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Promoting circularity to reduce waste from household appliances in Mexico City
A just transition perspective

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Abstract
E-waste, the fastest growing waste stream, is a global challenge for it contains toxic substances and should be properly managed to avoid environmental and health hazards. In Mexico, 90% ends up in informal management chains, where inadequate management is generalised. Household appliances make most of e-waste generated in Mexico, yet they are poorly studied and regulated, and few efforts to treat them exist in comparison to IT devices. They are thus more likely to reach landfills.

My thesis aims to respond "*How can waste from household appliances in Mexico City be minimised and better managed in order to reduce the social and environmental problems linked to its treatment?".* The hypothesis is this can be attained through a Circular Economy (CE) model, which aims to eliminate avoidable waste through design, servitization and remanufacture. The CE is used as the analytical framework. Parting from international best practises, an ideal prevention and valorisation scenario is set. I analyse the e-waste management system in Mexico City and the existing circular practises in it, in the regulatory and policy framework, the manufacturing and repair industry, and in consumer behaviour, through bibliographic research, interviews and direct observation. I find that home appliances are unattractive to recyclers because they are less abundant, less valuable and harder to process than other electronics. Waste reduction can mostly be attained at manufacture and, secondly, through higher valorisation capacities. Policy recommendations are formulated to incentivise the adoption of circular practises in the industry, to augment the value of non-valuable materials, and to empower small recycling entities.

Key words
Circular economy, e-waste, household appliances, Mexico

Why should I read this research?

Given the growth rate of electronics, shorter obsolescence periods, the presence of both precious metals and toxic substances and a widespread inadequate treatment of e-waste, this waste stream has been acknowledged as a global challenge and included in policy agendas all around the world. The Circular Economy (CE) appears to provide solutions to this problem, by proposing a model where waste is "designed out" of value chains by extending the life-time of products and by facilitating recycling through modularity and material selection. This framework has been applied to electronics in recent years in policies, regulations, innovative business models in the industry and different initiatives promoting sharing, reuse, repair, remanufacture and recycling. Notably, the European Union has implemented several measures to enable a circular transition for the sector. The Mexican legislation has also introduced a CE vision around the entire waste management system.

These measures have targeted IT devices particularly. Household appliances, which make most of e-waste flows, have received much less attention from researchers, legislators, and recyclers. This makes it more likely for them to reach landfills after their end of life. Likewise, there is no sector-specific approach for the implementation of the CE in this industry, and only a few companies have adopted circular practises internationally. This represents a gap in the literature and in the current regulatory and policy framework, as well as an opportunity to make the household appliances' industry more sustainable. My thesis comes in here. I study how waste from household appliances can be reduced and better managed to minimise the social and environmental problems linked to its treatment. The social problem is the predominance of the informal economy in e-waste treatment, as it employs vulnerable groups excluded from the formal labour market, under precarious conditions, and exposed to serious diseases.

My research is the first to study the application of the CE to the entire value chain of household appliances –from manufacture to final disposal- in Mexico City, under a "just transition" perspective that aims for waste reduction in the first place, and for a sound management that preserves the environment as well as the jobs of the involved workforce. I find two essential practises that already make the concerned waste flow considerably circular. The first is donation and second-hand markets, very common among low socioeconomic classes. The second is the intervention of e-waste managers, who recover and reincorporate discarded waste to the economy, valorising materials and creating a recycling market. However, the predominance of informal workers is problematic not only for social and environmental reasons, but because they undercut prices in the entire management chain, creating an uneven field for formal players and hindering the consolidation of a strong and profitable recycling industry in Mexico. This limits the maximal valorisation potential. Furthermore, discarded home appliances are unattractive to recyclers because their treatment is more a burden than a profitable business. Manufacturers have the largest influence to prevent waste generation from design in the first place, yet they currently lack the economic incentives to do so and are going on the opposite direction with increased planned obsolescence. My policy recommendations are based on these findings and formulated under a systemic vision to reduce waste and increase valorisation throughout the whole system.

Acknowledgements

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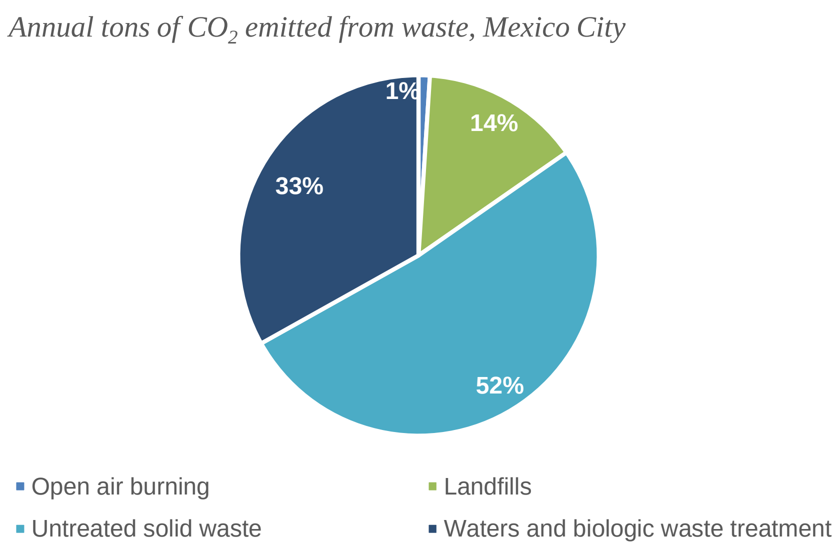
INTRODUCTION

The e-waste problem

Mexico City is the second most wasteful city in the world (Samayoa, 2017, p. 6), with 13,149 tons of waste generated daily on average (SEMARNAT, 2021, p. 14). A deficient waste management and separation at source causes an excessive volume reaching sanitary landfills. 15% of solid waste is recycled, 11% composted, 5% transformed into alternative fuels and the vast majority, 68%, is sent to landfills (Jiménez, 2019, p. 3). Landfills are problematic because they take up urban space –which is increasingly scarce (Ingeniería y Desarrollo Sustentable, 2010, p. 74)- and are highly pollutant. In 2011, Mexico City's last landfill, Bordo Poniente, was closed due to saturation. The city's waste now has to be transported to 6 landfills in adjacent states. Landfills emit high amounts of methane to the atmosphere, and leachate contaminates the soil and water (Samayoa, 2017, p. 6). Furthermore, illegal landfills or open dump are common in Mexico, one reason being the insufficient provision of collection services in certain areas. As these do not comply with environmental norms, they lack the necessary conditions to avoid the dispersion of pollutants to the environment. In 2019, 984 illegal landfills were reported in Mexico City (Ramos, 2020, p. 108). Incineration also has significant effects on the environment and human health, as it produces toxic nanoparticles that can be emitted to the atmosphere, especially when badly managed, which is common in Mexico. (Samayoa, 2017)

Waste is responsible for 722,784 tons of CO_2 emitted every year in the city, out of which: 7,291 tons are due to open-air burning, 103,461 tons to landfills and 372,682 tons come from untreated solid waste (Jiménez, 2019, p. 10).



Source: By author, from Jiménez (2019, p. 10)

Emissions are mainly related to transportation, as waste travels up to 111 km to landfills (Ramos, 2020, p. Annex 2), but also to the operation of plants and the decomposition of waste in final disposal sites. In addition, waste management is a financial burden for the government. In Mexico City, only final waste disposal costs 2,800 million pesos every year (Jiménez, 2019, p. 3) (equivalent to 129,055 euros), due to tipping fees of other states' landfills. Therefore, waste prevention has become a priority for national and local waste management policies.

Waste from Electrical and Electronic Equipment (WEEE) or e-waste is of particular concern. This is the fastest growing stream waste in the world, with 50 million tons generated in 2018 and 120 million tons expected by 2050 following current trends. (PACE, 2019, p. 10) In Mexico, e-waste grows at an annual rate of 5% (SEMARNAT, 2017, p. 196). This is due to fast technological development, shorter periods of obsolescence, and decreasing prices, together with demographic growth and an increasing purchasing power (Gaceta Oficial de la Ciudad de México, 2020). Higher wages are directly related to higher waste rates. (Fiore *et al.*, 2019). The electrical and electronic equipment (EEE) industry accounts for up to 20% of the global environmental impact linked to the depletion on non-renewable resources. (Cruz-Sotelo et al., 2017, p. 1) Mexico is the second e-waste generator in Latin America after Brasil, with 8.2 kg of WEEE per capita yearly. According to the National Institute of Ecology and Climate Change (INECC), Mexico generates around 29,000 tons of e-waste every month. 37% originates at the Metropolitan Zone of the Mexican Valley (ZMVM). (SEDEMA, 2019) What is more, Mexico is the third receptor country of WEEE after China and India, as e-waste is exported –legally or illegally- from the US. (García and Manske, 2019)

The problem with e-waste is that some devices contain toxic components or substances, such as heavy metals and persistent organic pollutants (POP). These make up 6% of their composition on average (SEMARNAT, 2021, p. 34). When managed under inadequate conditions or processes, these are released into the environment, depleting the ozone layer, polluting groundwater reserves, acidifying the soil and intoxicating our ecosystems, with severe risks for human health (Truttmann and Rechberger, 2006; Ramos, 2020). Populations residing in zones near WEEE management sites are particularly exposed. Thus, e-waste should be treated with special facilities, procedures and equipment to avoid environmental and health hazards. Yet Mexico City's environmental ministry SEDEMA (2019) states that 90% of WEEE is recycled inadequately. At the global level, even if e-waste represents only 2% of solid waste streams, it can make up 70% of the hazardous waste reaching landfills.(PACE, 2019, p. 7)

For the particular characteristics of WEEE, only municipalities or authorised enterprises should manage this waste stream. Yet the existing formal infrastructure to treat it is insufficient. The INECC estimates that from the total amount of WEEE generated nationally, only 10% is collected formally, 40% remains stored in households and 50% ends up in the public collection system, in the hands of informal recycling businesses, or in landfills (SEDEMA, 2019). The recycling industry for WEEE is incipient in the country, its processes relatively new, and their capacity limited (Cruz-Sotelo *et al.*, 2017). Mexico's recycling rate of e-waste was barely 3% in 2006 and 10% in 2014. (SEMARNAT, 2017, p. 197)

Beyond authorised entities, e-waste is mostly managed by a large informal sector that has found an attractive economic niche in electronics. This workforce is composed by low-income classes with low educational attainment and social exclusion, including women, immigrants, seniors and people with disabilities, all of whom encounter systematic barriers to access formal employment. The working conditions in this informal sector are precarious: workers have no access to social security nor protection against labour and health risks. Furthermore, they are exposed to the exploitation of powerful organisations that control the entire waste management system in the country. (OIT, 2015)

E-waste management in Mexico takes place within a lax regulatory framework and weak enforcement of the existent regulations, linked to poor capacities in the public sector and high corruption levels. Additionally, no specific control mechanisms target this waste stream. At the national level, no law regulates its specific management; there is no formal system to calculate and monitor its generation and management (García and Manske, 2019). WEEE flows are not specifically calculated, rather counted in the general solid urban waste flows (Ingeniería y Desarrollo Sustentable, 2010).

Another challenge for e-waste management is that collection levels of WEEE in Mexico remain low, especially from households. This is due to the lack of peoples' awareness about the implications of e-waste, insufficient information about collection sites, inconvenient drop-off facilities and lack of willingness to return obsolete appliances. Consumers often keep old objects at home because they think these might be useful in the future (Córdova, 2019). According to the SEDEMA, consumers in the ZMVM region discard the EEE they will no longer use in the following way: 11% keeps them at home, 17% sells them, 30% donates them and 42% delivers them at the garbage truck. (SEDEMA, 2019)

Among WEEE, household appliances are particularly relevant because they represent the biggest share of EEE sold nationally and of e-waste generated in the country (Córdova, 2019). An increasingly wide variety of ever-more complex products has been created, from kitchen equipment, cleaning and housekeeping devices to entertainment and personal care products. The household appliances' industry is significant and growing in Mexico, and Mexican households tend to increase their consumption. (PROMÉXICO, 2015)

Only in recent years, large equipment (refrigerators, washing machines, dryers, stoves and microwaves) and cooling devices (fridges, freezers, air conditioning) came to be regulated in Mexico, the first for their volume and their complicated management in traditional collection systems, and the second, for they contain ozone-depleting and other toxic substances (Ingeniería y Desarrollo Sustentable, 2010). Other than these, household appliances have been poorly studied and regulated in comparison to other IT and telecommunications equipment. From all the literature revised for this work, including academic papers, reports and legislation, only three documents focus on household appliances (Morioka *et al.*, 2005; Ingeniería y Desarrollo Sustentable, 2010; Fiore *et al.*, 2019), and two of them are not recent; the rest target mostly IT appliances. The only national census that presents data on the use of EEE, the National Survey about Availability and Use of Information Technologies in Households, excludes household appliances (García and Manske, 2019). With the exception of large and cooling equipment, notably fewer efforts to recover and recycle obsolete household appliances exist. Lastly, most of the actions taken are directed at recycling rather than at preventing waste generation in the first place.

Research question, focus and scope

Thus, this Master thesis is built around the following research question: *How can waste from household appliances in Mexico City be minimised and better managed in order to reduce the social and environmental problems linked to its treatment?* The hypothesis is this can be attained through a Circular Economy (CE) model, a framework that aims at "designing waste out" of value chains through a design for durability, reparability, upgrading and recycling, solutions for reuse and remanufacture, as well as services oriented at maximising use. This provides a preventive approach to eliminate avoidable waste as well as solutions to enhance valorisation.

My work is limited to waste generated from large and small household appliances in households in Mexico City, particularly fridges, freezers, air conditioners, washing machines, dishwashers, dryers, stoves, microwaves, blenders, irons, hairdryers, televisions and monitors. This list has been selected as they represent the most common domestic appliances owned in Mexican households but are not commonly studied as opposed to IT equipment. Cell phones, computers, laptops, lamps, entertainment devices, and others are excluded. Waste produced in the industrial process or that generated by the public and private sector are not addressed. The entire value chain of household appliances –from production to final disposal- is studied in order to obtain a systemic view of how waste can be reduced: on the top end of the chain, manufacturing practises determine the generation or minimisation of waste, whereas on the final end, proper management of WEEE increases the possibility of valorisation. Consumer behaviour and the repair industry of electronics are analysed marginally.

This research is especially concerned by the social issues brought up by e-waste management: the health risks to which informal e-waste managers are exposed, the precarious labour conditions under which they work, and the barriers they encounter to access alternative formal employment. The policy recommendations are thus formulated under the perspective of a just transition for the sector, that is, a transformation of the entire value chain of household appliances towards a sustainable model built over pillars of social and environmental justice, where sound treatment practises are ensured while decent jobs for this workforce are preserved.

Sections, method and sources

In order to respond the research question, I first present a synthesis of the literature of the analytical framework –the Circular Economy model- applied to the household appliances' industry at the international level. The literature review is made from academic papers, reports from the main institutions promoting the CE and a review of case studies compiled in one of the few studies that have focused on the application of CE to the industry, by Bressanelli et al

(2020). Secondly, I present the composition of household appliances, which is essential to understand their valorisation potential. This is followed by a synthesis of the most relevant policies that have been adopted in the European Union (EU) to promote circularity in electronics, considering that the EU has the highest standards for WEEE prevention and management. In particular, I revise the Directive 12/19 relative to e-waste and the Circular Economy Action Plan.

Then, an ideal valorisation scenario for household appliances after end-of-life (EoL) is constructed following CE principles. It details the optimal resource flow of the main materials and components (from collection to final disposal), the most efficient processes involved, and the required equipment, tools and security measures. This section is mainly based on specifications from the Directive 12/19; on one paper by Fiore et al (2019) which presents an optimal material flow and valorisation process for 7 of the 12 household appliances selected for the thesis, and on a manual for e-waste management elaborated by the United Nations Development Programme (UNDP) together with SEMARNAT in 2018. The paper and the guide were the most specific material found for this research.

In the next section, I explain the waste management system in Mexico City, where I identify the infrastructure, actors and policies involved in e-waste. I then make a revision of the regulatory and policy framework presenting the most relevant laws, norms and programmes that target e-waste at the national and local level. This is followed by a review of the existing infrastructure to manage WEEE, considering initiatives and capacities from manufacturers, civil society, and e-waste managers. The information concerning the WEEE treatment infrastructure is based ona study elaborated by SEMARNAT (2017), the most recent and rigorous research that has been done on the subject in Mexico. I complement this data with the latest public registry of formal special handling waste managers. Where no specific information was found for Mexico City, I refer to the national level.

Afterwards, I present the flow of waste from household appliances in Mexico City, constructed from a paper about the local e-waste supply chain (Cruz-Sotelo *et al.*, 2017), the study by SEMARNAT (2017), a comparative study of e-waste policies in Germany and Mexico elaborated by the GIZ (García and Manske, 2019) and a journalistic research by Cota and Smith (2016) about e-waste management at the Colonia[1] Renovación. This was completed with a series of semi-structured interviews and informal exchanges with a number of stakeholders.

Interviews	Cited in text as
Experts -Cristina Cortinas, expert in waste management legislation and Circular Economy, researcher and former public servant, Director of the Cristina Cortinas Foundation, participated in the construction of several environmental norms in Mexico	(Cortinas 2022)

[1] Territorial unity equivalent to a neighbourhood.

Interviews	Cited in text as
-Daniela Córdova, CE specialist, PHD thesis on the CE in the electronics industry in Mexico	(Córdova 2022)
Formal recyclers -Álvaro Núñez, CEO of REMSA -Salvador Álvarez, former CEO of Proambi -Visits and interviews at 2 small recycling centres	 (Núñez 2022) (Álvarez 2022)
Informal e-waste managers -Perifoneador[2] -Member of the National Confederation of Recyclers (CONIMER) -Exchange with the leader of one of the largest recycling businesses at Colonia Renovación -Informal exchange with one waste picker operating a garbage collection truck	 -- -- --
Repair industry -Site visit and informal exchanges with workers in 10 repair shops at the St. Artículo 123	
Manufacturing industry -Member of the National Association of Domestic Appliances Producers (ANFAD) and associate of Taurus -Head of the Sustainability department of Mabe[3]	 -- --
Government -Coordinator of the RAMIR and MP area at SEDEMA -Coordinator of Waste projects at SEDEMA	 (Sánchez 2022) (Reyes 2022)
Others -Isabella Cota, journalist, research about e-waste management in the Colonia Renovación in 2016	 (Cota 2022)

This is followed by a description of the valorisation of waste from household appliances, as it takes place today in the city. Factors that hinder the recovery of materials are explained. Then, I present the valorisation process (degree of recovery, procedures and capacities) at both the formal and informal sector. The interactions between both are analysed. Lastly, I present the scope of the household appliances industry in Mexico and its on-going sustainability practises relevant to the topic.

The main limitation of my thesis is the lack of information of the WEEE flow in Mexico, as most of it goes through informal chains and as the existing monitoring mechanisms are not strong enough to trace it. How the informal sector operates is not known with precision; many things are assumed. This does not allow to know the exact degree of valorisation of e-waste that takes place in the city. I counter this limitation with my interviews and on-field observation

[2] Pager/ Scrap dealer
[3] Taurus and Mabe are both global brands that manufacture and sell household appliances in Mexico.

at recycling and repair workshops, and with research about the informal sector in comparable contexts (OIT, 2015).

The analysis and findings section presents the gaps, barriers and enablers that were identified across the whole system of production and treatment of waste from household appliances in the city, by stakeholder, parting from the reference of the optimal valorisation scenario set at first. Three major factors determining the generation or reduction of waste in this industry are drawn. The first is the presence or the lack of incentives in the industry to adopt circular practises. Manufacturers are the actors with the highest power to prevent waste generation through design, servitization models and remanufacture. The second factor, which comes after EoL, is the value of waste, reflected by the price of materials in the market, their volume per equipment, their volume of collection and the cost of labour for waste managers to recover them. The third one is the capacity of e-waste managers to valorise materials, which refers to their size, level of knowledge, skills and facilities. Higher capacities account for larger volumes of waste treated, which decreases labour costs and raises the profitability of valorisation; precision in pre-processing enables a higher material recovery.

My thesis concludes that the CE model can indeed provide solutions to reduce waste from household appliances, at the manufacturing stage and through enhanced valorisation processes. The hypothesis is thus validated. My research finds that, in fact, the current management system of waste from household appliances in Mexico City is actually already circular to a certain extent for two reasons. On one side, consumers extend the lifetime of products through donation and second-hand markets. On the other, a large workforce of e-waste managers recovers valuable materials. Both are driven by economic rather than ecological incentives. Despite the contribution of consumers and recyclers, this system is far from optimal considering the ideal scenario of waste prevention and valorisation, and it has high social and environmental costs.

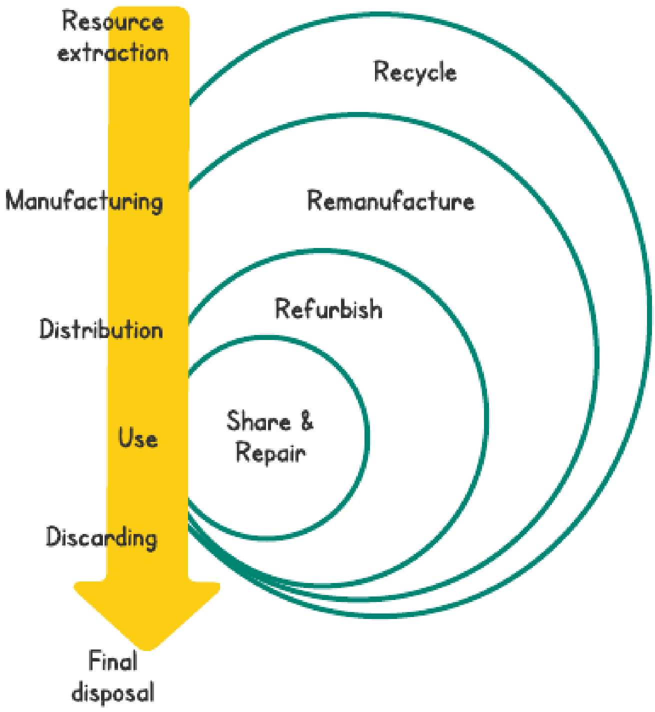
In line with the three factors determining the level of valorisation, I make key policy recommendations that could contribute to close the existing gap between the current system and the ideal one, and which should be implemented under a single strategy to reduce e-waste. Among the main recommendations, to incentivise the adoption of circular practises in the household appliances' industry, I propose the introduction of a mandatory circular label for electronics and the creation of collaboration spaces between stakeholders to develop circular solutions. Secondly, to increase the capacities of e-waste management, I propose the creation of a free training programme targeting small entities of repairers and waste managers (formal and informal), which would enable a higher valorisation and the formalisation of informal workers at the same time. I suggest the development of high-capacity public infrastructure to treat e-waste in Mexico City, where accredited waste managers would be hired to work on site under strict quality and protection standards. Lastly, in order to increase the value of poorly valued waste, an e-waste management tax is proposed for some household appliances, which would include transportation costs and a refundable fee to incentivise delivery after EoL. I suggest the creation of a material bank that would contribute to consolidate the secondary materials' market through timely information. I recommend that municipalities buy poorly valued materials from WEEE at the city's treatment plants, where they would be properly processed instead of landfilled.

STATE OF ART

The Circular Economy

The Circular Economy (CE) is a framework that proposes an alternative to our current "linear" economic system consisting of extraction-production-consumption-discarding: a highly wasteful dynamic in a context of finite resources and high environmental degradation. In the CE, the concept of waste is replaced by that of "resources". Before things end up incinerated or in landfills, they can be shared, reused, maintained, repurposed, and lastly, recycled. In a circular system, by-products, materials and components are meant to be recovered and reincorporated into the productive chains, and kept circulating in the economy for as long as possible, at their highest value or utility.

Circular economy model



Source: By author

As the diagram shows, materials after EoL can be diverted from final disposal and flow into a cascading cycle. In every loop, the value of the product -embedded at every stage of the value chain, from extraction and manufacturing to distribution and retail- is partially lost. Thus, it is optimal to keep the resources at the inner (smaller) loops the longest time possible. This means prioritising reuse before repair and remanufacture before recycling. The tighter the circle, the least a product or material suffers modifications and the more value is preserved. Reusing materials and components for their original purpose or bringing them back to their production chain to manufacture similar final products is the optimal scenario and is known as a closed-loop system. By contrast, recycling -process that involves a physical or chemical transformation of materials- should be the last resort, as the value that was embedded at extraction, manufacture and distribution (energy, resources and labour) is lost. Recycling an obsolete item before reuse, repair and remanufacture, when these where possible, would mean obtaining lesser value from secondary materials than the original product. Lastly, the use of resources for new products can be reduced by maximising the number of cycles of materials and components along this cascade: extending the amount of time an item is used and reused, the number of times a component is reused to remanufacture new products, and the number of times a material is recycled.

The Circular Economy applied to the electronic household appliances industry

The CE is being adopted globally as a useful framework to prevent and better handle all waste streams, in particular e-waste, notably in the European Union (EU). As it will be seen, the household appliances industry is a promising arena for the implementation of circular solutions, yet it is still at an embryonic stage, with few initiatives and research. No sector-specific approach for the implementation of the CE in this industry exists (Bressanelli *et al.*, 2020).

A CE model can be explained under different stages. Here, I will use four proposed by Bressannelli et al (2020) in a paper that systematises 20 cases of circular initiatives adopted in the industry at a global level. These are Reduce, Reuse, Remanufacture and Recycle. In the following pages I will describe how the CE can be adopted in the household appliances industry, using some examples and highlighting its benefits.

Reduce

Valorisation is first enabled at design, where over 80% of any product's footprint is determined (European Commission, 2020). Under the CE, materials and products are designed to be durable, easily maintained, remanufactured, upgraded, and recycled. Modularity, standardisation and the use of fewer materials facilitate disassembly and reassembly, enhancing multiple life cycles. A circular design also includes using bio-based and secondary materials instead of raw or virgin materials. Hazardous substances are avoided to facilitate a safe waste treatment. Pure materials, as opposed to composite materials which are non-separable but cannot be recycled together, are favoured for an easier sorting and recycling (Ellen Macarthur Foundation, 2015). Design can also play a fundamental role in consumers' behaviour for a sustainable use of their EEE (Bressanelli *et al.*, 2020). Eco-efficient design is encouraged to save energy consumption during use. (Morioka et al., 2005)
EEE manufacturers can minimise the number of parts (e.g. buttons, controls and wiring), and increase the quality of materials and components to extend lifespan. Sturdier tubes in irons, for example, could eliminate the need to use protecting springs, and would also avoid breaking during the assembly process. Multifunctional parts could be incorporated, for example: a timer

system and mechanical heat control could be combined into one complete control circuit in this device. (Nalbone, 2012)

Reuse

This stage refers to the extension of lifespan through maintenance (repair or refurbishing), or through use-maximisation (sharing, donation or second-hand sale). Repairing means fixing a faulty equipment to make it functional again. Refurbishing implies updating a product (cleaning, changing oil, replacing consumable items, making cosmetic improvements, among others), and can include repairing (Ecotech Services Limited, 2022). In this phase, products suffer none or little modifications.

Extended warranty and maintenance services, repair shops and second-hand markets play an essential role for reuse. Digital technologies to monitor product life can serve to inform consumers timely about the functionality and needed maintenance services of their appliances, while providing feedback to manufacturers about recurrent faults in their devices and opportunities for improvement from design (Bressanelli *et al.*, 2020). This type of solutions can prevent items from being discarded prematurely. Groupe SEB, a French multinational of household appliances, offers a service life of at least 10 years for its new products. To sustain this, it designs for and tests reparability, offers repair services and ensures availability of spare parts through 3D printing in technical service centres (where components can be immediately produced). Customers are rewarded with a coupon in exchange for their obsolete devices. (Bressanelli *et al.*, 2020, pp. 7–8)

Additionally, the CE promotes the replacement of business models based on sale and ownership to "product as a service", where providers sell functionality or use rather than the product itself. This is also known as servitization, as business models are oriented on offering services rather than selling products. It includes leasing, pay-per-use contracts, and sharing platforms. An example is Bundles, a Dutch company that offers laundry services through pay-per-use contracts. The washing machines remain Bundles' property; at the end of the contract, the firm recovers, refurbishes and reuses them. Furthermore, Bundles tracks the equipment's condition timely through sensors, and offers maintenance services accordingly, as well as personalised advice to clients on how to use the device more efficiently. Customers can save up to 1500 euros by paying a subscription fee during usage vs a full purchase price. (Bressanelli *et al.*, 2020, p. 7)

An example of sharing platforms is the Machine du Voisin, a French project that connects washing machines' owners willing to share them with their neighbours. The owner registers in the platform, specifies the place and time when it will be available, and makes direct arrangements with interested members (Bressanelli *et al.*, 2020, p. 10). Leasing and sharing business models not only allow to maximise the use of an appliance, but have a positive social impact in making them available to people that cannot afford a brand-new appliance. Ellen Macarthur states that high-end washing machines would be accessible for most households if they were leased rather than sold; customers would save a third per wash cycle, while manufacturers would increase a third in profits (2015, p. 14). Furthermore, these innovative business models engage customers in the long term and generate loyalty towards the brand.

Remanufacture

In this industrial process, parts from obsolete items are recovered, refurbished or upgraded and used to manufacture new devices (Reman, no date). Similarly, obsolete appliances may be reconditioned by replacing faulty components and upgrading software to deliver a product with an equal or improved performance as the original (Córdova, 2019). Remanufacturing involves collecting products after EoL, dismantling, cleaning, assessing functionality, sorting different materials and components, refurbishing and reassembling (Reman, no date). This stage requires reverse logistics, a service where the supplier collects material after consumer use (e.g. through collection points at stores), and processes WEEE to reincorporate it to the market (Bailey, no date). In order to be effective, reverse logistics need improved waste separation at source and user-friendly collection systems located in accessible points for both the consumer and the supplier or remanufacturer. Secondly, they rely on systems that allow to trace material flows, track their quality and status, and promote their trade between industries (Orgalim, 2021). Information sharing between manufacturers, distributors, retailers and customers is essential.

Through remanufacture, a high share of value can be recaptured from obsolete products and industrial resources needed to produce new items are saved, reducing material costs for manufacturers. Consumers might access quality products at reduced prices too.

Recycle

Lastly, recycling means transforming materials or components contained in waste into their basic materials or substances and reprocessing them into new materials with similar physical and chemical properties. Enhanced recycling demands sorting and pre-processing with high precision, infrastructure to recover different materials at high rates and quality levels, and compliance with environmental and health norms (PACE and Accenture, 2021). The use of secondary materials ensures a greater security of supply for manufacturers, reducing their exposure to increasingly volatile raw materials' prices and to fragile global supply chains that can be disrupted by global issues (PACE and Accenture, 2021), such as Covid 19.

Along these phases, extending lifespan through reuse of components for their original functionality is preferred to recycling and to replacement of old EEE with energy efficient devices, unless the innovation ratio in the industry is very high. Morioka et al explain that lengthening the product life through maintenance with used parts reduces the material input or resource use by 30% and the final disposal cost by 40%. It also reduces consumer expenses during the product's life cycle by 13%, even if electricity and refurbishment services are higher, because buying a new product is costlier (2005, pp. 12–13).

From a social perspective, the CE promotes job creation and innovation, as repair, remanufacture and manual recycling processes are labour intensive (Reman, no date). It demands new services and specialisation around material science, circular design, reverse logistics, servitization, sharing platforms, remanufacture, among others.

Household appliances: types and composition

Household appliances can be categorised as follows:

- Temperature exchange equipment: cooling, refrigerating and heating devices (fridges, freezers, air conditioners, radiators).
- Large equipment: dishwashers, washing machines, dryers, stoves, etc.
- Small equipment: housekeeping, kitchen, personal care items, among others (microwaves, vacuum cleaners, irons, blenders, toasters, coffeemakers, fryers, hairdryers, electrical toothbrushes, fans, sewing machines, etc.).

Although household appliances come in a large and increasing variety, all are mainly composed of metals, plastic, glass and electrical and electronic components. Metals include mainly steel, iron, aluminium and copper and are used to produce doors, hinges, brackets, mouldings, covers, compressors, grills and different accessories. Among plastics we can find ABS, bakelite, rubber, fibreglass, polystyrene, polypropylene, polyurethane, and nylon, from which hoses, fans, mouldings, buttons, and others are made. Among electronic components we can find embedded software and printed circuits or printed wiring boards (PWB). The electrical components integrate harnesses, cables, connectors, fuses and fuse links, among others (PROMÉXICO, 2015, p. 8). Some devices contain precious metals, including gold, silver, platinum and palladium. Less common materials are gravel, stone wool, concrete, ceramic, wood, bitumen, and rubber. (Cruz-Sotelo *et al.*, 2017)

According to the Recycling Electronics Mexico (Remsa) company, 46% of WEEE consists of glass and plastic, 31% of ferrous metals, 21% of non-ferrous metals, and 2% of electronic materials (EFE, 2018). It is estimated that in Mexico, 65.12% of WEEE materials are valuable, 28.89% are currently not valorised (e.g. ceramics, fibres and some plastics) and 5.99% are toxic components (SEMARNAT, 2021, p. 121). EEE are characterised by material complexity: one device can be made up of more than a thousand different substances and up to 60 elements from the periodic table (PACE and Accenture, 2021, p. 28). Although the use of hazardous substances has diminished due to international environmental regulations, they are still present in EEE.

In order to analyse the composition of household appliances, as well as their waste management, I will focus particularly on 12 devices:

Category	Device
Large appliances	Washing machine, dishwasher, stove, microwave
Cooling appliances	Fridge, freezer, air conditioner
Small appliances	Blender, iron, hair dryer
Others	TV, monitor

These have been selected as they represent the main type of EEE owned by Mexican households, they are manufactured in the country and are significant within the e-waste flows, yet they are not given enough attention. Large appliances, cooling equipment and TVs are the most predominant in the Mexican manufacturing industry (PROMÉXICO, 2015). For their volume and weight, temperature-exchange equipment represent the largest category of WEEE generated in the country (43.8%), followed by screens (35.5%) (Córdova, 2019, p. 58). According to the National Survey of Energy Consumption in Particular Households 2018, the main appliances owned by Mexican households are the following:

Device	% of Mexican households that own one
TV	91.5
Fridge	87.9
Stove	85
Washing machine	71
Iron	62

Source: SENER (2018)

According to projections realised by the consulting firm Ingeniería Sustenable (2010), the selected small appliances (iron, blender and hair dryer) are the most owned by Mexican households to date. The selection of different categories of EEE will allow to identify differences in their composition and the main implications for waste management in each.

The following hazardous substances are usually present in these household appliances:

Substance	Contained in
Arsenic	Computer chips, transistors, diodes and light-emitting diodes (LED)
Barium	Cathode Ray Tubes (CRT)
Beryllium	Switches and contacts
Cadmium	Used as a coating on contacts and monitors to prevent corrosion. Contained in some batteries (nickel-cadmium).
Chlorinated biphenyls (PCBs)	Contained in transformers, capacitors, electrical equipment (voltage regulators, switches, electromagnets, etc.), oils in motors, and cable insulation.
Chrome	Used as hardener in plastics and colouring agent in pigments. May be present in metallic parts' coatings.
Flame retardant	Added to plastics to prevent fires
Fluorescent powder	Contained in monitors
Gallium arsenide	Microwaves, LED
Lead	Used in CRT (leaded crystal), circuits, wiring plastics and welding
Mercury	Present in fluorescent light of plasma screens (LCD), from old devices. Present in some batteries.

Substance	Contained in
Refrigerant gas and cooling agents, oil	Used in temperature-exchange equipment. The first two may contain ozone-depleting gases.
Vinyl polychloride (PVC)	Used as cable insulator, in electric and plumbing tubes
Zinc sulphide	Present inside monitors

Source: By author, from García and Manske (2019, p. 19), Cruz-Sotelo et al (2017), Córdova (2019, pp. 36–37)

Components of household appliances that are of particular concern for their content of hazardous substances or parts are: CRT used in monitors (containing mercury, lead, cadmium, barium), batteries of lithium, nickel and cadmium, insulation foams, refrigerant gas and oil used in temperature-exchange equipment, fluorescent powder in monitors (containing mercury), and most importantly, PWB which contain lead in welds, gallium and arsenide in LED, flame retardants in plastics, cadmium and beryllium in switches and contacts, and mercury in interrupters. All these hazardous substances, materials or components are related to a vast range of diseases, including kidney, liver, lung and heart damage, dermatitis, problems in the respiratory and nervous system, genetic alterations, and cancer. Children are particularly vulnerable to them (Córdova, 2019). Likewise, they are highly intoxicating for the environment: they are bio-accumulated in fish, crustaceans, mushrooms and plants, and they pollute the water, soil and atmosphere (García and Manske, 2019). Only one cadmium battery can pollute 600 cubic metres of water. (Córdova, 2019, p. 37)

EU policies for circularity in electronics

The highest standards for WEEE prevention and management are set by the European Union (EU) and other countries like Japan. In the EU, the legislative framework regulating this waste stream is the Directive 12/19. This norm aims at preventing and recovering WEEE. It is based in the polluter-pays and the extended producer responsibility (EPR) principles (European Parliament, 2012). EPR is a policy tool that shifts responsibility to manage post-consumer goods from local governments to producers. This scheme allows to internalise the costs of environmental externalities caused by WEEE in the equipment price, which can then be indirectly transferred by manufacturers to consumers. (García and Manske, 2019)

The directive obliges manufacturers, distributors and merchandisers, including digital selling channels, to collect e-waste through return mechanisms at no cost for consumers. They must attain the specified annual collection rate to recover part of the total volume of EEE that they have placed in the market. Within the classification of WEEE, the directive includes two categories for household appliances: large and small devices. It set a recovery target of 80% for the first and 70% for the second, from the overall number of appliances placed in the European market. Likewise, it defined a recycling target of 75% for large equipment and of 50% for small devices. Producers should finance the collection, treatment, recovery and disposal of WEEE deposited from private households at collection facilities. Collective finance schemes are implemented to ensure proportional contributions, with differentiated fees based on how easily products can be recycled.

EPR is taken as a means to encourage eco-design facilitating repair, upgrading, reuse, dismantling and recycling (as manufacturers will seek to reduce the costs of deploying reverse logistics chains through life-extension of products and a slower production). According to the directive, reuse of components, sub-assemblies and consumables should be prioritised and recycled material should be reused to manufacture new equipment. Hazardous substances, components and mixtures should be properly removed from collected WEEE and treated as specified. Finally, the norm obliges member states to collect annual information on the quantity and categories of EEE placed on the market, collected, prepared for reuse and recovered. (European Parliament, 2012)

Beyond the Directive 12/19, the European Commission has mobilised several circular solutions for electronics through other regulations and policies in recent years, notably through the Circular Economy Action Plan, first launched in 2015 and renewed in 2020. E-waste is one of the seven key areas defined to achieve a CE in this plan. (European Parliament, 2021) Eco-labelling, the right of consumers to repair, and the creation of a market for high quality secondary materials are among the most relevant measures. The first seeks to empower consumers and to counter planned obsolescence through information about products' lifespan, obsolescence of software, availability of repair and upgrading services, spare parts and repair manuals (European Commission, 2020). Since 2019, producers in the EU are obliged to guarantee the availability of spare parts for refrigerating appliances, washing-machines, washer-dyers, and dishwashers for 7 years the first and 10 years the rest. Spare parts should be delivered in a period no longer than 15 working days and be replaceable with commonly available tools and without permanent damage to the appliance. Repairs should be simple and affordable, and producers should promote home or independent repairs through information. (European Commission, 2019)

Additionally, the Sustainable Products Initiative is about to launch the Digital product passport, which will collect data about the entire life cycle of consumer electronics (among other products) relevant for their reusability and recyclability, including materials used and their origin. Furthermore, economic incentives are being developed to promote sustainable products, such as environmental taxation (e.g. landfill and incineration rates), value added tax (VAT) rates to promote circular activities, notably repair services, and rewards for products based on sustainability performance. Requirements for recycled content are being introduced. It should be noted, however, that all these efforts also focus mainly on mobile phones, tablets and laptops. (European Commission, 2020)

Enhanced valorisation scenario for household appliances after EoL

In this section I will describe the ideal process needed for an optimal valorisation of waste from household appliances, taking into account the CE principles, the standard of policies set by the EU, several academic papers (OIT, 2015; Córdova, 2019; Fiore *et al.*, 2019) and a guide to implement best practises in WEEE valorisation, prepared by the project “Residuos COP”, by the UNDP/SEMARNAT in 2018. Tools, treatment facilities and safety measures are considered.

The entry point of the e-waste flow is collection of discarded appliances, which can take place at collection points set by the government, recycling companies or manufacturers, or through reverse logistic services provided by the last two. Collection under an EPR scheme is preferable as appliances can be recovered by their manufacturers and thus reused as spare parts, reconditioned and reincorporated to the original production chains, favouring a closed-loop system. Secondly, an evaluation of functionality of the EEE should be systematically carried on in order to identify and recondition equipment susceptible for reuse (repair, refurbishment, software upgrading, replacing parts). Manufacturers or recyclers can then place them in second-hand markets.

Only when equipment or their parts are no longer functional should these enter the process of disassembly or dismantling. This consists of fragmenting the device into its constituent components, first retrieving large parts (e.g. main case, batteries and screen), then internal ones (metals, plastics, electrical components and others). Dismantling can be manual or mechanical. Tools used here are: pliers, stilettos, hammers, magnets and manual and electrical screwdrivers. At this point, hazardous substances, materials and components are identified, separated, confined temporarily and sent to final disposal or safe processing through authorised service providers. Decontamination can be manual, mechanical, chemical or metallurgic. Hazardous waste should not be mixed with any other materials to avoid the dispersion of pollutants in the waste stream and in recycled materials. If landfilled, they should only be sent to hazardous waste landfills. (SEMARNAT, 2018a)

Among hazardous substances, flame retardants are very hard to detect and require expensive tests. According to the ISO 11469, producers should mark the plastics and components containing flame retardants to facilitate their separation and recycling.
Printed Wiring Boards (PWB) should be decontaminated by removing mercury and batteries before recovering valuable materials such as cables and electrical conductors. Metals are recovered through mechanical separation. Lastly, through refining at high-temperature ovens, precious metals can be recovered. (SEMARNAT, 2018a)
CRT are one of the hardest electronic waste to manage. Glass can be retrieved and re-melted into new CRT or broken down and used in road construction, tiles, concrete or cement bricks; yet decontamination is complicated and makes recycling difficult. (Wikipedia, 2022) Landfilling and incineration would be extremely pollutant. CRT should be put under controlled containment. (Córdova, 2022)

After dismantling and decontamination, valuable materials are recovered. They are shredded with grinders (in the case of plastics) or manual tools (e.g. hammers), then compacted with rollers (in the case of metals) to reduce volume and facilitate their transportation. Disassembly, separation, and shredding constitute the pre-processing stage. Facilities must be adapted to ensure safe pre-processing conditions. To name a few, sites should have impermeable surfaces and floors to prevent infiltration and soil contamination; they should have weatherproof covering, spillage facilities, appropriate containers and storage space, as well as controlled mechanical ventilation to prevent poisoning from toxic fumes or gases (European Parliament, 2012; SEMARNAT, 2018b). E-waste treatment entities should follow quality, environmental and protection standards set by international and national regulations, such as the ISO 9001 and ISO 1001. (Álvarez, 2022)

In the final processing, ferrous, non-ferrous and precious metals, rare earths, plastics, and glass are obtained through metallurgic, chemical or biological processes. Non-valuable, non-hazardous materials are sent to final disposal (incineration or landfill).

Value and ideal outputs and processes for the main components of household appliances

Components/ Materials/ Substances	**Value in the market**	**Ideal output**	**Requirements & specifications**
Ferrous, non-ferrous metals and copper	Highly valuable	Recycling	
PWB	Highly valuable / Hazardous	Processing Recycling (metals)	Decontamination and processing of hazardous waste. Recovery of electrical components. Refining to obtain precious metals
Electrical components: electrical conductors, permanent magnets, transformers	Valuable	Recycling	Specialised technology and safe processing; high investment
Plastics	Valuable	Recycling	Different pure plastics can be obtained (ABS, polystyrene, polypropylene and urethane)
Glass	Valuable	Recycling	
Glass from LCD	Valuable	Recycling	Previous decontamination
Refrigerant gas	Valuable	Reuse	Special treatment
Oil from cooling equipment	Valuable	Reuse	Special treatment

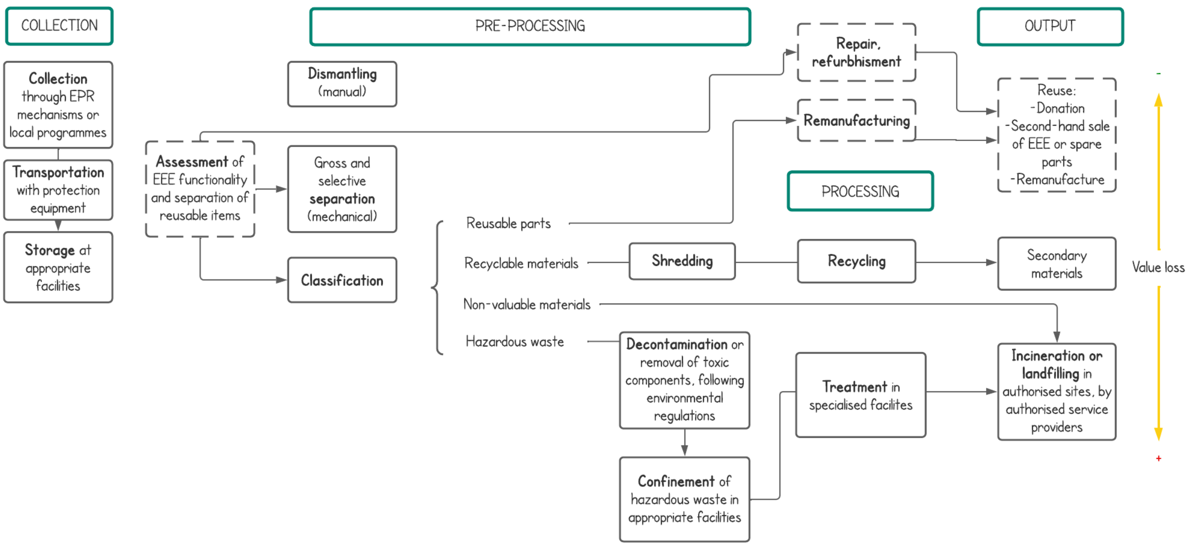
Components/ Materials/ Substances	**Value in the market**	**Ideal output**	**Requirements & specifications**
CRT	Valuable/ Hazardous	Reuse Processing Recycling	If reuse is not possible, glass can be decontaminated and recycled into new CRT. The rest should be put in controlled containment.
CRT monitors	Valuable	Recycling	45% can be recovered (Córdova 2019, p. 36)
Concrete, wood, stone wool	Valuable	Recycling	
Alkaline batteries	Valuable	Recycling	Refining
Lead	Valuable/ Hazardous	Recycling	
Capacitors	Non-valuable	Landfill	
Polyurethane	Non-valuable	Incineration	
Rubber	Non-valuable	Incineration	
Gases contained in insulation foams	Non-valuable/ Hazardous	Processing	Aspiration Special machinery
Polyurethane foam	Valuable	Incineration	
PCB	Non-valuable/ Hazardous	Incineration	Specialised technology
Batteries	Non-valuable/ Hazardous	Processing	Specialised entities
Mercury	Non-valuable/ Hazardous	Processing	Distillation Specialised infrastructure, authorised companies
Flame retardants	Non-valuable/ Hazardous	Incineration	Special facilities
Fluorescent powder	Non-valuable/ Hazardous	Landfill	Aspiration from CRT

Components/ Materials/ Substances	Value in the market	Ideal output	Requirements & specifications
LED and LCD	Hazardous	Incineration	Retrieval of mercury (LCD), distillation of screens and separation of liquid crystals for incineration

Source: By author, from Fiore et al (2019), Córdova (2019), OIT (2015), Morioka et al (2005) and SEMARNAT (2018b), (2018a)

Regarding efficiency in each process, according to the OIT (2015), manual dismantling accounts for a higher rate of recovery than mechanical disassembly, as original parts are less likely to break and can be reused. By opposition, a mechanical process is more efficient at the separation stage, and this requires specialised infrastructure. All metals are better recovered combining manual operations with shredding and automatic sorting. As for recycling, high levels of valorisation with a low environmental impact and safety require specialised knowledge and sophisticated technologies (Fiore *et al.*, 2019). Every process needs a large volume of inputs to function and be profitable. (SEMARNAT, 2018a)

Ideal resource flow for e-waste



Source: By author

In sum, the precision used at the disassembly process, the availability of specialised technology and the collection of large WEEE volumes increase the potential of valorisation. In Japan, one of the countries with the most advanced capacities to recycle this waste stream, up to 90-95% of materials from WEEE can be recovered. (Córdova, 2019, p. 36)

Fiore et al (2019) describe the optimal resource flow of 7 household appliances. By analysing the processes in a large-scale treatment plant (9900 tons per year) in Italy, the authors identify two valorisation scenarios -partial (S0) and enhanced (S1)- for three categories of WEEE. These are:

- R1. Cooling equipment -refrigerators, freezers, and air conditioners
- R2. Large household appliances- washing machines and dishwashers
- R3. TVs and screens

In the enhanced scenario, all valuable components are recycled, a minimum amount is incinerated and the rest landfilled. R1 had the lowest recycling rate, ranking between 40% (S0) and 80% (S1), followed by R2, between 65%-99%, and then R3, with the highest recyclability: 86% to 99% (2019, pp. 1–2). The following diagrams describe in detail the resource flow, the processes used at each stage, and the resulting mass balance (in tons, "t") for each category of WEEE. They show all the fragments (materials, components or substances) into which each category ("treatment line") is broken.

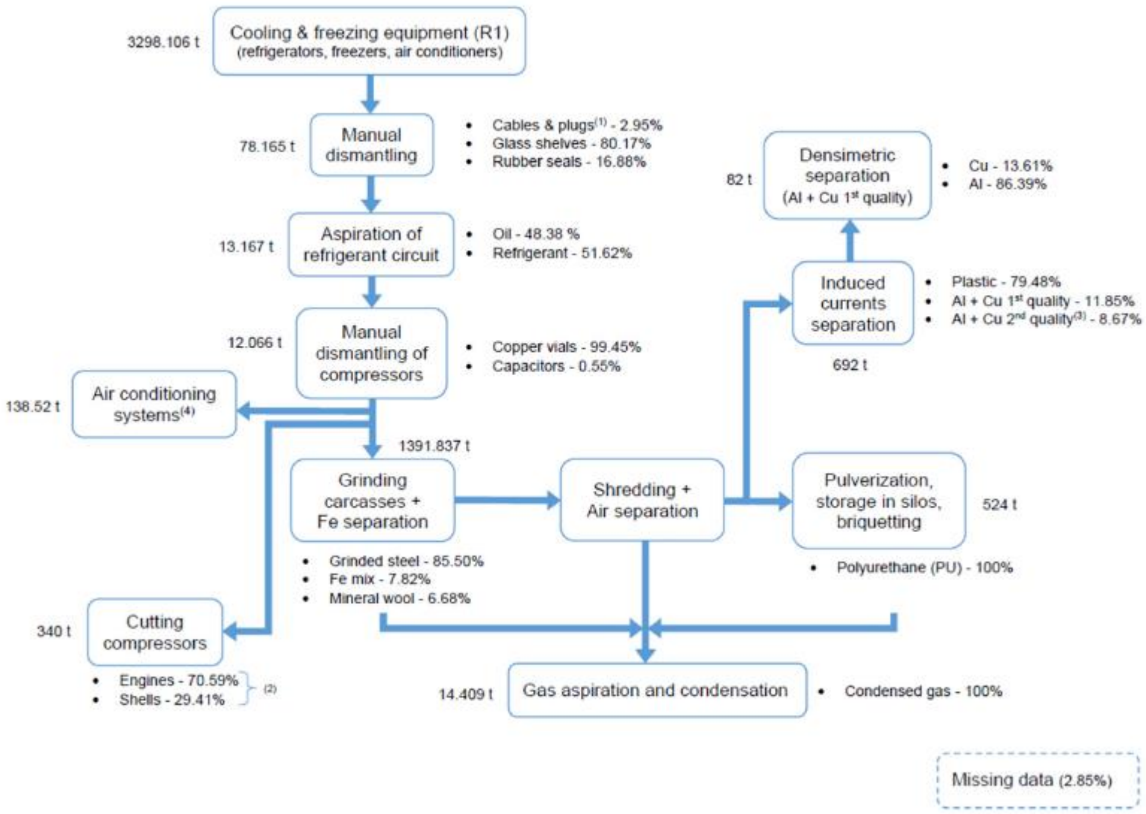


Fig. 1. Process scheme and detailed mass balance of R1 treatment line.

(Fiore *et al.*, 2019, p. 3)

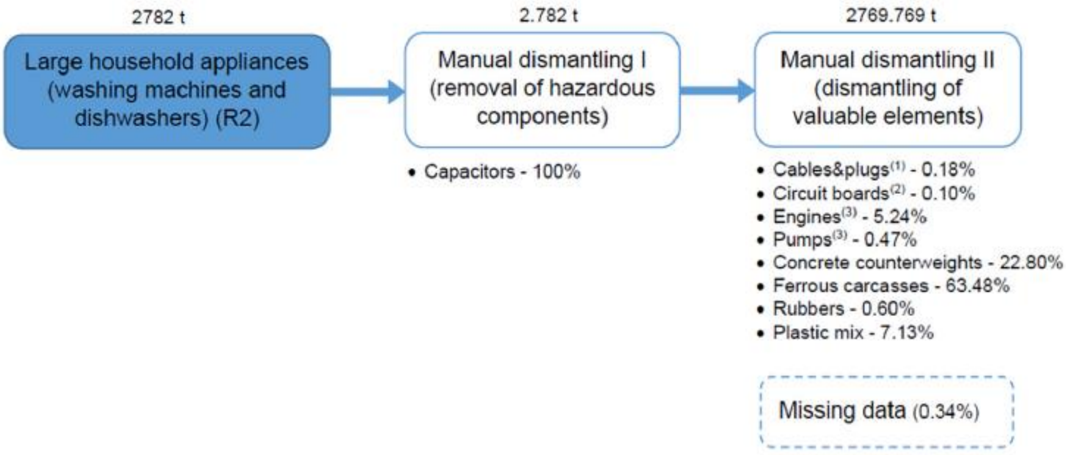


Fig. 2. Process scheme and detailed mass balance of R2 treatment line.

(Fiore *et al.*, 2019, p. 3)

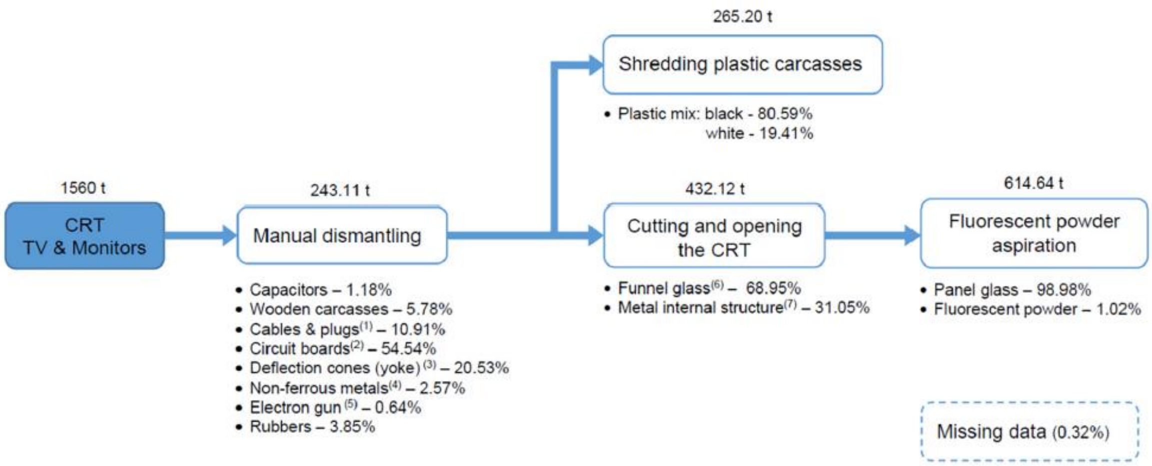


Fig. 3. Process scheme and detailed mass balance of R3 treatment line.

(Fiore *et al.*, 2019, p. 4)

This chapter has presented a reference of the optimal valorisation scenario in household appliances and will serve to identify gaps and opportunities in Mexico City's WEEE resource flow and management system.

Waste management system in Mexico City

Mexico classifies waste in three categories: urban solid waste, hazardous waste and special handling waste. States are responsible for the treatment of the first and the third, while the Federation is for hazardous waste (SEMARNAT, 2017, p. 46). Special handling waste is understood as waste that does not gather the characteristics of hazardous waste nor urban solid waste. It includes waste from construction and demolition, the automotive industry, tires, residual oils from restauration, furniture and other bulky products, and technological waste, including WEEE (SEMARNAT, 2021, pp. 29–35). States[4] are responsible for establishing guidelines and obligations for generators to prevent, valorise and realise an integral management, as well as to enforce their compliance through surveillance and imposition of sanctions. (Diario Oficial de la Federación, 2003)

The municipalities are in charge of the garbage collection system, run by a large workforce composed by both public workers and “volunteers”, all commonly known as *pepenadores* (waste pickers). Volunteers are not remunerated by the authorities but they make a living from recovering and selling recyclable materials. By doing so, these informal workers play an essential role in the valorisation of waste (Ramos, 2020). In 2019, Mexico City counted 15,464 workers (8,612 sweepers and 5,523 collectors), 1,329 of which are volunteers. (SEMARNAT, 2021, p. 39).

According to the norm NADF-024-AMBT-2013 enacted in 2015, which established a selective collection scheme, the garbage truck is supposed to pick up one specific type of waste every day of the week, to enhance separation at source: biodegradable waste, recyclable materials, inorganic waste and bulky or special handling waste (the latter includes WEEE and should be collected on Sundays). Garbage is then transported to transfer stations, compost plants, classification plants, compaction plants, and/or final disposal sites or landfills, depending on the type of waste. According to Nava (2021), from the 13,000 tons of solid urban waste generated in Mexico City, some 2,000 are separated by waste pickers at garbage collection trucks. To date, the recovery rate of the total solid urban waste is only 30.3% (SEMARNAT, 2021, p. 40).

The city’s management system for special handling waste is not differentiated from that of urban solid waste, nor is the generation of this waste stream calculated independently (SEMARNAT, 2020). Special handling waste that ends up in the municipal collection system is counted within urban solid waste in a national inventory, and represents 3.30% of inorganic waste (SEMARNAT, 2021, pp. 28–30). The city’s infrastructure for e-waste management consists of two selection plants where materials are classified, and those valuable are to be recycled. Every day 128 tons of e-waste are recovered; the rest (312 tons) is sent to compaction plants and used as fuel. However, according to the SEMARNAT, most of e-waste ends up in landfills: 2,813 tons a day (2021, p. 40).

The SEDEMA created the Reciclatrón to collect WEEE from households and micro-generators through itinerant collection points in different locations every month, where people can exchange their obsolete appliances for compost. This programme has collected 1.29 million tons of WEEE since 2013 (SEMARNAT, 2021, p. 41). The main appliances collected are TVs, monitors and computing equipment (García and Manske, 2019). WEEE are transported to a temporary storage location in the city, where they are disassembled, classified and sent to different private enterprises for their recycling (SEDEMA, 2019). However, the Reciclatrón has a very limited capacity; the city rather relies on private service providers to manage special

[4] Mexico City is considered as a state under the political division of the country.

handling waste. These authorised companies offer collection services or set collection points where citizens can drop off their old devices. Since 2015, these entities are registered at the RAMIR, the registry and authorisation of services or vehicles related to the integral management of special handling waste that operate in or transit through Mexico City. Integral management comprehends collection, transportation, recycling, reuse, and disposal. The RAMIR is managed by the SEDEMA (SEDEMA, 2022). Only authorised service providers can ensure a specific way to treat e-waste; through these, an effective valorisation and adequate disposition are more likely to take place. (SEMARNAT, 2020)

WEEE policy and regulatory framework

WEEE has only very recently been regulated in Mexico. E-waste is concerned by a number of national and local laws, norms and programmes. In this section I summarise the most relevant.

General Law for the Prevention and Integral Management of Waste (LGPGIR)

First published in 2003 at the national level, this law classified WEEE as special handling waste. It introduced three important principles: integral management, shared responsibility and valorisation, which shall be included in all policies, plans and programmes relative to waste management. First, integral management of e-waste consists of all activities directed to the reduction at source or waste prevention, separation, reuse, recycling, storage, transportation, and final disposal. These activities can be realised by generators of waste or third service providers. Secondly, integral waste management is understood as a "shared responsibility", principle that requires a coordinated and differentiated participation of producers, distributors, consumers, users of by-products and the government. Lastly, valorisation is defined as a set of actions oriented at recovering the residual value or the energetic content of the materials that compose waste, through their reincorporation to productive processes, under environmental, technological, social, and economic efficiency criteria.

The LGPGIR set general guidelines to be developed and instrumented in further policies. Some of the most relevant for the subject of study are the:

- Development of technologies and infrastructure for the integral waste management with the participation of private investors.
- Implementation of economic, fiscal, financial and market incentives for waste prevention and valorisation.
- Development of a market of by-products through financial instruments and an information system of the generation and integral management of each type of waste.
- Creation of a national diagnosis for special handling waste generation and management.

The LGPGIR was reformed in 2018 to introduce the concept of Circular Economy for the integral waste management, and incorporated the principle of Extended Producer Responsibility, but this only concerns plastic from packaging.

NOM-161-SEMARNAT-2011 and Management Plans

This national environmental norm, published in 2013 (Diario Oficial de la Federación, 2011), established that producers, international traders, distributors, large e-waste generators[5] and service providers are obliged to present "Management Plans" (here-on MP), reporting information relative to the waste treatment. The aim of this management tool is to minimise waste generation and maximise its valorisation. It involves producers, distributors, traders, consumers, users of by-products, large generators, and the government. Through MP, unnecessary disposal at landfills should be avoided. The NOM 161 established that WEEE generated at production processes or at the end of life are subject to MP (instrument that was introduced with the LGPGIR in 2003). The norm specifies the criteria to define which products or materials are subject to MP: 1) the actor has the needed infrastructure for their treatment, 2) the waste is generated in a high volume[6], 3) the waste is generated by a few generators, and 4) the materials have a high economic value (their treatment should be profitable). It should be noted that these criteria are rigid and could leave out many sources of e-waste.

MP are to be presented to and authorised by the corresponding authority (the SEDEMA in the case of Mexico City). Concerning e-waste produced after products' EoL, the obliged generators (producers) should report the following information:

- Potential sources of generation of the concerned waste
- An estimate of the volume generated
- Management process and involved actors
- The potential valorisation for every waste type, identifying specific productive processes or value chains where they could be reincorporated
- Recovery strategies (e.g. return mechanisms and reincorporation of waste to industrial processes) with defined targets in time
- Operation, control and monitoring mechanisms, with defined indicators
- Final destination of each waste
- Communication strategies targeting consumers to promote the prevention and correct disposal of the concerned waste. (SEDEMA, no date)

For waste types not explicitly subject to MP, these can be presented on a voluntary basis. Concerning WEEE discarded after EoL, the only listed products in the NOM 161 were: computers, cell phones, televisions, crystal and plasma screens, portable audio and video players, cables for electronic equipment, printers, refrigerators, air conditioning, washing machines, dryers, and microwaves.

States and municipalities in Mexico should control and monitor the integral treatment of special handling waste, mobilise generators to present their MP and elaborate a registry of the large

[5] Generators are entities that produce, directly or indirectly, special handling waste through their industrial, commercial or service activities. They are distinguished from Household generators, individuals who produce waste at home. Large generators are those who produce over 10 tons of waste a year.

[6] Representing at least 10% of the total amount of special handling waste included in the state's Basic diagnosis for integral waste management (excluding waste from construction).

generators and service providers present in their territory. Management plans are the mechanism by which the authorities can calculate the amount of waste generated, valorised, treated and disposed of in their territory (Ramos, 2020). With their input, the INECC elaborated the first annual Inventory of Solid Waste in 2007 for Mexico City, where special handling waste is included. Ever since, few studies concerning WEEE have been done in the country, mainly the Diagnosis about the Generation of WEEE in Mexico (2007) and the Inventory of WEEE Generation in Jalisco, Baja California and Mexico City (2015).

Apart from generators and waste treatment service providers, states are also entitled to develop and manage systems of collection, storage, transportation, treatment, valorisation and final disposition of special handling waste (Córdova, 2019).

NADF-019-AMBT-2018

Mexico City was the first state in the country to issue a specific law relative to WEEE treatment after EoL, although no equivalent exists at the national level. This norm states that valorisation should be attained through reuse, refurbishment, recycling, and recovery of secondary materials or energy from e-waste. It establishes the correct separation and classification as well as the specifications for the correct treatment of WEEE. Since its entry into force in 2020, the NADF 019 obliges producers, traders and distributors of EEE to present MP directly or through third parties (service providers) by 2021. They should take back obsolete EEE of their customers, at no cost for them. This instrument requires generators to deliver waste to authorised service providers if they do not have the capacity to treat their own waste.

Additionally, this instrument defines the conditions under which e-waste should be treated at all stages, requiring special facilities. Before recycling or final disposal, an assessment should take place to determine whether the EEE have certainly reached their EoL or can be refurbished and reused. Service providers should only realise the management activities for which they are authorised (collection, dismantling, transportation, etc.). Service providers should avoid that non authorised individuals have access to WEEE.

The NADF 019 enlarged the initial list of EEE of the NOM 161, including the following devices:

No.	Category
1	**Temperature exchange equipment:** Refrigerators, freezers, air conditioning and cooling appliances, among others.
2	**Monitors, screens and appliances with screens larger than 100cm2:** Screens, TVs, computers, among others.
3	**Lamps:** Fluorescent lamp, LED lamp, among others.
4	**Large appliances:** Washing machines, dishwashers, stoves, electrical ovens, among others
5	**Small equipment:**

	Vacuum cleaners, sewing machines, microwaves, fans, irons, toasters, electrical knives, boilers, clocks, shaving machines, scales, appliances for hair and body care, small electrical and electronic tools, among others
6	**Small IT equipment:** Cell phones, GPS, pocket calculators, laptops, printers, telephones.

Source: (Gaceta Oficial de la Ciudad de México, 2020, p. 14)

The norm specifies this list is not exhaustive.

Programme for the Integral Waste Management (PGIR)

The PGIR 2021-2025 is explicitly based on the Circular Economy. For the first time, it put together environmental and social objectives to improve the waste management system (Reyes, 2022).The PGIR set the ambitious target of reducing by 75% the amount of waste sent to final disposal through its various waste management plans. For this, it agreed on around 300 objectives with important stakeholders. In what concerns WEEE, the PGIR aims to enlarge the RAMIR and the number of Management plans; to build a solid infrastructure for the valorisation of e-waste through economic incentives, and to introduce ecolabels in traded products. Furthermore, the programme pursues a transition towards the CE in the industrial, trade and services sectors of the city by developing a “symbiosis platform” that would work as a bank of materials where companies will be able to trade waste. An information system of special handling waste management in the City, consisting of a web site for data consultation, will also be developed. Another relevant target is the promotion of a secondary materials’ market, for which the SEDEMA will seek to agree fixed prices for materials poorly valued to date (e.g. glass). (SEMARNAT, 2021; Reyes, 2022)

Additionally, the PGIR seeks to enhance the Reciclatrón with an increased number of collection events, locations and partners. Regarding consumers, the programme intends to educate children at schools and citizens through communication campaigns to understand the problematic of waste, its management system and the importance of separation at source. Lastly, the programme dedicates a chapter for employment promotion, which refers to informal waste managers, a “historically forgotten sector” (2021, p. 96) that the government intends to acknowledge. The PGIR pursues the sector’s professionalization through skills’ development, financial access to strengthen recycling entities and to support to create new ones. It intends to improve working conditions through the provision of protection equipment, training on security and health measures and monitoring visits to working centres. Another relevant target is the recognition of skills for repairing, refurbishing and remanufacturing WEEE in the national list of skills “CONOCER”. This means a standard of WEEE skills will be defined, together with the proper processes and security measures to be followed for a safe and optimal e-waste handling. Digital resources will be elaborated for this purpose, allowing for workers to further develop their expertise (Reyes, 2022). In order to achieve these objectives, the PGIR is linked to the programme “Promotion of Decent Work”, operated by the Ministry of Work and Employment Promotion (STyFE), under a scheme of training and temporary employment and support for entrepreneurs. Since 2019, 47 projects related to waste management have been deployed. In 2020, 2261 people benefited from it. (STyFE, 2021)

NOM-015-ENER-2012 and NOM-005-ENER-2016

These norms oblige manufacturers to present a label of energy consumption in certain products to promote energy efficiency by informing consumers (García and Manske, 2019). Water heaters, washing machines, refrigerators and freezers, air conditioning equipment, stoves, among other household appliances, are subject to them. (CONUEE, 2014)

Security norms

In addition, 16 national labour and health norms regulate the conditions under which e-waste management activities should be undertaken, specifying security measures regarding facilities, machinery, equipment, storage, and electric installations; protocols to manage dangerous chemical substances with personal protection equipment and strict surveillance; as well as risk identification and prevention practises. These aim to protect workers from accidents, intoxication or diseases, and avoid environmental hazards (See SEMARNAT, 2017, pp. 73–80). Workers should wear gloves, glasses, ear plugs, safety clothing and shoes, vest, respirators, helmet and lumbar belts for their security (Cordova-Pizarro *et al.*, 2019). Nonetheless, very few authorised companies comply with only a few of these regulations (SEMARNAT, 2017; Álvarez, 2022).

Infrastructure to manage WEEE in Mexico and Mexico City

In this section I will present the main actors involved in e-waste management and the most relevant initiatives at the national and local level. It will be seen that on the side of manufacturers there are only a few and sporadic campaigns focused on WEEE collection, mainly targeting IT equipment. The lack of consistent collection efforts of the industry and the government has left space for civil society to take action. I then describe the infrastructure to treat e-waste and the capacities of both the formal and informal sectors. Some considerations about the repair industry and consumer behaviour are included, as they play a fundamental role in e-waste generation.

EEE manufacturers

In Mexico, only a few manufacturing companies and distributors of electronics collect obsolete appliances at their stores, and they often do so through sporadic campaigns. García et Manske (2019) and Córdova (2019) identified the most relevant WEEE recycling campaigns at the national level, described in the following table. As it can be seen, most collection initiatives target IT and computing equipment, and only a few treat household appliances.

Brand	WEEE collected	Actions	Considerations
HP	Cartridges	Collection, recycling and disposition	Free domestic collection for over 5 cartridges
Dell	Laptops, computers, monitors, printers, scanners	Collection for reuse (donation and second-hand sale)	Only for Dell's products. Free domestic collection.
Samsung	Cell phones	Discount in a new purchase	Only for Samsung's products
Panasonic	Cell phones, telephones, fax, projectors, TVs, batteries	Recycling	Collection centre
Apple	Cell phones	Recycling	Only for Apple's products
Apple- PROAMBI	Computers, audio players, etc.	Collection, recycling	"Green Day" campaign, where consumers deliver old devices in exchange for gift cards to purchase new equipment.
Six-Flags, Movistar & TBS industries	Cell phones	Collection, compacting, exportation for processing	Sporadic initiatives, e.g. 1 month campaign where 5000 cell phones were collected
Motorola	IT equipment	Collection, recycling, final disposal	Consumers can deliver old devices from any brand in special containers
Telcel, Movistar, Iusacell	Cell phones	Collection	Permanent collection points at service centres
Walmart	Electronics	Collection	Only some locations accept electronics

Source: By author, from García et Manske (2019, p. 57), Córdova (2019, p. 61) and Ecolana (2022)

Civil society

In response to the e-waste problem and the lack of sufficient action in the government and the industry, civil society has played an important role in the collection of WEEE, by mobilising campaigns in schools, universities, cultural events or public spaces. In Mexico City, Huerto Roma Verde and Ectagono are community centres that have set recycling points where citizens can deliver their electronics. Punto Verde is a civil association that promotes sound electronics recycling through collection campaigns and 30 permanent collection points in all the country (Córdova, 2019, p. 61). It developed the app “Collect, Deliver, Recycle” (Junta, entrega y recicla), where consumers can register and ask for a domestic collection service by specifying the type and amount waste and by paying a fee. Again, this initiative only takes IT equipment (printers, laptop, cell phones, chargers, speakers- only ovens and monitors from our products of interest). Punto Verde is the only initiative that additionally promotes the prevention of e-waste through eco-design and EPR schemes by working with manufacturers (Punto Verde, 2022).

E-waste managers

WEEE management can be classified into four categories:

Level	Management activities
0	Collection, transportation and storage.
1	Gross separation of non-electronic waste.
2	Gross selection of recyclable materials and components with economic value; treatment or disposal of hazardous substances or parts; refurbishing and reconditioning of EEE.
3	Refining of materials and elimination of toxicity.

In 2017, 153 authorised companies providing e-waste treatment services were identified at the national level, with a total capacity for treating 235,859 tons per year. SEMARNAT (2017) estimated the total amount of the country’s e-waste generation at 383,424 tons for 2016. Twelve service providers operated in Mexico City, with a total treatment capacity of 24,884 tons of WEEE per year. These numbers, which do not even include the imported waste, show that the existing infrastructure is largely insufficient to treat the actual volume generated. Moreover, the vast majority of service providers in Mexico focus on the simplest management activities: collection, transportation and storage (69%) -and most of them stay only in the first. The remaining 31% does selective separation, equivalent to a capacity of managing 73,388 tons per year (SEMARNAT, 2017, pp. 14–15). Only 6% treated hazardous materials from WEEE and reconditioned obsolete equipment (García and Manske, 2019, p. 61). Not one single enterprise realised refining, which represents the most profitable activities in WEEE management. Toxic components or materials, together with PWB containing precious metals are rather exported to be processed in other countries (SEMARNAT, 2017). As of February 2022, the RAMIR counts 128 service providers in the country, 63 of which specified to operate in Mexico City, 11 handle WEEE and only 2 explicitly take household appliances. All those 11 focus on collection and transport, some also in storage, and only one does trituration additionally (SEDEMA, 2022). Ecolana maps 10 recycling entities that take cooling equipment and white goods in Mexico City (cookers, washing machines, dryers, frigdes, freezers, etc.) (2022).

The fact that no service provider realises refining is due to the lack of infrastructure to do it. Refining metals requires high-temperature ovens that are only available in a few developed countries. Córdova (2019) estimated that Mexico's economic loss from the PWB extracted from cell phones and exported -in the formal market- is equivalent to up to 12.4 million dollars (p. 145). Investors are interested in introducing the needed technology and equipment to do final processing in Mexico, but the low levels of WEEE collection would not allow to recover the investment in less than 5-8 years (p. 131).

The formal infrastructure to treat e-waste in the city and in the country is insignificant compared to the informal economy involved in this sector. Informal actors are in charge of 80% (García and Manske, 2019) to 90% (Córdova, 2019) of collection and recycling of WEEE in Mexico. It is estimated that some 100,000 informal individuals, and their families, work in this sector in Mexico City. Overall, there are 5,000 collection centres –formal and informal- employing around 30,000 workers in the city. (El Informador, 2021)

Electronics' repair industry and consumers

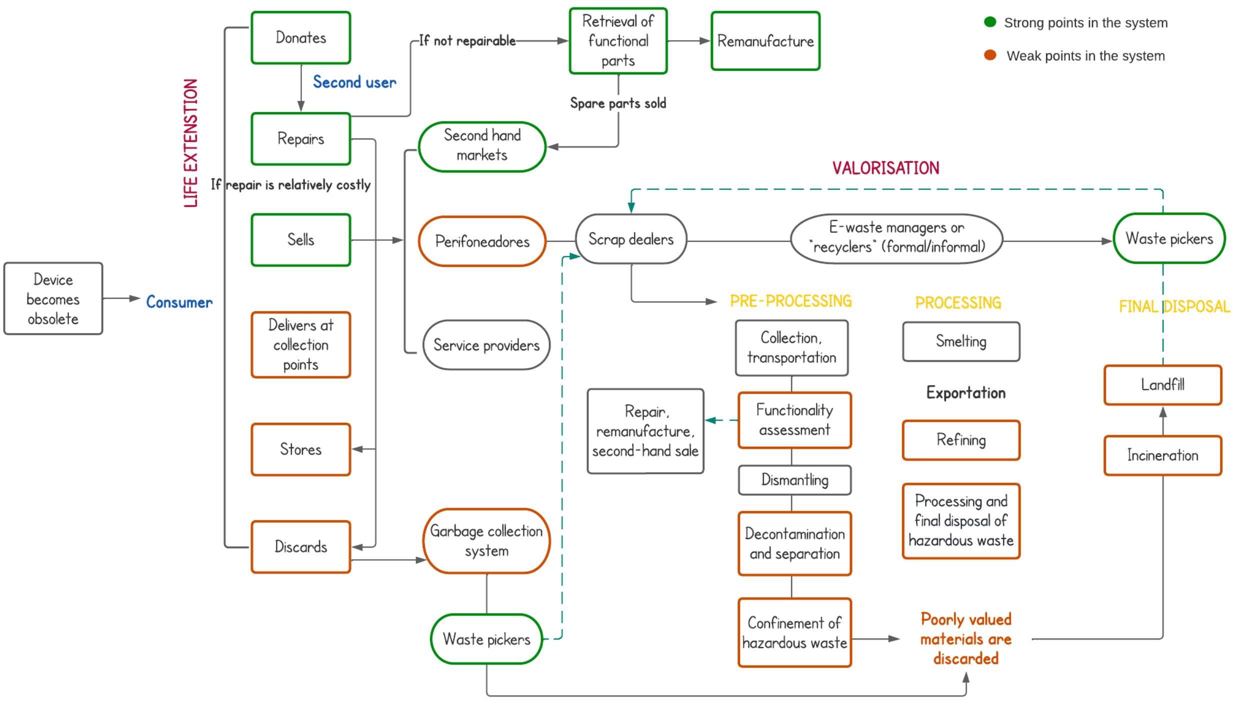
Mexico City has a considerable EEE repair industry, with 11,100 workers[7] and 2,873 establishments, most of them micro enterprises according to the National Survey of Occupation and Employment (ENOE)[8]. The informal economy predominates as well, with 56.8% of workers (Data México, 2021a, 2021b). Informal repair shops, with no proper facilities nor safety measures, cheap labour (child labour being common), rudimentary tools and generic spare parts (half the price of original parts), have a competitive advantage over formal ones, and offer faster services (48 hours on average to repair electronics vs 5 days in formal businesses) at a similar quality and lower prices (Córdova, 2019, p. 143). At the international level, repair and refurbishment services are often specialised in smartphones, laptops and computers, and less available for other electronics products (PACE and Accenture, 2021).

Consumer behaviour in the use of electronics is directly related to socio-economic level. An electronic device can be repaired up to three times if the repair service is not costlier than purchasing a new product. However, in Mexico, an expensive repair is the main reason for all economic classes to consider that an EEE is no longer functional (the lower the class, the more this often occurs). Likewise, discarding appliances due to faults in the operative system or in the battery are more common as classes descend, which can mean that the higher class is more willing to pay for their repair. By opposition, the higher the class, the higher the tendency to discard EEE and replace them by newer, improved items. This phenomenon, functional obsolescence, has little effect in low classes. (Córdova, 2019)

[7] Technicians dedicated to repairing electronic, telecommunications and household equipment.
[8] Businesses offering repair and maintenance services for electronic equipment and precision equipment

Waste flow from electronic household appliances in Mexico City

Once electronic household appliances are discarded by consumers, they usually enter the following resource flow, where they have three possible outcomes: reuse, secondary material for production chains, or final disposal at landfills.



Source: By author, from interviews, on-site visits and previous studies (Cruz-Sotelo *et al.*, 2017; SEMARNAT, 2017; García and Manske, 2019)

Firstly, consumers can choose to donate their appliances to relatives, friends, acquaintances, people that provide services to families (gardeners, domestic workers, drivers, etc.) or to associations, descending through social classes. This is mainly the case for bulky appliances, which are costlier, hard to manage and transport, and less likely to remain stored. (Ingeniería y Desarrollo Sustentable, 2010) Secondly, consumers should in theory be able to return their EEE to their provider, although no such return mechanisms for household appliances were found in Mexico City. Alternatively, consumers can deliver them at the Reciclatrón, at collection centres from service providers, or sell them to scrap dealers (*perifoneadore*s or *chatarreros* in Spanish). They can also be delivered directly at the garbage collection truck (on Sundays); when it comes to large appliances, waste pickers will usually ask for a stipend. According to Ingeniería y Desarrollo, (2010), hair dryers, irons, coffee-makers, blenders and EEE with similar characteristics often end up in landfills. This is less likely to happen with large appliances.

Perifoneadores are individuals who collect a large variety of discarded items directly at people's homes. They commonly drive a pick-up in residential areas around the whole country. Their name comes from the word periphonate, as they use a megaphone to announce themselves in the streets. *Perifoneadores* accept almost any item containing iron, one of the most valuable materials within WEEE. In most cases, they are informal workers.

Perifoneadores charging scrap in their pickups.
Source: Ríos (2021)

Another relevant source of WEEE is found at repair services. When devices are not repairable, functioning components are retrieved and sold at second hand markets. This can be clearly seen in Artículo 123, a street located in the city's centre that concentrates many repair businesses. Some establishments are specialised in repairing specific devices or product brands. They repair all types of household appliances, sell original spare parts and also faulty equipment (from manufacturers) at low prices. Only hair dryers and irons –it was observed- are not easy to repair, and few businesses accept them, for spare parts are rare and, being cheap products, customers find it more convenient to purchase new ones. As for the e-waste generated, some establishments have set arrangements with scrap dealers to whom they sell mainly metals, but this practise is not widespread. The remaining waste is discarded in the streets (rubber, plastic, glass, etc.), where the garbage truck or street pickers come in.

According to Córdova, who studied 66 repair formal and informal shops (specialised in cell phones) in the country, non-valuable materials are often thrown at rivers, buried or, in the best of cases, sent to landfills. 13% of the analysed shops donate obsolete phones and 15% give them to a specialised recycling entity, once or twice a year (2019, p. 116). The author states that all parts and components from electronics tend to be reused and e-waste generation at repair shops is minimal; yet where there is, it is most likely to be thrown at the common garbage. From interviews with *pepenadores*, we know that when EEE are discarded in the garbage truck, waste pickers themselves recover appliances to repair for their own use; if they are not repairable, they sell the materials to scrap dealers. At the end of the chain, scavengers pick up remaining valuable materials in landfills for their sale.

In sum, WEEE is valorised by a complex chain of formal and informal actors operating in a dynamic market and a highly organised system. Waste travels through numerous intermediaries with an increasing treatment capacity. After *perifoneadores* and *pepenadores* come intermediary scrap dealers and e-waste managers. These have different capacities of collection, transport, storage, pre-processing and recycling. Some of them play more than one role. As e-waste is pre-processed (disassembled, decontaminated, classified, etc.) by higher-capacity entities, prices of materials increase along the chain. The extent to which WEEE is valorised depends directly on the management capacity of each actor: the higher the capacity, the higher the degree of valorisation. At the end of the chain, a fundamental contribution is made by waste pickers and scavengers, who reincorporate discarded materials along the WEEE flow to the market, diverting them from landfills.

Valorisation of waste from household appliances

Before pre-processing, according to a study of 12 large volume firms by Córdova (2019) 58% of electronic waste can be reused and enter a second-hand market. Thus, their main business is reconditioning and remanufacturing WEEE (2019, p. 104). From this figure it could be interpreted that the large capacity of recycling entities might play a role in whether repair and remanufacture is carried on in WEEE treatment or not.

The most valorised materials are metals, plastics, cables and printed wiring boards (PWB), which can be reused or transformed into secondary resources for production chains. The vast majority of actors in this chain leave aside the non-valuable components (Cruz-Sotelo *et al.*, 2017). The general degree of valorisation can be visualised in the following table. Non-valuable materials are those who have no commercial value or whose treatment is not profitable and often end up in landfills.

Highly valued	PWB Aluminium, steel, iron, copper Cables
Poorly valued	Plastics, glass, rubber Electronic components: circuits, transformers, capacitors, clipboards, processing units
Non-valuable	CRT Batteries Refrigerant gases, grease, insulation foams

Source: By author, from Cruz-Sotelo et al (2017), Álvarez (2022)

Collection rates per material are explained by prices in the market, which are constantly fluctuating, but they are also determined by their abundance. The largest entities –formal or informal- can obtain a higher value from recovering the not-so-valuable materials, such as plastics, glass and rubber, as they can collect, store and treat significant volumes, as opposed to individual waste pickers.

Prices on Mexico City, February 2022

Material	**$/kg**	**€/ kg**[9]
PWB	250*	11.27
Copper	140-172	6.31-7.75
Nickel	100-120	4.51-5.41
Iron	62	2.8
Aluminium	20-35	0.9-1.58
Lead	25	1.13
Steel	10-13	0.45-0.59
PET	8.5-13	0.38-0.59
Batteries	7	0.32
Glass	0.4	0.018

Source: By author. Data from the price list exposed at a collection centre in Mexico City (as of February 2022) and Alejandro Sosa (2022, p. 24). The price of the PWB was taken from Cota and Smith (2016)

Price list at a collection centre in the colonia Independencia, Mexico City

Source: Picture taken by Sebastián Gómez Garcés on February 2022.

It turns out that valorisation of waste from household appliances is especially difficult relative to IT equipment, mainly cell phones and laptops, due to several factors. For instance, IT devices have shorter obsolescence periods and are more frequently replaced. Lifespan ranges from 2-5 years for mobile phones and personal computers, 5-7 years for TVs and around 10 years for washing machines, dishwashers, refrigerators and air conditioning units (Fiore *et al.*, 2019, p. 2). This makes their market of waste abundant and attractive for recyclers. More importantly, the quality and value of their materials are much higher, and so is the share of precious metals they contain (Álvarez, 2022). Consequently, they are highly valuable in the market, and their

[9] Prices converted at a rate of 1€ = $22.18.

treatment a self-sustainable activity for recyclers (Córdova, 2022; Núñez, 2022; Álvarez, 2022). By contrast, household appliances are less valuable, costlier and harder to treat, thus not a profitable business. Large household equipment contains an insignificant amount of precious metals relative to their size; large and cooling devices have many non-valuable materials (insulation foams, CRTs, batteries, gases and oil). Household appliances increasingly contain more rare earths (in electronic circuits and magnets) (Álvarez, 2022). Yet Mexico has no infrastructure to recycle batteries, to treat CRTs nor to recover rare earths. Therefore, they end up in permanent containment (buried), which is costly for recycling entities. Treating these and refining PWB would require the introduction of expensive specialised technologies and significant upfront investments. Lastly, domestic appliances are in general hard to dismantle due to adhesives and insulators, as opposed to small IT.

In sum, recycling household appliances is not a profitable business, which explains why so few entities are specialised on them. In fact, many service providers do not take household appliances. Proambi, one of the biggest recycling companies in Mexico, only accepted them at a cost for owners, but eventually decided to exclude them completely (Álvarez, 2022). Moreover, in recent years, the long durability of household appliances has been progressively reduced due to planned obsolescence. Breakdowns and malfunctions are appearing earlier and are increasingly harder to fix. Smaller transistors, for example, are more difficult to repair. As products become cheaper, their quality is reduced, obliging consumers to replace them more frequently (Peña, 2021). Furthermore, ever more sophisticated electronic products hinder their repair, disassembly and recycling (Córdova, 2019). Material complexity (alloys or composite materials, adhesives, hazardous substances, etc.), makes it hard to pre-process e-waste and to obtain the purer steams that are needed for high quality recycling. (PACE and Accenture, 2021)

In the following sections, I will describe the actors, capacities, processes, tools and degree of valorisation of WEEE at the formal and the informal sector.

Valorisation at the formal sector

The largest companies have the highest capacities of transportation, storage and management, a large staff and specialised machinery that allows to recover most of the components and materials from WEEE. However, most of the service providers in Mexico are small and medium enterprises, and big differences exist in their capacities (SEMARNAT, 2017). According to Cruz-Sotelo et al (2017), their source of WEEE is most commonly collection campaigns, collection points and logistics services.

Processes are basic, based on manual operations and mechanical systems. Medium and small waste managers use rudimentary tools and equipment, such as manual, electric and, less often, pneumatic screwdrivers, but no sophisticated machinery. Machinery for mechanical separation process include crushers, magnetic separators and metal compactors (Córdova, 2019). The main recovered materials are: ferrous and non-ferrous metals and plastics (through mechanical shredding), aluminium, copper, cables, chargers, PWB, electronic circuits (through manual fragmentation), data processing units, CRT’s alkaline batteries and displays; glass is less often recovered. From motors, usually only copper is valorised. According to SEMARNAT (2017, p. 106), the distribution of recovered waste in a year for a small enterprise (220t/y) is as follows: 57.7% of iron, 37.3% of plastic, 3.2% of aluminium and 0.9% of PWB. More specific separation of materials is done if clients demand it. However, the higher the separation, the more time and labour it requires, increasing the cost of the process.

Typical medium recycling centre in Mexico City

Source: Picture taken by Mariana Sosa, on March 2022 in the colonia Narvarte, Mexico City

The recovered materials are then sold to third parties for their re-processing. Metals are sold to smelters. Cables, chargers and parts containing copper are smelted to recover metals. In the case of the Reciclatrón, recovered materials are used to produce cases for new EEE, valves, electrical conductors, aluminium frames, steel mesh, nails, among others (SEDEMA, 2019). As Mexico lacks end-processing technologies to recover precious metals from PWB and other electronic components through refining, these are exported to Canada, Europe and Japan, countries that obtain their value. Some enterprises also export part of the collected aluminium and plastic, whereas all ferrous metals are processed in Mexico. Few enterprises do minor reparations (SEMARNAT, 2017); most of the collected WEEE are discarded without having been assessed and reconditioned, even when they are still functional (SEMARNAT, 2021).

Toxic waste is supposed to be confined before their final disposal, which is done through other authorised service providers in Mexico and sometimes in the US (Cruz-Sotelo *et al.*, 2017). Grease and refrigerant gas should be extracted with special equipment (Álvarez, 2022) and could be re-merchandised through authorised entities (Ingeniería y Desarrollo Sustentable, 2010). Non-recyclable waste should be disposed at authorised landfills (Cruz-Sotelo *et al.*, 2017). However, given the aforementioned regulatory context, this is not necessarily the case.

Valorisation at the informal sector

The informal sector of WEEE management is composed by the "volunteers" involved in the municipal collection systems (street and truck waste pickers), by scrap dealers, e-waste managers (disassemblers, classifiers, and even smelters and refiners!), and lastly, scavengers picking waste from landfills[10]. Informal actors can operate individually but they usually run family businesses, where all members take part, including women and teenagers. In larger structures, additional workers can be hired temporarily (García and Manske, 2019). Informal actors work in their own homes, in small workshops or even in the streets (Cruz-Sotelo *et al.*, 2017). In general, they realise the same activities than formal entities, although with less sophisticated techniques and under more precarious conditions.

According to their size (staff, storage facilities, vehicles, and tools), they can treat higher or lower volumes of WEEE. While some businesses can recover almost all materials and components, many individual workers lack the knowledge, skills, tools, and the facilities to recover the not so valuable resources. Quite frequently, unusable or hazardous substances or components are discharged at the common garbage, left on sidewalks or in illegal landfills (Cruz-Sotelo *et al.*, 2017), or dispersed in the environment in the dismantling process. In the case of monitors, for example, waste managers commonly shred the plastic parts to recover metals, liberating toxic gases that should be captured. Leachates generated at e-waste treatment are washed away by rain and reach the sewers and underground waters (Álvarez, 2022). Informal workers generally ignore the consequences that unsafe management practices can have on their health, such as burning parts adhered to metals and plastics, with no masks, gloves and eyewear, nor security measures. Some realise artisanal smelting, using dangerous and far from optimal methods such as roasting and acid baths to recover precious metals from printed circuits. Artisanal recycling liberates high amounts of toxins, lead and acid vapours which cause numerous diseases. (OIT, 2015, pp. 21–22)

The colonia Renovación is the most relevant place where the informal economy involved in WEEE recycling in Mexico City and in the whole country operates, within one square kilometre (SEMARNAT, 2017). This neighbourhood was built over garbage decades ago, when communities started settling around an old landfill and recovering valuable materials from waste to make a living. This business has been inherited from generation to generation up to the present. Some 14 years ago, this community started treating WEEE, in which they are now specialised (Cota and Smith, 2016). A big part of the aforementioned treatment chain

[10] "Recyclers" is informally used as a broad term to refer to all actors involved in waste management activities, by themselves, by their syndicate and by public authorities in Mexico.

eventually ends up in this neighbourhood, through numerous dealers. In some cases, authorised service providers directly supply WEEE. Even the public cleaning service from certain municipalities discharge e-waste on the site (García and Manske, 2019). Additionally, dealers from the northern border carry e-waste that has been illegally discharged from the US to Mexican territory to be treated at this neighbourhood. Others bring faulty devices sold at low prices by manufacturers at auctions.

The recyclers' houses serve as warehouses and workshops. Only 30% of the businesses has facilities destined specially for storage (SEMARNAT, 2017, p. 167). Entire families take part in the recycling process. They disassemble devices with hammers, screwdrivers, tweezers (García and Manske, 2019) and chisels for tools. Devices are shredded to obtain the valuable materials. Cables are burned all night long to remove the plastic and recover the copper contained in it. (Cota and Smith, 2016). Metals are flattened in rollers to be sold. Potent acids are used in artisanal recycling processes (Cota, 2022). Besides metals, copper, plastics and PWB, some businesses recover glass. Reusable components are sold to repair shops or second-hand markets selling spare parts for reconditioning (SEMARNAT, 2017). Moreover, the colonia Renovación has a sales centre where shipments of PWB are exported to Japan, Sweden Belgium and the US (Cota and Smith, 2016). Whatever is left is placed in the sidewalks, where municipal waste pickers collect all. According to SEMARNAT (2017) it can be assumed this is sent to landfills.

In the whole processing, no security measures are followed either, nor special equipment is used to protect workers from toxic substances. The concentration of recycling businesses in this location has made health problems related to bad e-waste management practices visible and alarming. The neighbourhood has seen a clear increase of diseases including pulmonary emphysema, fibrosis and bronchitis, as well as neurodevelopmental disorders, retarded growth and immunodeficiency in children, which are symptoms of lead poisoning (Cota and Smith, 2016). Children are the most vulnerable to health risks from exposure to heavy metals in WEEE processing, in which they sometimes take part. (OIT, 2015)

SEMARNAT identified between 20 and 25 recycling businesses in the neighbourhood with a processing capacity of 220 tons of WEEE per year, the majority focused in level 2 activities (gross selection, disposal of hazardous substances, refurbishing). Their total capacity would rank between 5,000 and 10,000 tons per year (2017, pp. 218–219). Yet according to Cota and Smith (2016), only the largest recycler processes 100 tons of e-waste each month. Interviewed informal recyclers stated that between 90 and 100% of WEEE is valorised in the sector. Having personally observed the repair workshops operating at Av. Artículo 123, and under the view of the journalist Isabella Cota, who undertook an 8-month on-field research in the colonia Renovación and who describes it as a "highly efficient system" where all recoverable materials are valorised (except for those liberated into the air, as there are no means to capture them), this empirical percentage is not hard to believe. According to Córdova (2022), very few electronic appliances can be found in landfills.

Recyclers treating e-waste in the street in Renovación, Mexico City, 2016

Source: Cota and Smith (2016)

However, numbers remain unknown and will continue to be so as long as this industry operates clandestinely. The major recent research project that has attempted to study it, carried out by SEMARNAT (2017) failed to collect much information, due to the lack of trust from the workers. I myself encountered many barriers to find information on the subject; several workers refused to talk about their job, and more than one advised me to stop inquiring. Two of the interviewees who also researched this topic were threatened for it.

Why so clandestine: crime, interests and power around WEEE management

As large, well-established, and organised as this conglomerate is, not one single recycling business in the neighbourhood has an authorisation to treat e-waste. The existence of this "clandestine" industry is well-known by all the concerned authorities in the city. Yet no action has been taken to regularise, sanction, or address the situation. No workshop has been ever closed or sanctioned (Cota, 2022). This situation is not surprising in a country where businesses operate in a deeply corrupted political system. Neither is it a surprise that the entire recycling apparatus functioning in the colonia Renovación is linked with criminal groups and criminal activities. Beyond WEEE management activities, families are involved in drug dealing, arms trade, kidnapping and prostitution. In fact, Renovación is the most dangerous neighbourhood in the city. Other than warehouses to store WEEE, households also serve as security houses. Men armed with AK47 are visibile everywhere in the streets. Even the police works for the organised crime in this zone.

Santa Fe, west of the city, has a similar but much smaller apparatus. The cartels ruling both zones are coordinated and define their respective territories within Mexico City. The link of these two niches with organised crime does not mean that all informal workers involved in WEEE management belong to criminal gangs. Nonetheless, like with any mafia, they are obliged to pay a quota to the organisation in power in the territory in which they operate, and they cannot trespass it. According to Cota and Smith (2016), the floor fee can rise to 6000 pesos a month (270 euros). Landfills are also controlled: armed individuals block the entry even to the municipal authorities; scavengers are allowed to enter after every discharge to recover materials by paying their quota (García and Manske, 2019). Overall, WEEE recycling is not centralised nor controlled vertically; informal players can work autonomously as long as they respect the rules. (Cota, 2022)

Despite informal management of WEEE being illegal, unsafe, linked with crime, diseases, labour precariousness and exploitation, workers have chosen this job. Recycling is a highly profitable activity and can actually pay much better than many manual jobs (García and Manske, 2019). According to one interviewed worker at a small collection centre, one can earn some 6,000 pesos a month (270 euros), twice than a factory wage. Cota (2022) states that many of the workers she interviewed in Renovación had previously been blue-collar workers in factories and enterprises, where they suffered all sorts of abuses, including miserable wages, privation of employment benefits, and being fired then hired again to avoid generating seniority. The prevalence of labour abuses in the Mexican labour market pushes a large number of workers towards the informal economy. Furthermore, she explains, Mexican workers prefer to perform as autonomous entrepreneurs: it is in our culture. Lastly, many barriers hinder the formalisation of this type of activity, starting with low access to financial support (García and Manske, 2019), complicated bureaucratic processes to constitute an enterprise, and high taxes.

Other than the aforementioned organisations present in the waste management system, waste managers are affiliated to powerful associations and syndicates, notably the National Confederation of Recyclers (CONIMER). In recent years, these have made notable efforts to protect the employment of recyclers from legislative initiatives that have menaced them. In 2019, through massive protests, the confederation managed to block an initiative that pretended to impose tariffs to recyclers. It has firmly denounced the government's intentions to "privatise" waste management by granting concessions for treatment projects to big firms, and a project to co-process waste for energy production, which would displace the entire recycling industry. During the discussions around the General Law for the Circular Economy (in process of approval) CONIMER managed to set a dialogue with the Senate to have the informal workers recognised in the legislation. The association has also obstructed the implementation of the selective collection of waste that the garbage trucks should follow since 2015, as collecting special handling waste at households would affect the jobs of *perifoneadores*. Even though this activity is illegal if vehicles are not authorised by the SEDEMA, and could imply high fines and even prison, megaphones that announce *perifoneadores* can be heard daily all around the city. The CONIMER supposedly advocates for the regularisation of the sector.

Interaction between the formal and informal sector

The informal sector presents several competitive advantages over the formal one for a number of reasons. For instance, under informality, workers are exempt from investing in the facilities, machinery and protection equipment required by law, which are costly. As opposed to formal enterprises, they do not pay taxes nor contributions for the health and pension systems. This difference in operative costs leaves informal businesses a margin to buy waste at lower prices than authorised entities (OIT, 2015) –at no expense of their own earnings, which are similar or higher than the wages offered at formal enterprises. Earnings can range between 2800-4800 pesos monthly in a small to a medium recycling entity respectively, and up to 6,000 in the colonia Renovación (SEMARNAT, 2017, p. 168). According to Córdova (2022) informal actors can earn two or three times what formal actors when recovering materials from WEEE.

Additionally, at-door collection, in a city where very few residents deliver their WEEE at authorised centres, allows informal scrap dealers to take most of e-waste. With a restricted access to their raw material, formal entities often rely on informal actors to buy WEEE (OIT, 2015). In fact, interviewed service providers state that their main source of WEEE is informal scrap dealers. Also, to avoid labour costs, formal entities frequently transfer selective separation activities to informal workers (García and Manske, 2019). For example, they buy clean PWB from *chatarreros* who previously dismantled devices containing them (Álvarez, 2022). Likewise, many formal entities deliver their own waste at the colonia Renovación instead of at third authorised final disposal service providers (Cota and Smith, 2016). Even transportation services are transferred: as special handling waste must be transported in authorised vehicles, it can be easier to transport them clandestinely, especially from Mexico City to other states. Informal actors are commonly the ones who transport electronic circuits to the US, where they are processed. (Álvarez, 2022)

In sum, the informal sector presents high competitive advantages over the formal sector in e-waste management. For collection, dismantling and selective separation, labour-intensive activities that need low financial and technological investment and imply low environmental and health risks, this might not be so problematic. However, their lack of compliance with regulations, mostly in the processing stage, is a serious problem in environmental and health terms. Furthermore, it allows informal waste managers to undercut market prices for the entire recycling industry. At the same time, a complicated regulatory framework for recyclers, in a context of generalised corruption, makes compliance with the legislation even costlier for formal entities. The former CEO of one of the biggest recycling companies in Mexico, Proambi, which holds several international accreditations for its responsible practises, states that playing "clean" made the firm less profitable and almost lead it to bankruptcy. This situation creates a vicious dynamic between authorised service providers and informal workers, where the latter transfer part of their activities to the former, taking advantage of "subsidised" unsound practises (Álvarez, 2022). Overall, both sectors are separated by a very diffuse frontier; they interact closely, in an informal and also clandestine manner.

Household appliances' manufacturers

The production of the manufacturing industry of household appliances in Mexico has been growing exponentially in the past decade, at a rate of 47% between 2009-2014 and of 171% between 2014-2019. It represented a value of almost 13 million dollars in 2019, after the US and before Poland, Italy, Germany and France, world leaders in the industry (CLELAC, 2021). The northern domestic appliances cluster CLELAC estimated in 2021 that the consumption rate of household equipment would grow at a rate of 15% compared to the previous year. Covid-19 and recent commercial adjustments made for the industry in the North American trade treaty have provoked the regionalisation of supply chains, as important companies are moving their global productive processes to Latin America and Mexico. The country, which had traditionally been assembler of equipment is being transformed into a local manufacturer (Plastics Technology Mexico, 2021). Global manufacturing companies (e.g. Samsung, LG, Whirlpool) and national companies (Mabe, Koblenz, Navia, etc.) have operations in the country, especially in Nuevo León, Guanajuato, San Luis Potosí, and Querétaro. Mexico City is the 6^{th} entity for the industry, with the presence of Mabe, Navia, Whirlpool, and Industrias Man. The most important firms in terms of national sales of household appliances are Mabe and then Whirlpool. (PROMÉXICO, 2015)

In the following paragraphs I describe the actions that are being taken to prevent and manage e-waste in the manufacturing industry of household appliances in Mexico, based on information on corporate websites, sustainability reports, an interview with the Sustainability department director of Mabe and a member of the National Association of Domestic Appliances' Producers, ANFAD.

Most sustainability efforts in the industry are oriented towards energy efficiency, substitution of toxic substances and green supplies. Mabe is working on a project to phase out the refrigerant gas HFC-134 based on chlorofluorocarbons and cyclopentane from foaming mixture for isolation (Mabe, 2019). Whirlpool is doing its part to eliminate expanded polystyrene and polyvinyl chloride (PVC) among others (Whirlpool, 2020). Firms intend to carry on lifecycle analysis of their products in order to assess their environmental footprint and identify improvement areas. Action is also being taken to implement eco-labelling. However, these initiatives are not explained in detail and seem to be at a starting stage. Koblenz vaguely mentions in its website that engineering is being developed to improve the durability of its products. All manufacturers offer assessment and repair services to their customers, permanent online support, access to manuals and technical specifications of their products, and sale of spare parts. Some of them offer extended warranty for certain products. Whirlpool, for example, offers an extended warranty of 5 years that customers buy with their product to have access to unlimited repair services and spare parts.

Whirlpool also announced the "circular" objective of attaining 18% of recycled plastics in their production by 2025 in Europe, Africa and the Middle East. It has put in place return centres where equipment is assessed and refurbished, components reused for remanufacture and repaired EEE are re-sold, in the United Kingdom, the US and Canada. Recycling and remanufacturing are mentioned for Mexico but these are not detailed. The member of ANFAD, who is also an associate of the Mexican brand Taurus explained that the firm is already using 60% of recycled plastic in their production (2 tons of recycled plastic a year). Taurus is developing a line of circular products, the first ones –a blender and a desk fan- having been piloted 2 years ago. These are produced with low-carbon and easily recyclable materials, including a mixture of agave biomass and plastics. Although the products are 30% costlier, their quality is higher, the energy consumption is significantly lower and customers can benefit from a 5-year warranty. Other than this, he affirms, the industry is not necessarily familiarised, aligned and mobilised towards a circular economy model.

Actually, the ANFAD member states that, despite the fact that all firms "in theory" have return points at their service centres, they avoid making publicity out of them and remain unknown to customers. Indeed, navigating in manufacturers' webpages, no return mechanisms for any company are traceable. On the last 18 years, numerous efforts to implement an EPR policy in Mexico have taken place without success. The same international firms that have adopted this scheme in Europe and other countries with a strong legislative enforcement, have put an effective resistance through lobbying in Mexico to avoid the costs it would imply for their production, and have managed to block it so far. (Cota and Smith, 2016; Núñez, 2022) According to both interviewees, the EPR is about to be approved for electronics in Mexico, starting with a 1% collection target for manufacturers (needless to say the figure is insignificant). The sector is negotiating to keep further targets at their lowest. To date, EPR is not present in the Mexican legislation (except for plastics in packaging). In any case, the member of ANFAD trusts this policy would only stay in paper and "nothing would really happen". Yet he agrees the best policy to push the industry towards a circular economy is an EPR with aggressive collection targets: to lower the costs of recovering products after EoL producers will be motivated to extend their lifespan, instead of selling ever cheaper products with short obsolescence periods.

ANALYSIS & FINDINGS

In this section I present the gaps, barriers and enablers that were identified across the whole system of production and treatment of waste from household appliances in Mexico City, by focusing on the main actors involved on it.

Government, regulatory and policy framework

National and local policies and regulations relative to special handling waste have been very recently developed and are still in construction. No national law regulates e-waste specifically; only the NADF-019 in Mexico City does, but has just been implemented. This regulatory framework explicitly aims at the prevention and reduction of WEEE generation, the recovery and valorisation of materials in productive chains, avoiding unnecessary final waste disposal. In the last years, CE principles have been incorporated. In fact, the concerned legislation is not remarkably different from the standard set by the EU in its Directive 12/19 (except there is no EPR). However, several limitations hinder its actual implementation.

To begin with, laws and regulations still lack the normative instruments and institutional capacities to be implemented and enforced. Additionally, they remain too generic and provide general guidelines that still need to be specified (Cortinas, 2022). The language they use is ambiguous and not binding, all verbs commonly being “promoting”, “incentivising”, “enabling”. The lack of precision leaves a large margin for stakeholders to escape their obligations (Sánchez, 2022). Regulations are especially ambiguous concerning preventive measures (Cortinas, 2022) and are almost exclusively focused on recycling and final disposal. The CE in the Mexican legislation is taken almost as synonym of recycling (Córdova, 2022). Furthermore, critics highlight that the legislation presents numerous inconsistencies and is complicated to understand and follow; it should be harmonised at the different government levels, and simplified (Flores, 2022; Sosa, 2022).

Many of the guidelines established in the General Law for the Prevention and Integral Management of Waste (LPGIR) in 2003 are taken up by the Programme for Integral Waste Management of Mexico City (PGIR) 2021-2025 and have still not been specified, developed, least say implemented. To date, there is no systematic control of e-waste flows –only sporadic studies at some Mexican regions-, no clear economic or fiscal incentives to prevent WEEE generation and to enhance recycling have been developed, and no ecolabels- other than energy efficiency labels- have been introduced. Perhaps the most important contribution of the regulatory framework for CE in e-waste prevention and management is the prohibition and control of hazardous substances used in consumer goods, in line with international treaties such as the Basel and the Stockholm Conventions.

The principle of shared responsibility conceived in the LGPGIR, as opposed to the Extended Producer Responsibility, fails to assign specific obligations for each involved actor along electronic equipment’s lifecycle. Management plans are the only mechanism to introduce EPR for e-waste, and the only instrument to calculate its generation and control its integral treatment, but as Cruz-Sotelo et al (2017) state, they have had a very low response from generators, service providers and even from authorities. According to Sosa (2022), 18 years after their adoption, they simply do not work. Defining more explicit obligations, it was the NADF 019 that finally mobilised producers and recyclers of special handling waste to actually present their MP, even if these existed since the NOM 161, and were originally defined in the LGPGIR in 2003. Still, only 5 MP were authorised for special handling waste managers in 2019 (Ramos, 2020, p. 138). Many present incomplete information and fail to follow all requirements (Sánchez, 2022). Registered service providers are not subject to surveillance mechanisms because there is no monitoring capacity from the authorities. Failing to present an MP does not imply any sanction. Thus, there are no clear incentives to comply with this supposed obligation.

According to the LPGIR, final waste disposal should occur only when waste management is not economically viable, technologically feasible, and environmentally adequate (Diario Oficial de la Federación, 2003). The principle of valorisation is then subject to economic efficiency or profitability rather than actively promoted through financial and fiscal incentives, which are inexistent (Sosa, 2022). As it has been said, the criteria established by the NOM 161 to determine which discarded products are subject to be presented in MP also leaves out a large number of e-waste sources.

While the city's programmes to address the e-waste challenge are well designed, their capacity is largely unproportioned to its dimension. This is due to the lack of a financial structure supporting their operation (Núñez, 2022; Sosa, 2022). By consequence, the related public agencies rely on minimal budgets and insufficient staff, insufficiently skilled and with poor means to implement their strategies (Cortinas, 2022). This, in turn, translates into insufficient action. As an example, in the PGIR, the government recognises that the informal sector involved in waste treatment should be acknowledged, formalised, and provided with higher capacities in order to comply with the highest standards for the recovery of valuable materials. Yet the initiatives oriented at empowering them through formal, decent work, are basically reduced to the creation of 5 recycling cooperatives and small enterprises; the provision of a few trainings per municipality, the publication of one manual of security and sanitary measures, and 40 inspections at working centres, by 2025 (SEMARNAT, 2021, pp. 97–100). On a positive side, the program envisions the development of eco-design standards and a platform to promote the market of secondary materials, essential measures for circularity that will be hopefully implemented soon. In other matters, the Reciclatrón has succeeded at increasing the collection rates of e-waste from households in Mexico City and is expected to extend its scope. Yet, to date its contribution is not significant in relation to the total amount of waste generated.

All in all, the main obstacle of the regulatory framework of WEEE is the lack of vigilance measures and enforcement, which allow companies to operate with no transparency and no guarantee of a proper treatment (García and Manske, 2019). A context of generalised corruption and a strong lobbying in the household appliances manufacturing industry block the adoption and the enforcement of effective measures for circularity.

Manufacturers

Design can greatly determine the possibilities of a product after EoL to have a longer life cycle, to be repaired, upgraded, remanufactured and recycled. Business models based on servitization have proven effective for use maximisation, life-extension, and remanufacture in the household appliances' industry. Yet the sustainability actions of the manufacture industry in Mexico are not clearly oriented in this direction. Recent efforts have been mainly focused in replacing hazardous substances in their products and increasing energy efficiency. The second is important under the CE perspective but does not contribute to decrease waste. Only one initiative in the firm Taurus, to develop a line of ecological products with bio-based, recycled, recyclable and higher quality materials, offering a longer period of warranty (5 years), was identified. No similar projects were found in other companies, nor efforts to adapt design for modularity or standardisation. On the contrary, as it has been said, planned obsolescence is increasingly being introduced to this industry, shortening the lifespan and the replacement frequency of household appliances.

Manufacturers' actions for reuse are limited to the provision of repair services, extended warranties, access to manuals and specifications of their products. Yet consumer access to repair and refurbishment services is hindered by growing product complexity, design characteristics (e.g. irreversible adhesives), and software restrictions. Plus, cheaper new products and improved features lead consumers to opt to purchase new devices instead of repairing their old ones (PACE and Accenture, 2021). To date, if return mechanisms exist at manufacturers' centres, they are not traceable in any firms' websites.[11] The fact that collection of waste from obsolete appliances is not carried out by their manufacturers means the value of materials and components cannot be preserved at the highest level, as they are not reintroduced into their original production chains nor reused for their original functionality. Closing the loop within the industry would imply the highest degree of valorisation.

However, manufacturers encounter significant barriers to do to adopt circular practises. For instance, adapting material use for an improved recyclability (e.g. phasing out hazardous substances, replacing composite materials, using bio-based ones) requires material engineering, costs of research and technology development, as well as close collaboration with raw material suppliers and recyclers (Ellen Macarthur Foundation, 2015). Material science is at an early stage, and collaboration across the value chain is low. Here, it is worthy of pointing out that the localisation of supply chains in the industry that has been taking place in recent years in Mexico could facilitate coordination and alignment for circularity, which is a strong enabler.

Secondly, increasing the content of recycled materials is challenging for two main reasons. On one hand, the secondary materials' market has unstable flows due to uncertain collection rates, and cannot guarantee long-term supply, complicating procurement planning for manufacturers. Prices can fluctuate in the medium and long term, too. On the other hand, given that scrap materials pass through multiple traders and processing cycles, there is no transparency on their origin, grade, content of contaminants and quality, least say the environmental and social standards used to obtain them. All of this puts secondary materials in disadvantage compared to virgin materials, which has a flexible supply chain. (PACE and Accenture, 2021)

In third place, producing more durable equipment translates into less sales and more expensive products. Reverting the tendency of programmed obsolescence and increasingly cheap consumer goods implies, in turn, creating a market to ensure demand. Re-educating consumers to change their behaviour is needed. Furthermore, shifting to circular business models implies high operational costs (monitoring products during use, repair, testing, reverse logistics) and requires large upfront investments with a longer payback period that companies might not be ready or willing to make. The benefits of innovative business models, such as a higher customer loyalty and reduced production costs, are not all that evident for manufacturers so far (PACE and Accenture, 2021). Moreover, if manufacturers actually comply with their part of the "shared responsibility" and install return mechanisms, they will face two considerable

[11] In general, there is poor information available about sustainability in these companies. Only two sustainability reports were found for manufacturers present in Mexico City, but they are global and not updated.

challenges. One is the low collection rates of WEEE from households. Strong incentives would be needed to get consumers return their devices and to return them *to their providers*. The second is the presence of informal actors, who presently collect the majority of WEEE with a method highly convenient for consumers: paid and at their own homes. Manufacturers would also compete with recycling entities who already struggle to collect e-waste in campaigns.

Consumers

Consumers in Mexico City actually play an important role in extending the life of household appliances through two generalised practises that reflect a culture of reuse: donation and second-hand purchases. In the first, people tend to donate their old devices to acquaintances from lower classes, and in the second, low-income groups tend to buy at second-hand markets. Even if these are driven by economic incentives rather than by ecological reasons, they make a significant contribution to the circular economy. Nonetheless, a considerable share of citizens keeps their old electronics at home (11%) and a large part delivers them at the garbage truck (42%). Storage hinders the recovery of value, while discarding at the public collection system is not the most effective way to ensure valorisation. Moreover, the appearance of increasingly cheap products in the market and the relatively high costs of repair push consumers to discard items before their EoL. Lastly, the lack of awareness about the e-waste problem and the need to treat WEEE properly, plus the convenience of having them collected at home from scrap dealers with a pay, get in the way between consumers and formal treatment chains.

E-waste management chain

The waste management chain that recovers and valorises waste from household appliances and e-waste in general is a complex network of formal and informal actors holding a dynamic interaction based on economic efficiency and competition. Although it is a very functional system, it is not coordinated, which creates space for several inefficiencies. Moreover, the treatment practises of WEEE are not homogenous, but highly variant among different actors. For instance, on the entry point, collection is fragmented and actors compete for resources. Informal actors have a competitive advantage over authorised service providers due to their lower operation costs, which allows them to offer home-collection. However, this mechanism is largely inefficient considering that, although they are numerous, they generally have a very limited capacity. *Perifoneadores* operate small pick-ups and spend hours circulating on the streets until they have the chance of catching a seller. Thus, no large volumes of WEEE can be collected at once. The only way to collect appliances in large volumes are collection campaigns, but these exclude large equipment because of their difficult management.

At a second stage, one of the most important gaps for circularity is the fact that discarded items are seldom assessed to verify their functionality and confirm they have reached their end of life. Few actors –formal and informal- repair appliances before pre-processing because this requires specific skills and knowledge on electronics. This might be related to the size of the entity. Hence, many appliances enter pre-processing even while still being functional. Ensuring a systematic evaluation of functionality, repair and reuse of components before pre-processing would account for the highest value recovery of obsolete appliances. Furthermore, when obsolete appliances end up in this chain, the possibilities for closing the loop by reincorporating parts and materials at their original production chain are lost, as most recyclers are not linked to manufacturers.

The current unstable market for secondary materials (unstable inflow, changing prices, lack of transparency on quality, complexity of materials and costly logistics and environmental regulations) hinders the economic viability of e-waste recycling in Mexico. Additionally, with no EPR schemes and with low collection rates at the formal market, nothing ensures stable WEEE inflows and thus economic sustainability for formal recycling of e-waste. This, in turn, discourages investment in e-waste recycling infrastructure, which is presently very limited and unable to process hazardous components and precious metal content. Therefore, Mexican recyclers stay stuck at the simplest and least profitable activities, and the highest value exported and recovered abroad. Plus, no incentives have been developed for investment in infrastructure and technological development in this sector. These factors could explain why in general so few (formal) recycling entities have been constituted in Mexico.

This leads us to the most important barrier in e-waste management: the coexistence of the formal and informal sector. Paradoxically, as much as informal waste managers contribute to circularity through repair services and valorisation, their predominance in WEEE treatment hinders the development of a solid circular system. For instance, their higher access to WEEE restricts collection at the formal sector, affecting its capacities to valorise waste in high volumes, with high precision and quality. This has obstructed investment for the development of infrastructure to refine in Mexico, which could make the whole recycling industry grow with its profits. As long as infrastructure remains poor, the recycling sector will remain precarious. Secondly, the mere existence of the informal sector implies uncontrolled treatment practises which are especially problematic during pre-processing and processing (collection and transportation can be less of a problem). Informal recyclers lack the technology, equipment and knowledge to follow the highest valorisation standards, and they have no incentives to comply with environmental and health standards. Unsound practises are almost the rule under informality. Moreover, by undercutting market prices, informality promotes the generalisation of unsound practises in e-waste treatment on both sides, as formal entities transfer part of their activities to informal workers to lower their operation costs.

Yet the lack of control is not exclusive of the informal sector. As it has been seen, the only mechanism to control and monitor (formal) special handling waste in Mexico- Management Plans- is not functional to date. With no precise data about the flow of WEEE in the city on both the informal and formal sectors, it is impossible to track the material flow and know the amount of resources that are recovered and lost, thus to make punctual improvements. Poor accountability mechanisms for authorised service providers also leaves margin for them to incur in unsound practises, as they often do.

Factors determining the level of valorisation

From this analysis, three major factors explaining the degree to which waste from household appliances is prevented and valorised in Mexico City have been identified: the value of waste, the capacity of each actor in the chain to valorise it, and the incentives of the industry to adopt circular practises. I will hereby explain each one.

The value of waste

The first factor that will determine if a material is valorised or not is whether a market exists and the price it is worth. Glass and plastic are the least attractive materials because there is no market for them to be sold. In the particular case of PET, Mexico has practically attained a warranty price, being a world leader in its collection and recycling (SEMARNAT, 2021; Reyes, 2022). Prices are determined by both the local and the global economy: the decrease of prices of raw materials in the international market drives down the prices of secondary materials, whereas the scarcity of raw materials strengthens the recycling market.

A second variable is how abundant the material is, which relates to the volume contained per equipment and to the level of collection of discarded appliances. When a not-so-valuable material is present in an obsolete appliance in insignificant amounts, it will most likely be sent to final disposal. As Sosa (2022) remarks, guarantee of flow and of price could account for an increased collection. In addition, how much labour it takes to dismantle, classify and process a given material plays a fundamental role. While copper is recovered from cables, the plastic wrapping it is not worth the effort. Furthermore, the cost of labour that it takes for each actor or entity to valorise one given material is another determinant and leads us to the next factor.

Capacities to valorise waste

In both the formal and informal sector, the level of WEEE valorisation depends on each actor's capacities. Both sectors are nevertheless not homogeneous themselves. There are highly varying capacities amongst formal service providers and informal recyclers. Capacities refer to knowledge, skills, facilities (storage space), equipment and tools. Big recycling entities have the capacity to treat large volumes of waste, which diminishes the costs of labour and can lead to a higher recovery. On the opposite, many scrap dealers who are newcomers in the business, lack the knowledge about all they can valorise and tend to recover and sell iron, copper, and aluminium exclusively. In this sense, recovering poorly valued materials is specially a challenge for small entities or individual actors. Inadequate pre-processing reduces the valorisation potential of materials (e.g. dismantling without precision can translate into broken parts).

One challenge for the valorisation of waste from household appliances is the very fact that only a few authorised service providers are specialised in this type of equipment. Specialisation is even less likely in the informal sector, where scrap dealers usually do not discriminate between different types of WEEE. However, the formation of economies of scale can contribute to a higher recovery, which is the case in the neighbourhood Renovación and in the street Artículo

123. The concentration of repair and recycling businesses in a shared location reduces costs for all (e.g. transportation) and promotes the specialisation in a variety of services, increasing the capacities of each actor to recover more materials and components. Yet even in the case of these two hubs, suboptimal treatment practises and precarious capacities persist. Capacities under informality are lower.

Incentives of the industry to adopt circular practises

Given that the highest preservation of value of household appliances is determined at the design stage and takes place through reuse and remanufacture, the actor with the greatest influence to reduce waste in the whole system is the manufacturer. Through circular design and services based on use rather than ownership, they could shape consumer behaviour to close loops within the industry. Moreover, considering that the valorisation of waste from household appliances is particularly problematic in relation to other types of EEE, hence less convenient for e-waste managers, manufacturers have the largest action margin to change the status quo by preventing the generation of e-waste in the first place. However, rather than incentives to adopt circular practises, manufacturers face significant barriers to embark in such a transition. Actually, so far, they have not been hold responsible for handling the waste that their products generate. By transferring their obligations to present an MP to service providers, who end up paying the costs of waste disposal (e.g. tariffs to discharge on landfills), manufacturers do not have incentives to reduce the amount of waste they place in the market.

CONCLUSIONS & POLICY RECOMMENDATIONS

This research has shown that, indeed, a Circular Economy model can contribute to minimise waste from household appliances in Mexico City and improve its management. Circular design has proved effective to eliminate avoidable waste by enabling durability, repair, remanufacture and recycling, through material selection, standardisation of parts and components and modularity. Product-as-a-service business models and sharing models can maximise use before discarding. The former, together with reverse logistics, can extend product life by facilitating repair and refurbishment for reuse, as well as remanufacture. Circular flows of electronics can avoid further resource extraction, hence more future waste generation, by keeping products circulating in the market as long as possible. All these are means to reduce overall material use. Additionally, solid secondary material can increase the value of currently poorly-valued materials to avoid unnecessary landfilling. Adequate e-waste treatment practises, which can also be enabled through circular design (making dismantling easy, for example), is key to increase the valorisation of waste from household appliances and minimise final disposal. The hypothesis has thus been validated. Nonetheless, it should be acknowledged that, if a CE model does not manage to slow down production and consumption, but rather increases them through efficiency gains, then it will only perpetuate the current linear, wasteful system.

Based on the findings, and in line with the three main factors that determine the level of valorisation and prevention of waste from household appliances, I make some key policy recommendations that can contribute to close the existent gap between the current system and the ideal one. Under the ideal scenario, environmental and health risks are tackled. The social problems implied in informal e-waste treatment should be reduced through the promotion of formalisation and empowerment of recycling entities. My recommendations have at the core the preservation and improvement of employment of the existing workforce. The propositions are general but include key considerations for implementation. They take into account the existing actions, capacities and limitations.

Incentivise the adoption of circular practises in the industry

Introduce a circular label for electronics

It is widely acknowledged that the best policy option to promote circular design is through an EPR scheme, which drives manufacturers to reduce the amount of EEE placed in the market through life-extension, to compensate for the costs of collecting a proportional share of WEEE. An alternative is the introduction of a mandatory circular label for all EEE manufactured and sold in Mexico, requiring specific product information and compliance with the following circular targets:

- Durability: indicate average years of lifespan
- Reparability:
    1. Provide complete and comprehensible information to repair devices at home or in independent shops (access to manuals and product characteristics).
    2. Provide an extended warranty period (including repair services, access to spare parts and software updates) for all household appliances (periods should be defined per device and be longer for poorly valued devices in the recycling industry).
    3. Guarantee the availability of spare parts during all the products' lifetime.
- Recyclability and improved waste management:
    1. Provide information about materials' characteristics (type, quality, origin), recycled content and hazardous substances.
    2. Comply with targets of recycled content, which should be set for all the applicable materials.
    3. Identify flame retardants to facilitate their separation and correct final disposal.
    4. Add a standard symbol showing the device should be delivered at authorised WEEE collection sites. Add a QR code leading to a site where formal collection centres or services can be found.

This measure would serve the same purpose as the EPR. Remanufacture and product-as-a-service business models in the household appliances' industry could be additionally promoted through tax reductions for manufacturers and distributors, although this would imply a monetary loss for the government, whereas an EPR mechanism would not. In any case, legislative efforts must be doubled to pass a robust instrument that obliges manufacturers to reduce e-waste generation through an improved design and production processes.

Promote innovation and collaboration for circularity in electronics

The city could launch innovation funds and challenges to promote the development of circular solutions for electronics (circular design, material science, reverse logistics, repair, remanufacture, product-as-a-service models, sharing platforms and improved e-waste management). These could target universities, research centres, associations, and entrepreneurs, or be open to citizens. Creating spaces for collaboration between all actors involved in the value chain is needed to develop circular solutions. For example, a close interaction between designers, materials engineers, raw materials suppliers and recyclers could bring up strategies to improve product conception and management at the end of life. Coordination among manufacturers, retailers and e-waste managers could help build a stronger reverse logistics system for an enhanced material recovery. The SEDEMA could lead these efforts through networking events, forums, co-creation workshops, research and collective impact projects. Effective collaboration mechanisms will contribute to align stakeholders, mobilise them towards a shared direction and pool resources, reducing transactions costs for each, all of which will enable a circular transition of the electronics industry.

Increase the capacities to manage e-waste

Create a programme for capacity development in e-waste management
Recognising that the current actions taken by the SEDEMA under the PGIR 2021-2025 are appropriate but dispersed and far from sufficient (digital resources and a few sporadic trainings and monitoring visits with no derived sanctions), these would be integrated and expanded under this programme. It would target micro and small enterprises involved in EEE repair and e-waste management, regardless of their status (formal/ informal). It would be operated by municipalities at local facilities (e.g. community centres) and delivered at least every trimester. It would consist of free trainings of integral e-waste management per stage (collection, transportation, storage, functionality assessment, dismantling and separation, recycling, and final disposal). These would be based in the manuals elaborated by the UNDP/SEMARNAT (2018) and constantly updated in accordance to international best practises. Trainees would also learn about the environmental and quality norms related to e-waste management. An accreditation of skills of e-waste management (per activity), based on the standards defined at CONOCER, would be provided at the end of the training. The trainees would receive a card acknowledging them as “e-waste management technicians”, which would provide benefits like access to public employment in the sector. The programme could include training for repair and remanufacture, too. Additionally, face to face support and personalised accompaniment should be offered for the formal constitution of an enterprise or cooperatives. Micro-credits could be provided to formal entities to invest in facilities, equipment and protection gear.

Furthermore, municipalities could promote association schemes between waste managers for an improved coordination, increased capacities, reduced costs, and higher efficiency in collection and transportation. This could contribute to transform the current dynamics of competition and better integrate the e-waste management chain. The development of digital technologies could facilitate collaboration among waste managers.

Strengthen the capacities to control e-waste treatment
The RAMIR and the MP is the existing mechanism of the city to control the flow of WEEE and their adequate treatment. However, both still present many opportunity areas and the

authorities already aim to strengthen them under the PGIR. Linked to the previous proposed programme, municipalities could offer personalised support to formalised enterprises to join the RAMIR. The SEDEMA could create additional digital resources to facilitate the compliance of the quality and environmental standards set by the regulatory framework related to e-waste management, which are required by the RAMIR. A revision should be made to simplify the administrative procedure required to join the registry, by eliminating unnecessary documents and paperwork. Most importantly, random monitoring visits should be implemented to verify the compliance of authorised service providers with the corresponding norms. Every year, audits should be carried on in all sites of e-waste treatment in order to renew the registry, and sanctions must take place in case of mismanagement. However, support and accompaniment should be provided to non-compliant establishments before the imposition of sanctions, in order to improve their performance, the objective being to keep their authorisation. At the same time, the MP should be improved for a better control of WEEE flow, which would allow to identify opportunities to optimise the overall valorisation system in the city. This will not be possible without increasing the operation capacities of the SEDEMA. A platform could be developed to digitalise the monitoring of WEEE flow (currently done in paper) to enhance the control of information.

Both measures seek to strengthen the capacities of small actors (formal or informal) to increase e-waste valorisation. At the same time, they are a strategy to enable the formalisation of informal managers through stronger incentives and means, and to enhance the control of WEEE treatment. Countering informality is essential to reduce the asymmetries between the informal and formal sector and level the playing field to boost the whole industry. In the same measure, countering the current lack of control through an enhanced monitoring system and stronger governmental capacities, is key to optimise e-waste treatment.

These two policies would need to be strongly marketed among informal waste managers, through a special campaign seeking to create trust rather than a sense of exclusion and punishment, and highlight the benefits of formality. This could be achieved through the municipal authorities in direct relation with waste managers involved in the city's collection and treatment system. Efforts will need to be doubled to establish a partnership with the CONIMER to mobilise unionised e-waste recyclers. Given that the whole strategy hereby proposed has at the core the preservation of improvement of waste managers' jobs, this should be possible.

Develop physical infrastructure for high-capacity e-waste treatment in the city

Mexico City lacks public infrastructure to specifically treat e-waste. Through private investment, the government could develop infrastructure for WEEE integral management at high volumes and high quality standards, with the proper facilities, equipment, tools and safety protocols. The treatment plant would have the capacities to process hazardous substances (or third parties to do so). Moreover, the project would include the introduction of machinery to refine PWB, which would ensure financial sustainability in the long term. The treatment of e-waste in large volumes would also make it more profitable. Workers accredited as e-waste managers would be hired through a special sub-programme of the Ministry of Work and

Employment Promotion's green jobs scheme, to treat WEEE on site, which should ensure access to social security, decent wages and protection gear. The plant would be part of the RAMIR, hence have permanent monitoring to ensure compliance with environmental and quality standards and to control the resource flow of WEEE. E-waste would be provided by several sources:

a. The public garbage collection system
b. Scrap dealers: non-pre-processed equipment would be bought per kilogram
c. Authorised service providers: disassembled parts would only be bought to entities registered at the RAMIR, to ensure sound pre-processing.

The location of this treatment plant should be strategic and allow for the construction of other recycling entities in the zone, with the purpose of creating an eventual conglomerate for e-waste management, which would increase volumes of WEEE and reduce operation costs. If effective, this public project would serve as a leading example of a circular model for high-capacity e-waste treatment in Mexico.

Increase the value of waste

Finance e-waste management of household appliances poorly valued in the market

In order to incentivise the proper treatment of waste from household appliances that are currently not attractive to e-waste managers because they imply a cost rather than profit, a finance scheme must be defined. This cost would be paid by the consumer. It would concern, at least, cooling equipment, washing machines, dishwashers, stoves, ovens, and all small appliances except for IT equipment. One way to do this would be imposing an e-waste management tax to products, equivalent to 1% of their cost at purchase. According to Álvarez (2022), this percentage would suffice to cover the cost of recycling. The cost of the transportation should be calculated and added to this tax; it would be proportional to a devices' size.[12] An additional "return fee" should be included in the tax and refunded to the consumer when delivered to service providers after EoL. Delivery or domestic collection services should hence come at no extra cost for customers. Through a trust managed by the National Bank, this tax would be transferred to authorised service providers. These, in turn, could pay authorised *perifoneadores* the collection and transportation of WEEE, and the latter would be in charge of giving the return fee to customers. If consumers have no interest in recovering this fee paid at purchase and discard their appliance, other collectors (e.g. waste pickers) could claim it.

This mechanism would create three important incentives. One, for *perifoneadores* to formalise as they would be paid by their service. Second, for consumers to give back their obsolete appliances, and to do it at authorised sites. Thirdly, this policy would enable e-waste managers to take household appliances that are currently excluded from their services.

[12] The Special Tax over Production and Services (IEPS), which is used on cigars, alcoholic beverages and sodas in Mexico, among other products, can be used for this purpose to avoid the creation of a new tax.

Create a secondary materials' bank
The SEDEMA plans to develop a platform where all actors will be able to trade materials. This information system should be robust enough in order to contribute to the consolidation of a secondary materials' market. The bank could function at the regional level (including Mexico City, Estado de México and other central states) and would show timely information about material availability, supply and demand, volumes and prices. Material characteristics of WEEE could be included using the circular label. Other than recycled materials, recovered parts and components could be sold in the platform to incentivise remanufacture (manufacturers would access inputs for remanufacture at lower prices). Information and transparency could be enhanced with the creation of standards and certifications for secondary materials' quality. All actors in the value chain should be involved and mobilised to use the bank, including repairers, as well as other industries that could use WEEE as secondary materials for their own productive processes.

Buy poorly valued materials from WEEE at the city's treatment plants
Municipalities currently spend a significant budget in landfill tariffs. Part of this budget would be transferred to buy from scrap dealers, at fixed prices, poorly valued materials and components from discarded household appliances (CRT, batteries, glass, plastics, rubber, insulation foams, refrigerant gases, etc.), at the city's treatment plants. There, these would be properly processed or sold to authorised service providers for their processing. This would be a mechanism to incentivise the collection of non-valuable materials and divert them from landfills.

Involve citizens
Beyond manufacturers and recyclers, consumer behaviour is fundamental to reduce and manage e-waste properly. This actor should be actively involved and made part of the solution. Much more action is needed to raise awareness about the problematic of e-waste and educate for a correct treatment through public campaigns and the engagement of social institutions (schools, firms, associations, etc.). As it was mentioned before, a symbol indicating electronic devices should be taken to authorised collection sites after use could be developed by the government, and added to products. This symbol would need to be socialised through marketing. Products would also have a QR code leading to a site that presents all the authorised services or drop-off points in the city, to help consumers find the most convenient one. The existing map of Ecolana could be the starting point for such site. Communication campaigns should also inform the consumer that the e-waste management tax added to household appliances would be lost if these are not delivered at authorised collection sites after their EoL.

Furthermore, the city could also install containers in parks, shopping malls and other public spaces where people will be able to deliver their small old electronic appliances (which include the least valued household appliances), in exchange for a reward. This WEEE would be collected by accredited e-waste managers. Collecting small appliances together would increase the chances of valorising materials that are present in low amounts per equipment. Both measures would aim to increase collection to make WEEE more abundant and increase its value in the market, while avoiding it to be kept stored at households or reach informal management chains or landfills.

Overall, these policies focus on waste from household appliances but can apply to WEEE treatment more broadly. They can actually be useful to increase valorisation in other problematic waste categories (e.g. tyres). My recommendations are meant to produce a systemic change and should all be adopted in parallel, under a single strategy to reduce e-waste. In this sense, their implementation would demand the national recognition of e-waste as a security issue affecting human and environmental health as well as human rights, and make of WEEE prevention and adequate management a key environmental policy. Nonetheless, beyond political will, the adoption of such a strategy would demand addressing structural barriers that obstruct solving this and potentially all major problems of the country. These barriers are a weak rule of law and public institutions with poor capacities to operate and enforce the legislation; high levels of corruption affecting the entire Mexican bureaucracy, and an industry that is well-organised, tightly linked to the political apparatus and has a strong lobbying capacity to preserve the status quo. Thus, tackling the e-waste problem is much more complex than it seems. My policy recommendations are a first approximation to address it.

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GLOSSARY OF TERMS AND ACRONYMS

ANFAD: National Association of Domestic Appliances Producers.
By-products: Waste or secondary products generated at productive processes.
Closed-loop system: Industrial model that reuses materials and components for their original purpose, or brings them back to their production chain to manufacture similar final products.
CONIMER: National Confederation of Recyclers.
CRT: Cathode Ray Tube. Glass video display component of an electronic device. (EPA, 2016)
Just transition: This concept used in the field of sustainable development. It calls for the implementation of compensatory measures to address the social issues that environmental policies might arise (e.g. transferring credits to low-income individuals affected by carbon taxes, or labour insertion programmes to upskill and employ workers at sectors in transformation, like oil companies).
EEE: Electrical and Electronic Equipment. All appliances that require electric current or electromagnetic fields, and those necessary for generating, transmitting and measuring such currents and fields. EEE include large household appliances, small household appliances, IT and telecommunications equipment, consumer equipment and photovoltaic panels, lighting equipment, electrical and electronic tools (with the exception of large-scale stationary industrial tools); toys, leisure and sports equipment; medical devices (with the exception of all implanted and infected products); monitoring and control instruments, and automatic dispensers. (European Parliament, 2012)
EoL: Stage of a product's lifecycle posterior to consumer-use, reached once it has been discarded.
EPR: Extended Producer Responsibility. Policy tool that shifts responsibility to manage post-consumer goods to producers.
Functional obsolescence: Newer and improved versions of electronics in the market make old devices obsolete because consumers prefer to replace them.
Generators: Entities that produce, directly or indirectly, special handling waste through their industrial, commercial or service activities. Large generators are those who produce over 10 tons of waste a year.
GIZ: German Corporation for International Cooperation.
Hazardous waste: Corrosive, reactive, explosive, toxic, flammable or infectious waste.
INECC: National Institute of Ecology and Climate Change
IT: Information Technology
Landfill: Permanent deposit or confinement of waste in sites or facilities with conditions that allow to avoid their liberation to the environment (Diario Oficial de la Federación, 2003).
LCD: Liquid Crystal Display. Used in electronic screens.
LED: Light-Emitting Diode. Semiconductor device that emits infrared or visible light when charged with an electric current.
LGPGIR: General Law for the Prevention and Integral Management of Waste.

MP: Management Plans. Instrument where producers, international traders, distributors, large e-waste generators and service providers are obliged to report information relative to special handling waste treatment (volume, methods of treatment, destination, etc.) to the authorities.

Material flow/ Resource flow: The movement and processes that materials (in this case e-waste) undergo after the end of life of a product.

NOM: Mexican Official Norm

Pepenadores: Waste pickers that compose the city's garbage collection system and operate in streets and public spaces, the garbage truck and landfills (the latter also known as scavengers).

Perifoneadores: Scrap dealers that collect obsolete equipment from households in pick-ups. They are usually informal workers. The translation for perifoneador in English is pager

PGIR: Programme for the Integral Waste Management in Mexico City.

POP: Persistent Organic Pollutants

PWB: Printed Wiring Board. Board that contains electronic components. They are present in many home appliances and IT equipment.

RAMIR: Registry and authorisation of services or vehicles related to the integral management of special handling waste that operate in or transit through Mexico City.

Recycle: Transforming materials or components contained in waste into their basic materials or substances, and reprocessing them into new materials with similar physical and chemical properties

Refurbish: Updating a product (cleaning, changing oil, replacing consumable items, making cosmetic improvements, among others), which can include repairing.

Remanufacture: Industrial process where parts from obsolete items are recovered, refurbished or upgraded and used to manufacture new devices, or where obsolete appliances are reconditioned by replacing faulty components and upgrading software to deliver a product with an equal or improved performance as the original.

Repair: Fixing a faulty equipment to make it functional again.

Scavengers: Waste pickers (here referred to those operating at landfills) .

Scrap dealers: workers (usually informal) who buy and sell scrap or valuable materials from waste. They can be perifoneadores or not.

Secondary materials: Recycled materials.

SEDEMA: Mexico City's Environmental Ministry.

SEMARNAT: National Environmental Ministry.

Service providers: Authorised entities that provide special handling waste treatment services, from collection to final disposal. They are registered at the RAMIR and authorised by the SEMARNAT (national level) or the SEDEMA (Mexico City). They represent the formal infrastructure to treat e-waste in Mexico.

Servitization: Business models based on services for use (leasing, pay-per-use contracts, sharing platforms) rather than products' sale.

Special handling waste: Under the Mexican legislation, this is waste generated that does not gather the characteristics of urban solid waste or hazardous waste. It includes waste from electrical and electronic appliances.

STyFE: Ministry of Work and Employment Promotion.

UNDP: United Nations Development Programme.
Valorisation: Set of actions oriented at recovering the residual value or the energetic content of the materials that compose waste, through their reincorporation to productive processes, under environmental, technological, social, and economic efficiency criteria. (Diario Oficial de la Federación, 2003)
Waste managers: All the actors involved in waste management, who contribute to recover and valorise materials (waste pickers, scrap dealers, recyclers).
WEEE: Waste from Electrical and Electronic Equipment. All electric and electronic devices, and their components, which have been discarded by their owners as waste, with no intention of using them again. (Córdova, 2019)
ZMVM: Metropolitan Zone of the Mexican Valley

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Promoting circularity to reduce waste from household appliances in Mexico City

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Abstract

E-waste, the fastest growing waste stream, is a global challenge for it contains toxic substances and should be properly managed to avoid environmental and health hazards. In Mexico, 90% ends up in informal management chains, where inadequate management is generalised. Household appliances make most of e-waste generated in Mexico, yet they are poorly studied and regulated, and few efforts to treat them exist in comparison to IT devices. They are thus more likely to reach landfills.

My thesis aims to respond “*How can waste from household appliances in Mexico City be minimised and better managed in order to reduce the social and environmental problems linked to its treatment?”.* The hypothesis is this can be attained through a Circular Economy (CE) model, which aims to eliminate avoidable waste through design, servitization and remanufacture. The CE is used as the analytical framework. Parting from international best practises, an ideal prevention and valorisation scenario is set. I analyse the e-waste management system in Mexico City and the existing circular practises in it, in the regulatory and policy framework, the manufacturing and repair industry, and in consumer behaviour, through bibliographic research, interviews and direct observation. I find that home appliances are unattractive to recyclers because they are less abundant, less valuable and harder to process than other electronics. Waste reduction can mostly be attained at manufacture and, secondly, through higher valorisation capacities. Policy recommendations are formulated to incentivise the adoption of circular practises in the industry, to augment the value of non-valuable materials, and to empower small recycling entities.

Key words

Circular economy, e-waste, household appliances, Mexico