/dismantler and one member of management from each participating acopiadora), which would then identify methods for maintaining assessment and certification.

Features of Centralized Phase

The centralized phase, which proceeds after and builds on the implementation of the previously outlined decentralized system, not only requires legislative action and EPR to be financially sustainable, but it involves significant capital investment. The four objectives of the program, which are again listed below, identify the features of the centralized model that meet the program's stated objectives:

1. *Mitigate environmental and public health impacts found in the current system of managing end of life electronics.*
    - Improved dismantling workspaces for certified scavengers located at a centralized location
    - Reduced copper cable burning due to incentivized chopper machine at centralized facility
2. *Preserve and enhance the main actors involved in the current system.*
    - A few dozen walking scavengers are certified and engaged in an enhanced, centralized dismantling system
    - Around ten acopiadoras already collecting electronic scrap are certified and engaged as partners
3. *Increase the collection and recycling of electronics at its end-of-life stage.*
    - Simple text message system connects homes with electronics to scavengers
4. *Be financially sustainable.*
    - As shown below without legislation and/or EPR, the centralized model is not financially sustainable. The funding level in such a system would be set to ensure sustainability.

Financial feasibility of a centralized dismantling facility

StEP Business Plan Tool

Early in 2016, the Solving the E-Waste Problem Initiative (StEP) released a spreadsheet tool which is designed to help plan an economically and environmentally viable business, and is freely available for this project[9]. **Error! Reference source not found.** demonstrates the processes within the facility that are mapped in the tool. **Error! Reference source not found.** lays out the types of inputs and outputs from the tool. For this study, Camanoe Associates has tailored the inputs and structure of the tool to apply to the Mexicali case.

The tool offers three main options for "dismantling depths":

A) Hazardous components and high valuable components, like printed circuit boards, are removed only and the remaining parts are destined to mechanical separation/ recycling.

B) Apart from removing hazardous components, manual dismantling of components is conducted where viable with reasonable effort in order to receive more or less pure materials and recyclable fractions is conducted where viable with reasonable effort.

C) Appliances are manually dismantled up to a point, at which further separation into pure materials is not possible without mechanical shredding. This scenario includes CRT-glass separation.

The tool begins with a set of default values representing the price and cost of the output materials after dismantling, proper disposal of hazardous components, the wages of workers and managers, transportation costs, investment and rental costs for facility and equipment, estimates the number of workers needed to manage the input tonnage of material.

Custom inputs

Users can override any of the defaults with more location-specific information, as we have done in several cases using data from surveys and interviews done by UABC. The default weights in the tool were changed to match the weights used in the generation model. If one has data on fees that would be paid by an Extended Producer Responsibility system, they can be input as well. We did not include the insulated copper cable stripping operation as it was not available in this version of the tool.

The inputs often vary based on the system design option. For example, the default CRT management option is various levels of dismantling. We obtained estimates for prices to manage CRTs at the TDM facility in Mexicali. Since TDM in Mexicali charges a lower fee for whole CRTs, that was put in as a parallel option for the TDM option. For the CRT warehouse option, we doubled the estimated floor area needed. Also, printed circuit boards can be sold locally in Mexicali at a lower price than abroad, so those options with transport cost tradeoffs were included. There is an option to receive the material free via drop-offs at *puntos limpios*, or alternately for pepenadores to be paid to bring used electronics to the site. Currently, costs are unknown for retaining a collection space at *puntos limpios,* so none are input.

[9] http://www.step-initiative.org/business-plan-calculation-tool-for-manual-e-waste-dismantling-facilities.html

Since there is a good deal of uncertainty in many of the assumptions, a Monte Carlo simulation was run to estimate the range of outcomes and also to determine which assumptions were influential to the outcome. Monte Carlo simulations allow you to assign probability distributions to variables, and then for each trial a different value along the variable is pulled, so that for the 1,000 trials many combinations of the possible values for the variables are tested. Oracle's Crystal Ball plugin is used for the simulations.

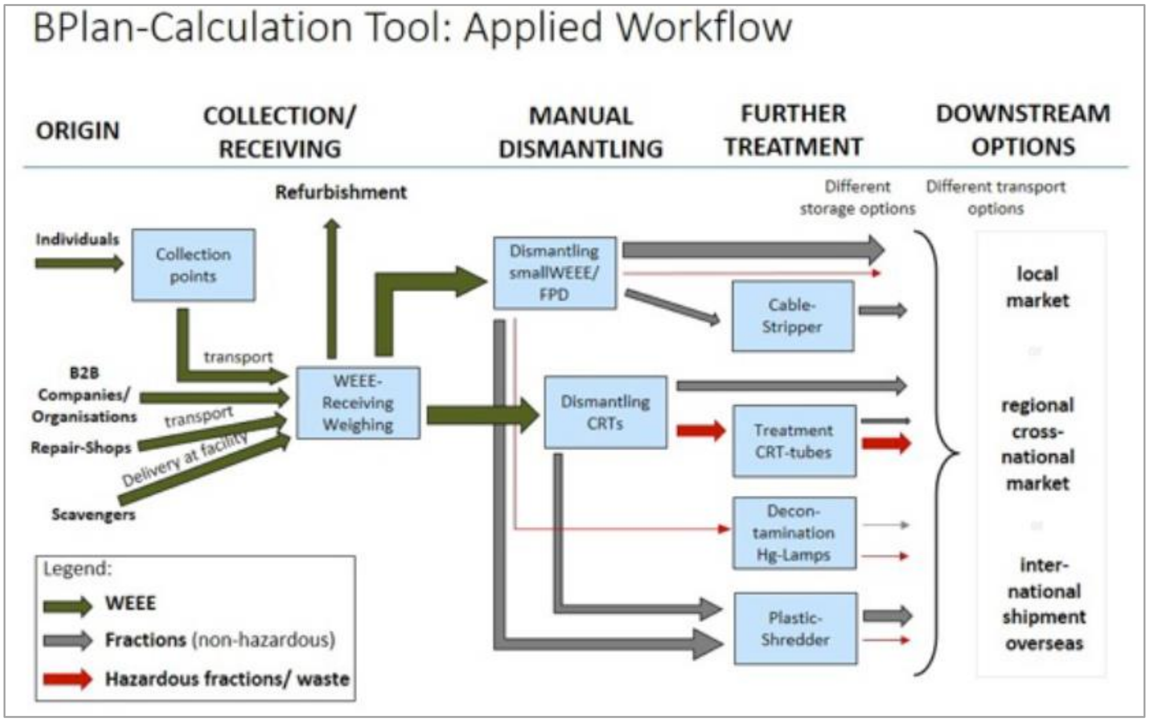
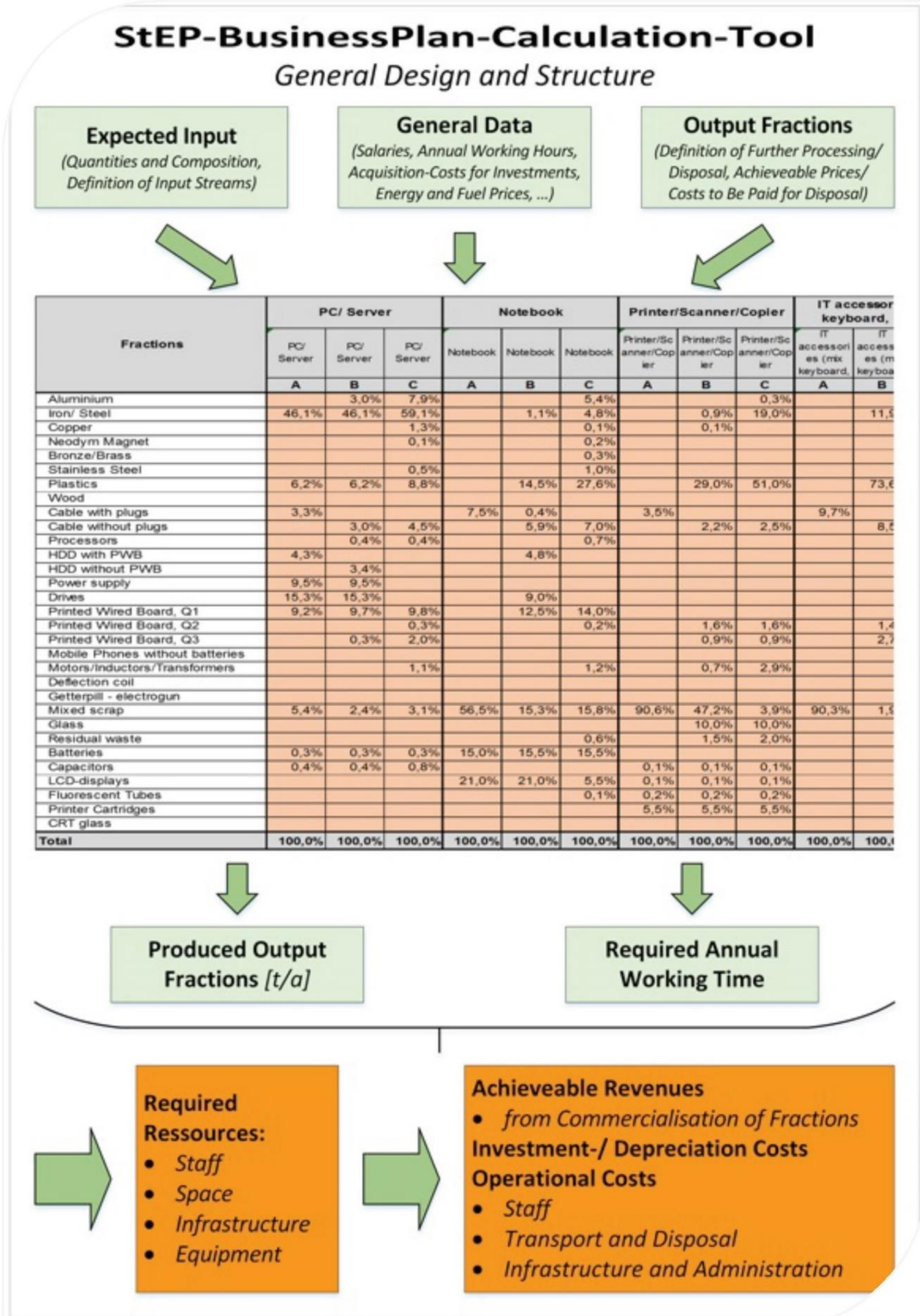


Figure 50: Processes mapped within the business plan calculation tool



Fractions	PC/ Server			Notebook			Printer/Scanner/Copier			IT accessor keyboard,	
	PC/ Server	PC/ Server	PC/ Server	Notebook	Notebook	Notebook	Printer/Scanner/Copier	Printer/Scanner/Copier	Printer/Scanner/Copier	IT accessories (mix keyboard,	IT accesses (m keyboa
	A	B	C	A	B	C	A	B	C	A	B
Aluminium		3,0%	7,9%			5,4%			0,3%		
Iron/ Steel	46,1%	46,1%	59,1%		1,1%	4,8%		0,9%	19,0%		11,
Copper			1,3%			0,1%		0,1%			
Neodym Magnet			0,1%			0,2%					
Bronze/Brass						0,3%					
Stainless Steel			0,5%			1,0%					
Plastics	6,2%	6,2%	8,8%		14,5%	27,6%		29,0%	51,0%		73,
Wood											
Cable with plugs	3,3%			7,5%	0,4%		3,5%			9,7%	
Cable without plugs		3,0%	4,5%		5,9%	7,0%		2,2%	2,5%		8,
Processors		0,4%	0,4%			0,7%					
HDD with PWB	4,3%				4,8%						
HDD without PWB		3,4%									
Power supply	9,5%	9,5%									
Drives	15,3%	15,3%			9,0%						
Printed Wired Board, Q1	9,2%	9,7%	9,8%		12,5%	14,0%					
Printed Wired Board, Q2			0,3%			0,2%		1,6%	1,6%		1,4
Printed Wired Board, Q3		0,3%	2,0%					0,9%	0,9%		2,7
Mobile Phones without batteries											
Motors/Inductors/Transformers			1,1%			1,2%		0,7%	2,9%		
Deflection coil											
Getterpill - electrogun											
Mixed scrap	5,4%	2,4%	3,1%	56,5%	15,3%	15,8%	90,6%	47,2%	3,9%	90,3%	1,
Glass								10,0%	10,0%		
Residual waste						0,6%		1,5%	2,0%		
Batteries	0,3%	0,3%	0,3%	15,0%	15,5%	15,5%					
Capacitors	0,4%	0,4%	0,8%				0,1%	0,1%	0,1%		
LCD-displays				21,0%	21,0%	5,5%	0,1%	0,1%	0,1%		
Fluorescent Tubes						0,1%	0,2%	0,2%	0,2%		
Printer Cartridges							5,5%	5,5%	5,5%		
CRT glass											
Total	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,0%	100,

Figure 51: Business plan calculation tool general design and structure (StEP 2016)

Option C1: Free devices at Puntos limpios, centralized dismantling, send CRTs to TDM

After running the Monte Carlo simulation, probability distributions of each financial parameter can be found. These charts represent the likelihood of each result after trying 1,000 combinations of likely values of the input variables. In the first scenario in **Error! Reference source not found.**, pepenadores are not paid to bring used electronics to the facility and instead it relies on donations at *puntos limpios,* neglecting fees to maintain those points. The results suggest that with the mix of incoming products, it is unlikely to make a profit using route C with full dismantling, and is possible with some configurations of route A or B.

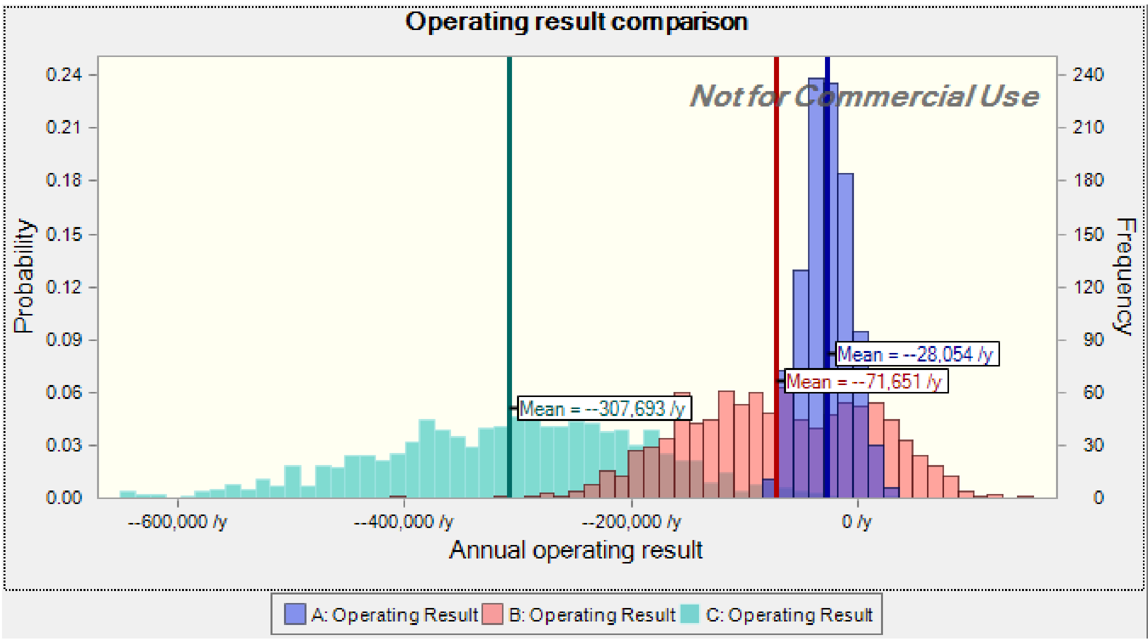


Figure 52: Operating result comparison for dismantling depths A, B, and C. Scenario: no purchase price for products, send to TDM.

Table 8: Key drivers for profitability, aside from free products. Number refers to rank of influence, with 1 being the most influential.

	Dismantling Depth A	Dismantling Depth B	Dismantling Depth C
Dismantling CRTs, not sending them whole	1	7	
Sending PCBs abroad	2	1	2
Better PCB prices		4 & 5	6
Fewer managers	3		
Better price on cable with plugs	4		
Lower skilled wage	5	3	3
More cell phones	6	2	1 & 4
More desktops	7		
More printer/scanners		6	5
Fewer CRT monitors			7

The key drivers of making a profitable operation shown in **Error! Reference source not found.** above. From the results, it will be very difficult to arrive at a profitable scenario. Note that in terms of the products, surprisingly, the emphasis is on retaining higher value products rather than avoiding costly CRTs. The price of printed circuit boards is very important, which will be a challenge because it fluctuates in the market considerably.

Option C2: Purchase devices from pepenadores, centralized dismantling, send CRTs to TDM

Looking at the scenario where pepenadores are paid about what they are currently paid by recyclers, about $2/ device, none of the scenarios are profitable.

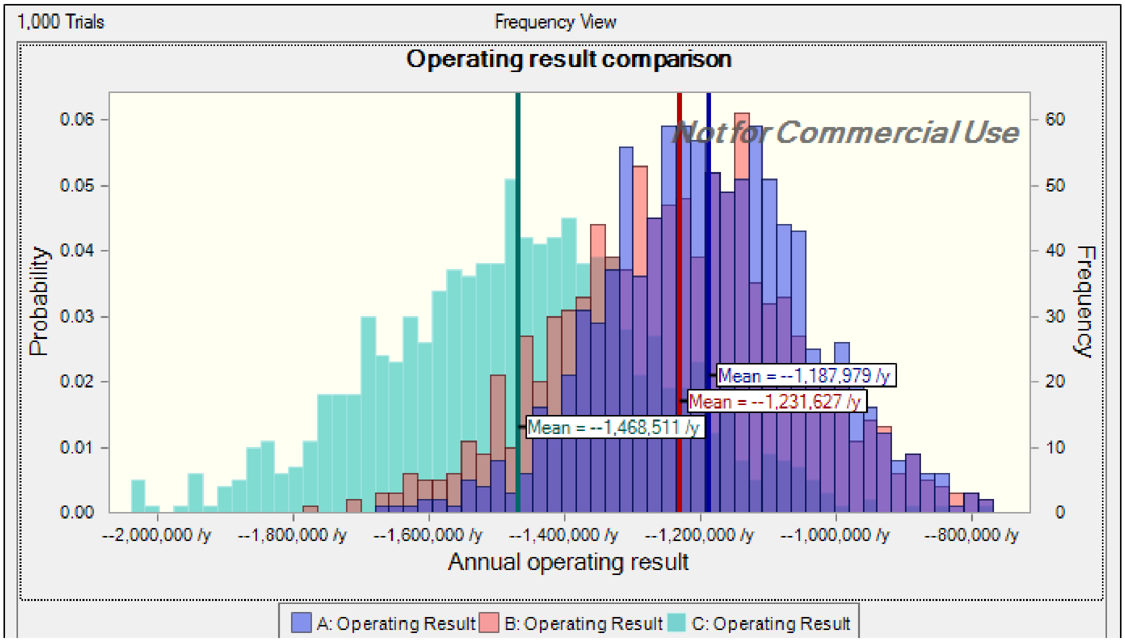


Figure 53: Operating result comparison for dismantling depths A, B, and C. Scenario: pay about $2 per product and send to TDM.

Option C3: Purchase devices from pepenadores, centralized dismantling, warehouse CRTs

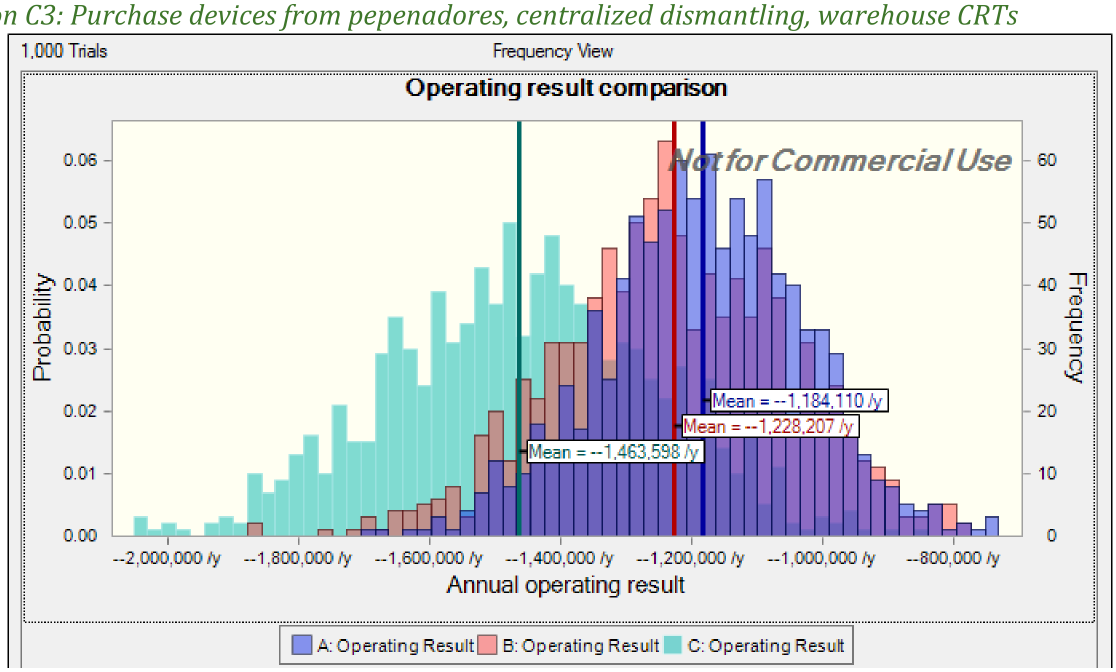


Figure 54: Operating result comparison for dismantling depths A, B, and C. Scenario: purchase products, warehouse CRTs.

Interestingly, we get very similar results as the TDM option for the warehouse option. It could be that the higher cost of rent and lost materials from dismantling the CRTs results in an overall similar situation.

Option C4: Free devices dropped off by resident, centralized dismantling, warehouse CRTs

Again, this has similar results to the second option with the same set of drivers, suggesting that the CRT management isn't key to financial feasibility.

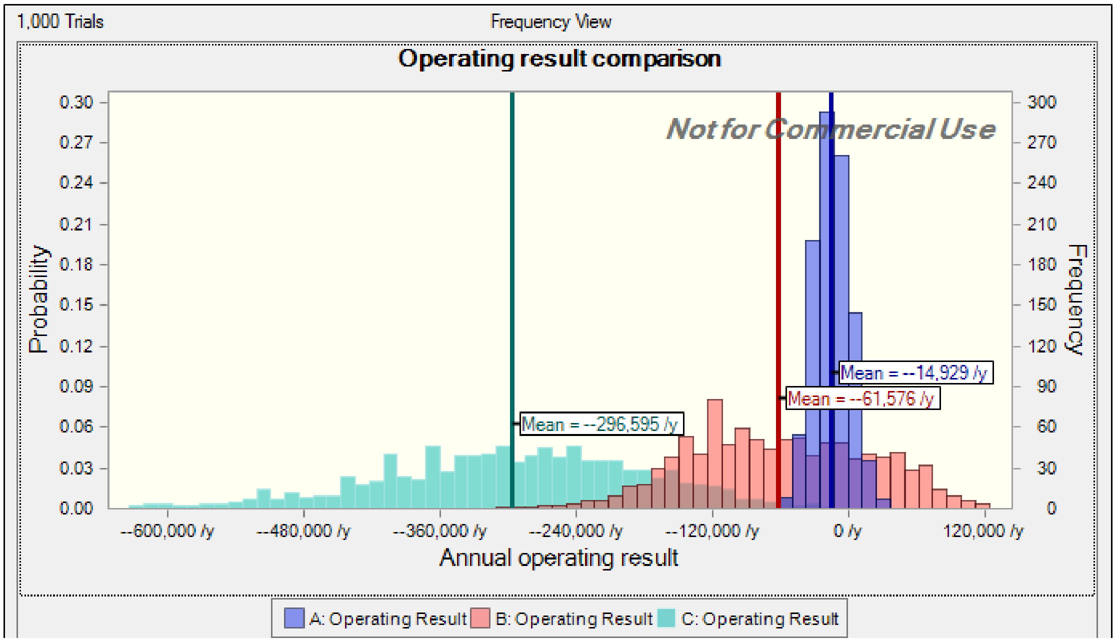


Figure 55: Operating result comparison for dismantling depths A, B, and C. Scenario: no purchase price for products, warehouse CRTs.

Centralized facility feasibility without EPR funding

From the analyses we have run, there is a very high probability that properly managing the e-waste volumes expected from residential and small businesses sectors would not be profitable. Given that reality, we emphasize the need to embark on a decentralized phase while garnering support for legislation that will enable producer responsibility to fund a sustainably functional system.

Appendix

Appendix A: Comparison of Chemical Substances and Selected Electronics

Table 9: Chemical Substances of Concern, Selected Electronics and Standards, adapted from {miller 2013}

Chemical Substances of Concern	Selected Electronics						Standards						
	Desktops & Laptops	CRTs	Flat Screens	Printers	Circuit Boards	Mobile Phones	OSHA [1]	Basel [2]	R2 [3]	BAN & ETBC [4]	RoHS [5] & Prop. RoHS [6]	CERCLA [7]	HR 2284 / S 1270 [8]
Aluminum	√	√	√	√		√	√					187	
Antimony	√	√			√	√	√	√				219	√
Arsenic	√	√	√	√		√	√	√		√		1	√
Barium		√				√						109	√
Beryllium	√	√		√	√	√	√	√		√		42	√
Cadmium	√	√	√		√	√	√	√		√	√ x	7	√
Hexavalent Chromium	√	√			√	√	√	√		√	√ x	18	√
Cobalt	√					√	√					49	
Copper	√	√	√	√		√	√	√				128	
Flame Retardants	√	√	√	√	√		√	√	√	√	√	√	
HBCDD[i]				√							xi		
PBB[ii]											√	143	
PBDE[iii]		√									√		
PCBs[iv]							√	√	√	√		5	
TBBP-A[v]	√	√	√	√	√						xi		
Lead	√	√	√	√	√	√	√	√	√ ix	√ ix	√ ix	2	√
Lithium	√						√						
Manganese						√	√					117	
Mercury	√		√		√	√	√	√	√	√	√ x	3	√
Nickel	√	√	√	√	√	√	√					53	
Organic Solvents													√ xii
Platinum							√						
PAHs[vi]							√					8	
PVC[vii]	√	√	√	√	√								
DEHP, BBP,&DBP[viii]	√	√	√	√							xi	76, 195&52	
Selenium	√				√		√	√		√		147	√
Silicon							√						
Silver	√	√	√	√	√	√	√					214	√
Thallium													
Zinc	√	√	√	√	√	√	√	√				74	

Notes from Table 9:

- i Hexabromocyclododecane (HBCDD)
- ii Polybrominated biphenyls (PBB)
- iii Polybrominateddiphenyl ethers (PBDE)
- iv Polychlorinated biphenyls (PCBs). Banned from US since 1976; may find capacitors in old mainframe computers with this chemical. [E]
- v Tetrabromobisphenol A (TBBP-A)
- vi Polycyclic Aromatic Hydrocarbons (PAHs)
- vii Polyvinyl Chloride (PVC)
- viii Bis (2-ethylhexyl) phthalate (DEHP), Butylbenzylphthalate (BBP), Dibutylphthalate (DBP) are plasticizers that can be found in PVC.
- ix These standards only list these chemicals when contained in specific items.
- x These standards list these chemicals with specific exceptions.
- xi These chemicals are not currently listed in RoHS, but have been proposed.
- xii This chemical is only listed when ignitable in batteries.

Standards:

[1] **OSHA Air Quality Limits.** These air quality limits apply when the substance is in a form that could be inhaled by a worker. This is relevant because items may enter particulate form during some processing steps. "United States Occupational Health and Safety Administration (OSHA) exposure limits in the workplace for some substances contained in computing equipment". (PACE, 2011)

[2] **Basel Convention Controlled Waste.** Listed in Annex 1 of the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal, Categories of Wastes to Be Controlled. These substances are only controlled when they are in wastes, defined by the Basel Convention as "substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law." However, it is difficult to determine with certainty whether exported items are destined for disposal. (PACE, 2011)

[3] **R2 Focus Materials.**(R2 Solutions, 2008)

[4] **BAN & ETBC Extended Focus Material List.** (Basel Action Network and Electronics TakeBack Coalition, 2008)

[5] **Existing RoHS Substances**. Article 4 (1) of European RoHS [Restriction of Hazardous Substances] Directive 2002/95/EC, (Wäger, Schluep, & Müller, 2010)

[6] **Proposed RoHS Substances.** (Rita Groß, Gensch, Zangl, & Manhart, 2008)

[7] **CERCLA Priority List of Hazardous Substances.** The 2007 ranking assigns the highest priority to 1 and the lowest priority to 275. "It should be noted that this priority list is not a list of "most toxic" substances, but rather a prioritization of substances based on a combination of their frequency, toxicity, and potential for human exposure at NPL [Superfund US National Priority List] sites." (US ASTDR, 2007)

[8] **Restricted in Bill HR 2284 / S 1270.** HR 2284 /S 1270: Responsible Electronics Recycling Act (Green, 2011)

Table 10: Comparison of Chemical Substances and Selected Electronics, adapted from {miller 2013}

Chemical Substances of Concern	Desktops & Laptops	CRTs	Flat Screens	Printers	Circuit Boards	Mobile Phones
Aluminum	[1 P]	[1 P]	[1 P]	[1 M]		[9]
Antimony	[4]	[4]			[4]	[9]
Arsenic	[1 T]	[1 T], [4]	[1 T]	[1 T]		[9]
Barium		[3], [4]				[9]
Beryllium	[1 M], [4], [5], [6]	[6]		[4, laser]	[4], [5], [6]	[9]
Cadmium	[1 T]/[1 P], [4], [6]	[2], [3], [4], [5]	[1 T]		[4], [6]	[9]
Hexavalent Chromium	[4], [6]	[3]			[4]	[9] (Lists Cr)
Cobalt	[1 P]					[9]
Copper	[1 P]	[1 P], [3]	[1 P]	[1 P]		[9]
Flame Retardants	[1 P], [4], [5], [8]	[1 P], [2], [6], [8]	[1 P]	[1 P]	[4], [5]	
HBCDD[i]				[8]		
PBB[ii]						
PBDE[iii]		[2]				
PCBs[iv]						
TBBP-A[v]	[8]	[8]	[8]	[8]	[8]	
Lead	[1 M], [3], [5], [6], [7]	[1 P] ,[3], [5], [6], [7]	[1 T], [7]	[1 M], [7]	[3], [5]	[7], [9]
Lithium	[1 M]/ [1 P]					
Manganese						[9]
Mercury	[1 T], [4]		[1 T], [4], [5]		[4]	[9]
Nickel	[1 P], [4]	[1 M], [4]	[1 M]	[1 M]	[4]	[9]
Organic Solvents						
Platinum						
PAHs[vi]						
PVC[vii]	[1 P]/ [1 M], [8]	[1 P], [8]	[1 P], [8]	[1 P], [8]	[8]	
DEHP, BBP,&DBP[viii]	[8]	[8]	[8]	[8]		
Selenium	[1 T], [4]				[4]	
Silicon						
Silver	[1 M], [3]	[1 T]	[1 T]	[1 T]	[3]	[9]
Thallium						
Zinc	[4]	[1 T], [3], [4]	[1 T]	[1 T]	[4]	[9]

Notes from Table 10:

- i Hexabromocyclododecane (HBCDD)
- ii Polybrominated biphenyls (PBB)
- iii Polybrominateddiphenyl ethers (PBDE)
- iv Polychlorinated biphenyls (PCBs). Banned from US since 1976; may find capacitors in old mainframe computers with this chemical. [E]
- v Tetrabromobisphenol A (TBBP-A)
- vi Polycyclic Aromatic Hydrocarbons (PAHs)
- vii Polyvinyl Chloride (PVC)
- viii Bis (2-ethylhexyl) phthalate (DEHP), Butylbenzylphthalate (BBP), Dibutylphthalate (DBP) are plasticizers that can be found in PVC.
- ix Substances listed to be in circuit boards were also listed in this category, in addition to substances listed directly to be in desktops or laptops. There were few differences in the lists of substances for these two items, which is why they are presented jointly.
- [1] [1 P] = Priority Constituent, [1 M] = Minor Constituent, [1 T] = Trace Constituent. From (PACE, 2011)
- [2] (Wäger et al., 2010)
- [3] (Li, Richardson, Walker, & Yuan, 2006)
- [4] (OH EPA)
- [5] (Greenpeace)
- [6] (National Geographic, 2008)
- [7] (Timothy G. Townsend et al., 2004)
- [8] (Rita Groß et al., 2008)
- [9] (Wu, Chan, Middendorf, Gu, & Zhong, 2008)

Appendix B: Insulated Copper Cable Chopping Machinery

GUIDETTI

PRUEBA ANTES DE COMPRAR

LABORATORIO DE PRUEBAS

- Elige el equipo mas adecuado.
- Prueba tu material.
- Comprueba directamente el resultado.

SINCRO 315 eko

GRANULADOR COMPACTO

El granulador compacto **SINCRO 315 eko** se ha diseñado para reciclar los cables eléctricos rígidos y flexibles. Permite obtener cobre o aluminio puros gracias a un proceso de trituración y siguiente separación del material aislante (plástico, papel o goma). El granulador se puede cargar manualmente o en automático con cinta transportadora según las necesidades.

Capacidad de producción hasta 130 kg/h material en entrada, variable según el material procesado.

Molino de cuchillas
con alta eficiencia de corte y sistema para el enfriamiento de la cámara de corte.

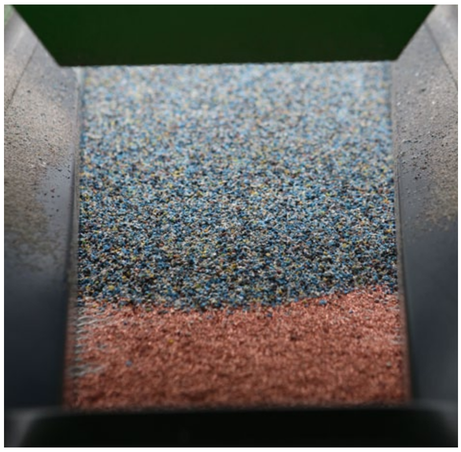
Separador vibrante en seco
de fácil acceso y ajustable.

Panel de comando
fácil de utilizar.

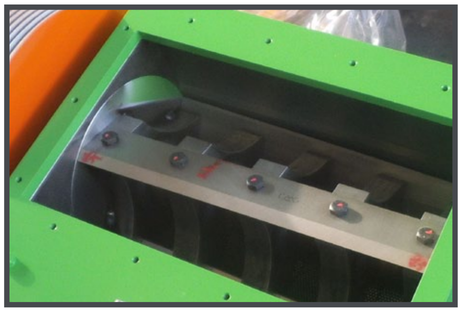
Dos circuitos de aire independientes
para mejorar la separación de los materiales y reducir el mantenimiento.

CE

made in italy

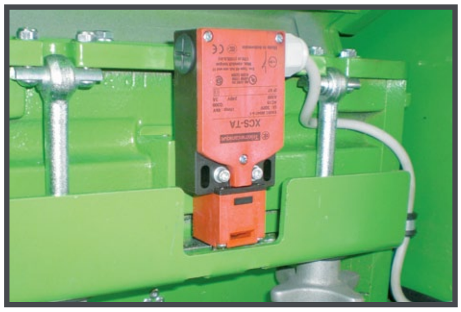


Cámara de corte



Fácil mantenimiento

En conformidad con las normas CE



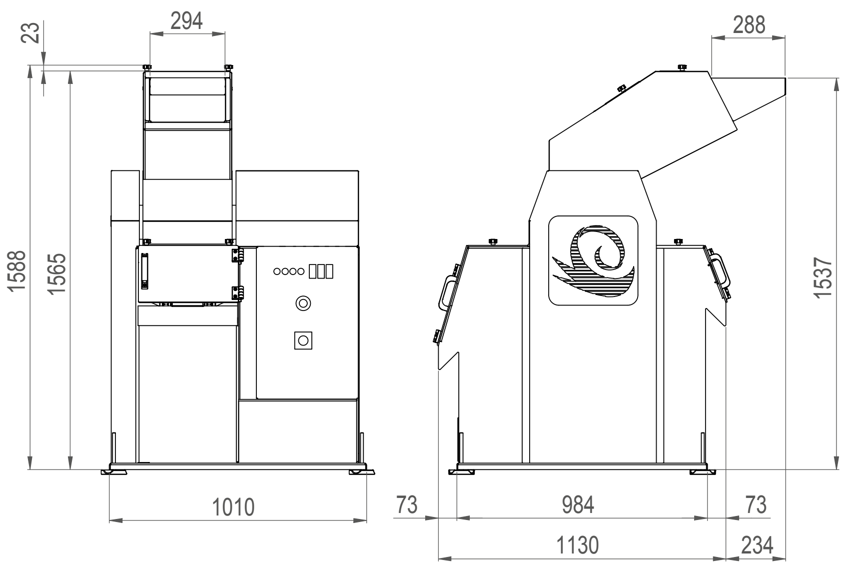
RECYCLING SYSTEMS

EJEMPLOS MATERIALES DE ENTRADA (INPUT)

PRODUCTO DE SALIDA (OUTPUT)

DATOS TECNICOS

- Carga: **Manual o Automática**
- Diámetro del rotor: **170 mm**
- Número de cuchillas giratorias: **3**
- Número de contra-cuchillas ajustables: **2**
- Parrilla disponible con huecos diámetro: **Ø 2-3-4-5-6-8 mm**
- Tipo de transmisión: **Con correa**
- Potencia total instalada: **6,1 kW - 12,2 A**
- Voltaje (Estándar): **400 V - 50 Hz**
- Mesa de separación disponible con red: **de 60µ a 200µ**
- Peso total: **458 kg**
- Nivel de ruido (con cable muestra): **83 db(A)**



VARIACIONES EN EL RENDIMIENTO DEL EQUIPO

La producción puede variar según el tipo de cable procesado y el tipo de parrilla instalada. La combinación con el pre-moledor permite optimizar el resultado, reducir el desgaste (un imán instalado sobre la cinta permite separar el hierro), y la mano de obra.

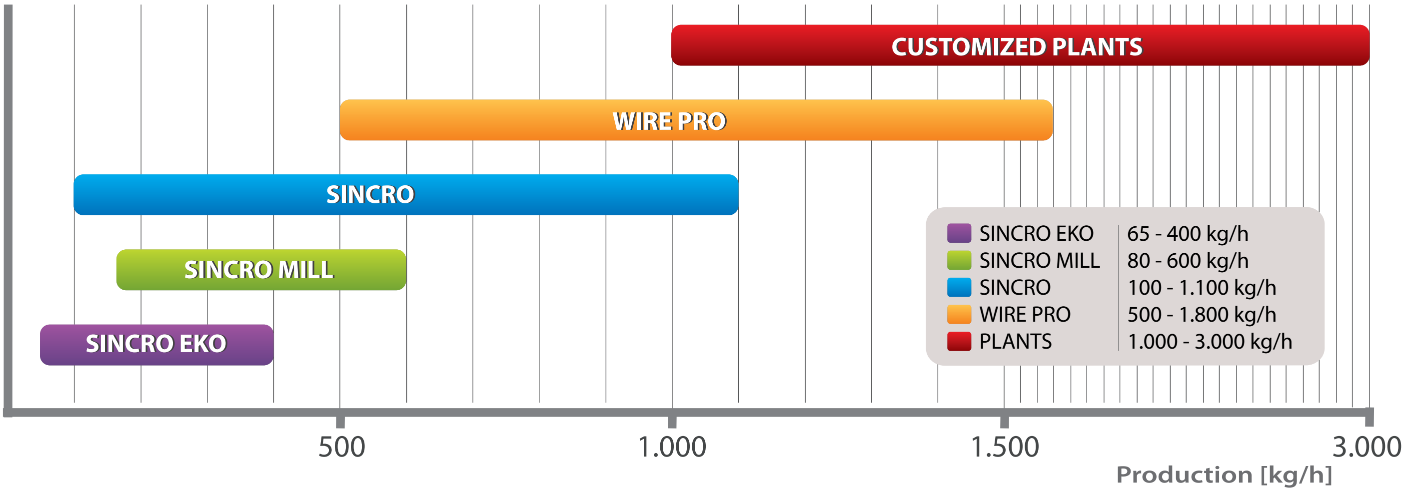
DIAMETRO MAXIMO CABLE NO PRE-TRITURADO

- Cable de cobre flexible: **Ø22-25 mm**
- Cable de cobre rígido: **Ø20-22 mm**
- Cable de aluminio: **Ø20-25 mm**

OPCIONES

- Válvula giratoria.
  (Para asegurar una carga constante)
- Dosificador polvos.
  (Para reciclar cables con grasa o sustancias aglutinantes)
- Conexión electrónica.
  (Para el funcionamiento en automático con el pre-moledor)
- Doble volante.
- Sistema de aspiración.
  (Para recojer el polvo en un filtro de mangas)
- Extensión de la garantía.

GRAFICO COMPARATIVO CAPACIDAD DE PRODUCCION PARA LÍNEAS DE MAQUINARIAS



POR QUE' ELEGIR SINCRO 315 EKO

- Mejor relación calidad/precio.
- Rápido y alto rendimiento de la inversión.
- Mantiene un valor alto a lo largo del tiempo.
- Compacta, la solución perfecta para espacio limitado.
- Ecológica, con consumo energético y nivel de ruido muy reducidos.
- Amplia gama de materiales que se pueden reciclar.
- Fácil de utilizar y de mantener.
- Ayuda rápida y fiable de los técnicos Guidetti.

COMBINACIONES

Todos los granuladores de la serie Sincro pueden trabajar con otros equipos Guidetti para incrementar su capacidad de producción y calidad del producto:

- Pre-triturador de la serie PMG.
- Cinta transportadora.
  (Para carga de cables o recogida materiales separados)
- Criba vibrante.
  (Para recuperar los polvos de metal)
- Separador magnético.

EXTENSION DE LA GARANTIA

"YOU WORK WE CARE"

La extensión de la garantía de hasta 2 o 3 años prevé la reparación o sustitución de los componentes defectuosos, excepto aquellos sujetos a desgaste, el servicio de teleasistencia donde previsto y la visita de un técnico Guidetti al término de cada año de trabajo (2 o 3 según la extensión adquirida) para averiguar el estado general del equipo.

SERVICIO AL CLIENTE
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service@guidettisrl.com

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Ph. +1 770 9548780
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GUIDETTI RECYCLING SYSTEMS

Estimada Empresa

PONTIFICIA UNIVERSIDAD CATOLICA DEL PERU
LIMA (PE)

Tipo de documento	Fecha	Pág.
Presupuesto n. 2016R.124	19/04/2016	1 / 2

A la cortés atención de: **Ramzy Kahhat, Ph**

Re: **PRESUPUESTO GRANULADOR GUIDETTI**

Código	Descripción	C.dad	Precio unidad	Descuento	Precio total	VAT
SINCRO_315EKO	**GRANULADOR COMPACTO MOD. SINCRO 315 EKO** Equipado con mesa de separación 60 micron y parrilla diam. 3mm ENTREGA: 8 semanas de la confirmación pedido y del pago depósito PAGO: 30% depósito con la confirmación de pedido saldo antes la entrega de la mercancía EMBALAJE Y TRANSPORTE: no incluidos INSTALACION no incluida El equipo es nuevo y fabricado en Guidetti srl según las normas CE El equipo se entrega junto con el Manual de Utilizo y Mantenimiento y declaración de conformidad CE GARANTIA: GUIDETTI S.r.l. suministra un producto garantizado durante un periodo de 12 (doce) meses a partir de la fecha de entrega con la condición que el mismo se utilice de la manera prevista y consentida en el Manual de instrucciones que se entrega con la máquina. La garantía no comprende el desgaste normal de las partes que dependen del producto, los componentes eléctricos, las cuchillas, los útiles y las herramientas que se entregan con la máquina. Las obligaciones de la garantía cesan en caso el usuario utilice repuestos no originales o no respete las condiciones de pago.	NR 1,00	15.999,00		15.999,00	
				Total parcial:	**15.999,00 €**	

Código	Descripción	C.dad	Precio unidad	Descuento	Precio total	VAT
KIT_315EKO	JUEGO DE REPUESTOS PARA 315 EKO	NR 1,00	1.410,00		1.410,00	
TS1.1980.60.B	MESA DE SEPARACION 215/315 EKO	NR 1,00	0,00		0,00	
SC0125	JUEGO DE CUCHILLAS FIJAS (2) SINCRO 315	NR 1,00	0,00		0,00	

Pago	Facturación
.	.
Porte .	**Entrega** 0 días laborales de la confirmación de pedido
Embalaje .	**Incoterms** .
Garantía .	**Instalación** .

Moneda	Validez de la oferta	Gastos transporte	Cargos de embalaje	Descuento total	Descuento	Total mercancías
EURO	60 días					

Note

Sigue >>

GUIDETTI RECYCLING SYSTEMS

Estimada Empresa

PONTIFICIA UNIVERSIDAD CATOLICA DEL PERU
LIMA (PE)

Tipo de documento	Fecha	Pág.
Presupuesto n. 2016R.124	19/04/2016	2 / 2

SC0126	JUEGO DE CUCHILLAS ROTATIVAS (3) S.315	NR	1,00	0,00		0,00	
SC0190	JUEGO PERNOS PARA CUCHILLAS	NR	1,00	0,00		0,00	
SC0132	FILTRO	NR	1,00	0,00		0,00	
SC0355	CORREA PARA SINCRO 315 EKO	NR	1,00	0,00		0,00	
CELE.04.0023	FUSIBLE 1421002	NR	3,00	0,00		0,00	
CELE.04.0026	FUSIBLE CH10 GG 25A 500V	NR	3,00	0,00		0,00	
CELE.04.0039	FUSIBLE 10x38 1a	NR	1,00	0,00		0,00	
CELE.10.0001	LUZ BLANCA	NR	2,00	0,00		0,00	
CELE.10.0002	LUZ ROJA	NR	1,00	0,00		0,00	
M0177	TAPA REINFORZADA	MT	1,80	0,00		0,00	
M0140	CINTA GOMA NEGRA	MT	0,50	0,00		0,00	
CGOM.01.0003	TAPON GOMA CON CINTA BIFAZ	MT	1,60	0,00		0,00	
SC0188	PARRILLA DIAM. 4MM PARA SINCRO 315C	NR	1,00	0,00		0,00	
					Total parcial:	**1.410,00 €**	

Pago .	Facturación .
Porte .	Entrega 0 días laborales de la confirmación de pedido
Embalaje .	Incoterms .
Garantía .	Instalación .

Moneda	Validez de la oferta	Gastos transporte	Cargos de embalaje	Descuento total	Descuento	Total mercancías
EURO	60 días					**17.409,00 €**

Note	Precio Total
	17.409,00 €

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