Environmental pollution of E-waste: generation, collection, legislation, and recycling practices in Mexico

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18.1 Introduction

The accelerated technological progress has led to massive manufacturing of electrical and electronic equipment (EEE) with shorter lifetime span due to technological change. At present, the lack of prevention, control, and information measures has led to the development of improper practices in the management and disposal of waste electrical and electronic equipment (E-waste).

Given the growing technological development, it is time to analyze and make decisions in the search for alternatives for the sustainable management of this type of waste. With the arrival of the information society and the high consumption of EEE, the authorities face the challenge of managing E-waste flow in a sustainable and responsible manner. Electronic equipment turns obsolescent at a rapid pace, generating a growing stream of E-wastes that require a proper channel for disposal and recycling. However, most E-wastes are disposed on the streets and vacant lots, or mixed with municipal solid wastes and buried in local dumps. At present, the lack of prevention, control, and information measures has led to the development of improper practices in the management and disposal of waste electrical and electronic equipment (E-waste). Local authorities need to develop new strategies for the sustainable management of these wastes.

Consumers are replacing their products more frequently, and the lifespan of the EEE is shrinking. It is important to highlight that the periods of obsolescence are increasingly shorter, complemented by a cost of acquisition with a downward trend; in this sense, Vega (2012) indicates that technological obsolescence is a growing phenomenon in the information society and knowledge, which causes an

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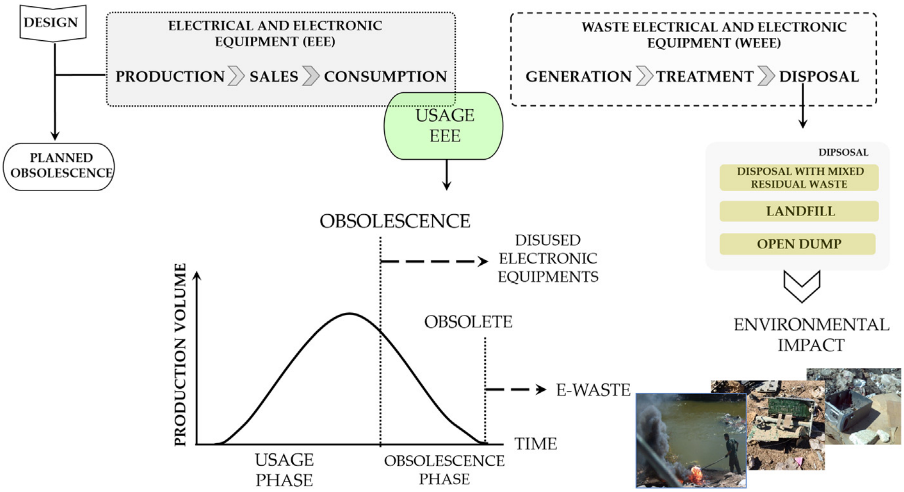


Figure 18.1 Obsolescence and life cycle of electric and electronic equipment.

environmental problem by generating electronic waste. This has influenced the exaggerated increase of products that become electronic garbage because the useful life of many devices is reduced to the minimum before the production of new EEE. Fig. 18.1 shows a diagram that shows the flow of electronic devices from production to final disposal, it is observed that in the culture of consumption the obsolescence of the EEE influences the generation of E-waste, so that it is important to establish mechanisms to size the problem and carry out generation and quantification studies to know the recovery potential of the electronic components and materials that can be recycled, as well as the equipment that can be reused before they become obsolete. This will prevent the improper disposal of E-wastes from ending up in the final disposal sites that tend to throw residential generators among them sidewalks, vacant lots and open dumps, causing environmental impacts and damage to health.

The E-wastes make up a complex and rapidly growing waste stream, increasing at a rapid pace. According to Cucchiella et al. (2015), it grows three times faster than urban waste. It is estimated that by 2021, the generation of E-waste will increase to 52.2 million metric tons (Mt) or 6.8 kg/inhabitant, with an annual growth rate of 3% to 4% (Baldé et al., 2017). The problem of electronic waste is global, this waste stream is part of the urban waste stream. Fig. 18.2 shows a diagram of the flow of electronic waste in the current of the MSW. The term E-waste is used to include all electrical and electronic devices, as well as their components that have been discarded by their owner as waste without the intention of reuse. For this research, E-waste refers to damaged or obsolete EEEs that are discarded by the consumer. It includes a wide range of devices such as computers, consumer electronic equipment, cell phones, and household appliances that are no longer used or desired by their users, including all the components, subassemblies, and consumables that a user considers obsolete or undesirable (Kahhat, et al., 2008).

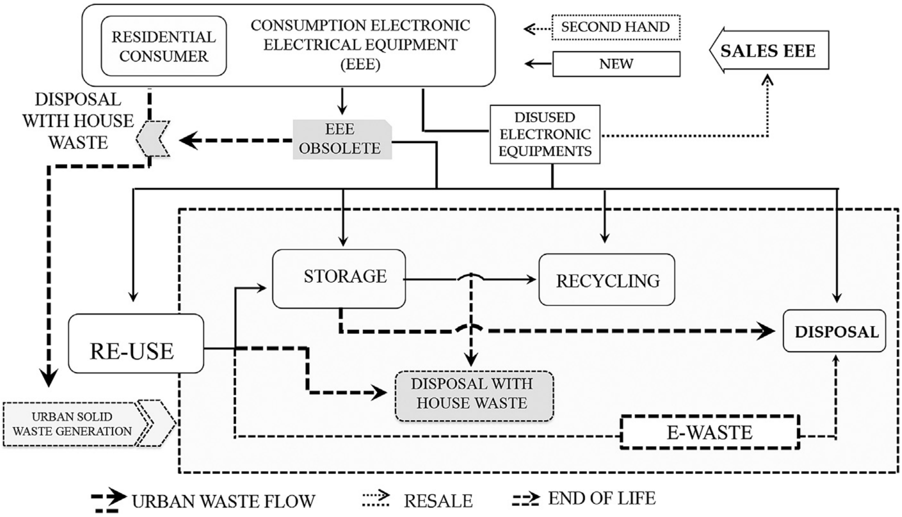


Figure 18.2 E-waste and the flow of urban solid wastes.

The E-waste according to the Organization for Economic Cooperation and Development (OECD) is any device powered by a power supply that has reached the end of its useful life. Many of the EEE that are approaching the end of their useful life; they can be reused, restored, or recycled, depending on the country that manages them and, above all, on the legal regulations regarding their management, as mentioned by Widmer et al. (2005). Other authors such as Sinha et al. (2009) define E-waste as any electrical device that has failed to fulfill the purpose for which it was manufactured. The E-waste designation includes all electrical and electronic devices that are nearing the end of their useful life and become waste, considering all those components and subsets that are part of the product at the time it is discarded. Many of these products can be reused, restored, or recycled. In the case of Mexico, electronic waste is defined by the legislation as technological waste coming from the informatics industries, from the manufacturers of electronic products that, at the end of their useful life due to their characteristics, require special handling (DOF, 2015).

E-waste is an emerging waste stream globally due to the high consumption of electronic products. However, integral E-waste management presents great challenges for developing countries such like Mexico without the proper recovery technology. The complexity of diverse components of electronic equipment and products make them difficult to recycle, however a number of shops using human labor work on disassembling the main component and materials to sell them on local recycling markets (Huang et al., 2009, and Mihai et al., 2019).

The lack of E-waste collection infrastructure, as well as the absence of consumer awareness are the main obstacles for an environmentally sound E-waste management program.

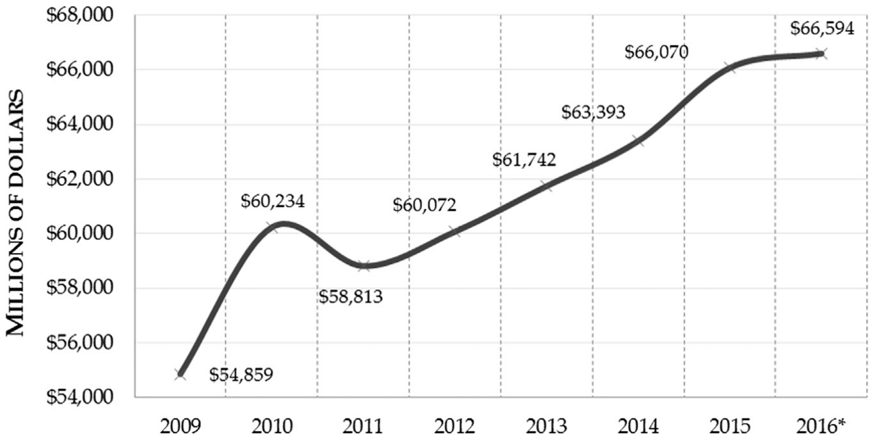


Figure 18.3 Production of electronic goods in Mexico.

18.2 Electronic industry in Mexico

Nowadays E-waste has emerged as one of principal types of waste in the world because of market expansion and shorter life cycles of electronic products. Electronic industry is responsible for 10%−20% of global environmental impact related to depletion of nonrenewable resources (Araújo et al., 2012 and Georgiadis and Besiou, 2009). Electronic industry has an important role in country's economy and Mexico is well-positioned worldwide as an exporting country and electronic products assembly. Fig. 18.3 shows the value of electronic production in Mexico and by 2016 the electronic production will be worth 66,500 thousand millions of dollars and it also shows how has this sector behaved since 2009 (Promexico, 2016).

In the electronics sector, the Secretariat of Economy points that Mexico is one of principal countries in terms of electronic export and assembly. The country has been the main exporter of flat-screen TVs, the fourth place in computers export, and the eighth-place in production of cellular phones worldwide. United States was the primary exportation destination and this country represents 85.4%, followed by Canada, Colombia, and the Netherlands. Fig. 18.4 shows the destination of electronic equipment and products manufactures or assembled in Mexico.

18.3 Consequences for health and the environment

E-waste contains a wide range of substances, some of which are economically valuable and others are harmful to health and the environment. Fig. 18.5 shows the characteristics that differentiate them from other waste streams: among them are their potential for use, having high value recoverable materials; the presence of toxic elements and dangerous substances that, although they are necessary to

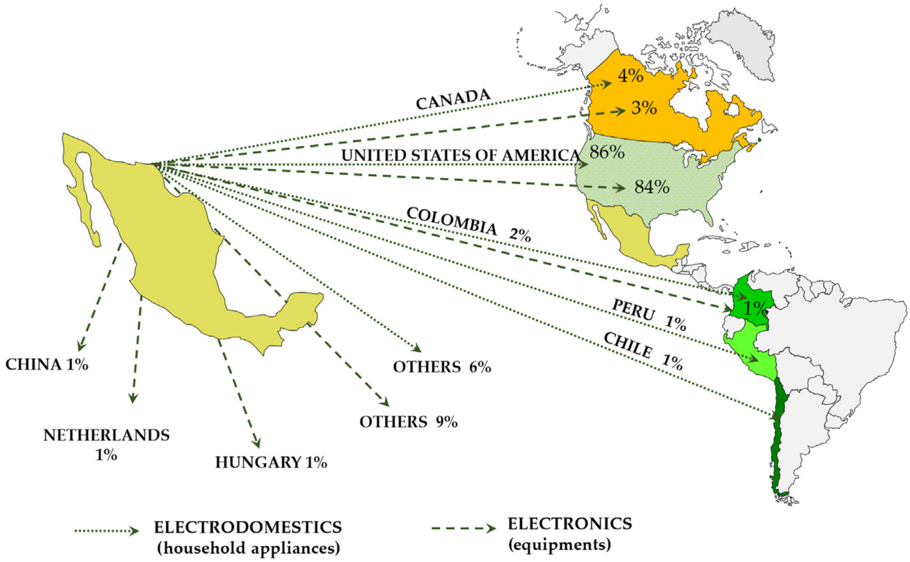


Figure 18.4 Home appliances exportation flow of Mexico and other countries.

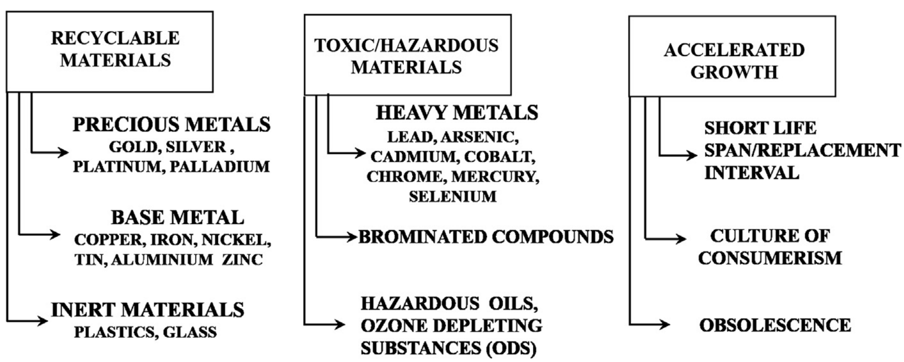


Figure 18.5 Characteristics that differentiate E-waste from other waste streams.

guarantee their functionality, when released to the environment can be harmful to health and cause pollution problems, therefore they require an environmental management that protects ecosystems and public health; and its volumes and accelerated rate of growth, determined by the phenomena of technological change, associated with the culture of consumption and obsolescence.

The management of E-waste is complex since its material composition is very heterogeneous and may contain a variety of hazardous components, which represent a problem during the management and final disposal phase. Among the most problematic substances contained in these wastes are heavy metals, including mercury, lead, cadmium, and chromium. Halogenated substances such as chlorofluorocarbons (CFCs), chlorinated biphenyls (PCBs) and polyvinyl chloride (PVC), as well as some flame retardants.

Some of the hazardous substances are compounds that include metals and organic compounds emitted during the combustion process and those that form immediately after combustion. Some of the organic compounds are persistent organic pollutants (POPs) such as brominated flame retardants (BfR), polybrominated diphenyl ethers (PBDE), polycyclic aromatic hydrocarbons (PAHs), polychlorinated Dibenzo-p-dioxins and furans (PCDD/FS), these have significant implications for human health and environmental safety (Ohajinwa, et al., 2019).

The E-wastes are some of the agents that pollute the subsoil, water, and air, and consequently, threaten human health. In emerging countries such as Mexico, this is aggravated due to the lack of control in their management and final disposal, since a large number of electrical and electronic devices at the end of their useful life reach final disposal sites mixed with MSW, increasing the heterogeneity, dangerousness, and impact of the resulting mixture.

Electronic equipment and appliances contain different toxic substances such as lead, mercury, zinc, tin, silver, arsenic, cadmium, selenium, hexavalent chromium, and flame retardants. When E-waste is improperly disposed, there is a high risk of pollution of local water sources. Another problem is the common practice of burning wire and other electronic components that generate toxic fumes.

It is important to highlight that the health of the human being and the care of the environment are the determining factors to take measures against this problem. The health effects from exposure to any hazardous substance are diverse, in different organs and different magnitudes, depending on the duration and form of exposure (inhalation, ingestion or direct contact), dose (amount), and range from nausea, pain (head and chest), respiratory failure, decreased concentration to congenital disorders, and cancer, among others.

Another factor that we must consider is that these components are not regularly found purely or naturally, but are combined with thousands of kilos of other electronic devices and various wastes that are mixed to generate new toxic products that have different and harmful behaviors.

In electronic devices and, therefore in the E-waste stream generated there are two groups of substances considered toxic to the environment and human health polybrominated organic compounds and heavy metals.

Printed circuit boards (PCB) may contain components that contain toxic metals such as beryllium, lead, and cadmium. Metal parts, such as housings and screws, can be protected against corrosion with a layer of hexavalent chromium carcinogen. Some components, such as specific switches and the backlights of liquid crystal displays (LCD) contain mercury. Hazardous organic substances such as chlorinated biphenyls (PCBs) can be found in condensers. Plastics in the EEE use brominated flame retardants to meet fire safety requirements. Some substances of this group have a high potential for dioxins and furans if they are burned, among which are the polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE).

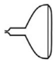
TOXIC COMPONENT	ELECTRONIC COMPONENT	ROUTE OF EXPOSURE	HEALTH EFFECTS
Lead and cadmium beryllium	Printed circuit boards (PCBS). 	Inhalation, ingestion and dermal contact.	Damage to kidney and central nervous system, skyn Lung damage beryllium is a suspected human carcinogen
Lead oxide and cadmium beryllium	Cathode ray tubes (CRT) 	Inhalation and ingestion	Affect vital organs like heart, liver and muscles.
Mercury	Liquid crystal display (LCD) 	Inhalation, ingestion and dermal contact.	Brain, skyn, kidney, lung, fetal, bone marrow, higado and anemia.
Phosphorus	PC monitors 	Inhalation, ingestion and dermal contact.	Kidney, heart and bone system.
Arsenic	Microprocessor 	Inhalation, ingestion and dermal contact.	Skin, nervous system and cancer (inorganic arsenic is a known human carcinogen).
Brominated compounds	Plastic and metal covers 	Inhalation, ingestion and transplacental	Persistent and bioaccumulative, contaminate the food chain, carcinogens (having a capacity to initiate cancer in a live tissue), damage reproduction and immunology of humans.

Figure 18.6 E-waste, toxic substances, and health.

Brominated flame retardants or polybrominated organic compounds are persistent chemicals in the environment and some of them are highly bioaccumulative and capable of interfering with the normal development of the brain in animals. Polybrominated diphenyl ethers (PBDE) are flame retardants for use in electronic products and potentially harmful for fetal development, even at very low levels. Metals are the main core of the E-waste, but at least their recycling is feasible since reusing metals saves their extraction. Some of the problems associated with the handling of electronic waste are the cross-border flows from developed countries to third world countries becoming receptors of pollution. By not having management systems for their management and final disposal, mechanisms must be implemented to prevent and mitigate the costs and impacts on the environment and the effects on human health. Fig. 18.6 shows some of the health effects associated with the toxic components of E-waste.

The proper treatment of electronic waste can limit the impacts of hazardous substances on electronic waste. The know-how and technologies are available and applied at least in some developed countries. Heavy toxic metals, such as lead can be recycled to a certain extent, otherwise they can be controlled and prevented from being released into the environment. However, the high amounts of electronic waste generated in emerging countries, which are not collected properly and, therefore are very likely to end up on the streets, vacant lots, and outskirts of urban settlements.

Orlins and Guan (2016) point out that informal recycling of E-waste generates work for the informal sector, but inadequate dismantling and burning of E-waste for resource recovery exposes workers to toxins and heavy metals and causes a serious air, water, and soil pollution. E-waste recycling practices can result in direct or indirect exposure to a variety of hazardous substances that are contained in the EEE and are released by unsafe recycling practices.

Direct exposure involves the contact of the skin with harmful substances, the inhalation of fine and coarse particles, as well as the ingestion of contaminated dust, in addition those who participate directly in the recycling of E-waste with little protection incur in high levels of direct exposure. Unsafe recycling techniques used to recover valuable materials often increase the risk of hazardous exposures, for example, plastics burn out, often at low temperatures, to get rid of computer cases or to recover metals. The valorization of printed circuit boards and other components. Even though incineration releases heavy metals such as lead, cadmium, and mercury, the toxic fumes released by these practices often contain polyhalogenated dioxins and furans, generated by incomplete combustion at low temperatures.

Therefore, in countries such as Mexico, in which the informal sector plays a central role in the recovery of waste, it is important to establish proper regulations in order to avoid exposure to toxic substances when disassembling E-wastes. The country also needs an innovative public policies and legal framework to regulate de production, disposal and recycling of electronic equipment in order to prevent the disposal of E-waste in municipal dumps.

18.4 Estimating quantities for E-waste

Bernache and Chávez (2014) studied the production of electronic waste, in the context of the national program of replacement of cathode ray tube televisions by flat televisions. E-waste is a broad category of waste that is associated with both electrical appliances, electrical appliances and a whole range of electronic devices commonly used in academic, institutional, and domestic contexts. The presence of E-waste is increasing in the urban waste stream because of the high consumption of electrical and electronic equipment, by the short life cycle (two to five years), and renovation of this type of goods (Román, 2007). In 2013 it was estimated that post-consumer electronic waste production in Mexico was 338,194 tons per year (Table 18.1).

According to Baldé et al., the region of Latin America generated 4.2 Million tons (Mt) of E-waste during 2016, with an average of 7.1 kg/person. Latin American countries with the highest E-waste generation are Brazil 1.5 Mt, Mexico 1 Mt, and Argentina 0.4 Mt. The top three countries in Latin America with the

Table 18.1 Postconsumer E-waste generation (2013).

	E-waste in tons
México	338,194
Jalisco State	21,983
Metropolitan Area of Guadalajara	13,190

Source: Estimates from data reported by Román Moguel, Guillermo, 2007. Diagnóstico sobre la generación de residuos electrónicos en México. Informe Final. Instituto Nacional de Ecología, desarrollado por el CIIEMAD del Instituto Politécnico Nacional, México, D.F.

highest E-waste generation in relative quantities in 2016 were Uruguay (10.8 kg/person), Chile (8.7 kg/person), and Argentina (8.4 kg/person).

The Ministry of the Environment in Mexico has taken up the figures published by Baldé et al. (2017) and refers that the country generated 1.1 Mt of E-waste in 2015, with an annual growth rate of 2.18%, so that the amount of annual production of electronic waste could reach 1.35 Mt for the year 2026 (SEMARNAT, 2018a,b: 17). The same source reports a generation range of 8.2 to 9.2 kilos per year per person. The commercial exchange of Mexico with the United States and the movements of goods used at the border generated in 2011 a transfer of electronic waste from the US to Mexico of 80,000 Mt, especially TVs and monitors. Mexico in turn exports printed cards and circuits obtained from electronic waste to the United States (SEMARNAT, 2018a,b: 20). Under certain conditions the amount of electronic waste may suffer significant variations, this happened in 2014 and 2015 in Mexico with the program of transition to digital television. The federal government distributed 13.8 million flat TV sets of digital LED technology free of charge. This program will have the side effect of converting cathode ray tube analog TVs into obsolete ones. So that would be discarding 276,000 tons of this type of TVs in the 30 months of effectiveness of the program of delivery of flat TVs, June 2014−December 2015. As of January 1, 2016, television signal would be transmitting only in digital format.

18.5 E-waste legislation

The regulation of waste in Mexico is based on an international framework that includes agreements and treaties that it has signed, such as the Basel, Stockholm, and Rotterdam agreements, among others. In addition to a regional approach, which is applied by the situation of North America and Latin America in terms of electronic waste, in which Mexico has participation in different programs and agreements related to the subject in both areas, such as the Commission for the North American Environmental Cooperation (CCA) and the Regional Platform on Electronic Residues in Latin America and the Caribbean (RELAC). Fig. 18.7 shows a scheme that shows the legislation that applies to E-waste in Mexico and shows the planning instruments that have been developed to address this waste stream. It mentions the international framework that our country must respect, as well as the policies of the regional framework.

The inclusion of the international and regional framework for the management of electronic waste is important because it establishes a point of reference in the development of public policies on waste at the national level. The management of electronic waste in Mexico has become important mainly due to the presence of some contaminants that are found in these wastes and that, when disposed of improperly, can be released to the environment.

In the international context, Mexico adhered to the *Basilea Convention*, in the 1990s, taking important steps in the protection of the environment, through the legal

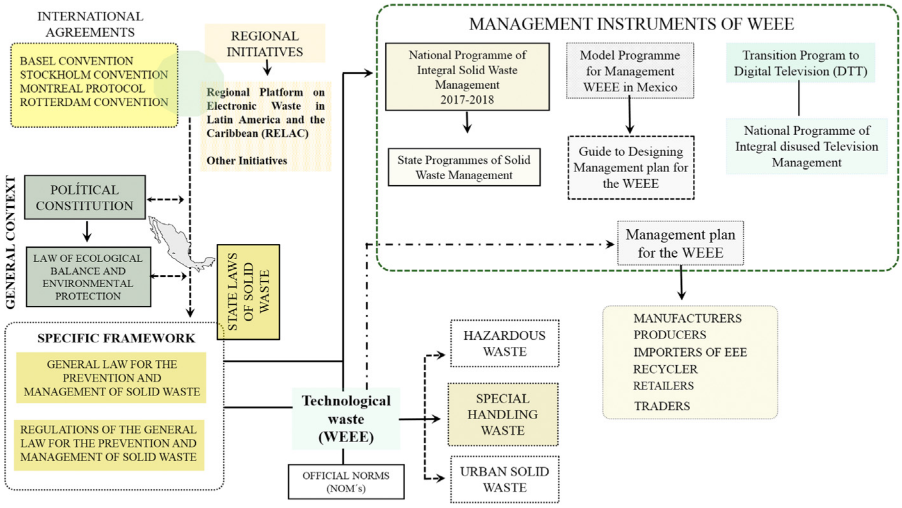


Figure 18.7 Regulatory framework international and regional for E-waste.

regulation of transboundary movements of hazardous wastes, by establishing a framework of general obligations for the countries that participate. The agreement seeks to minimize the generation of hazardous waste and the transboundary movement of these, ensure their environmentally sound management, as well as promote international cooperation to achieve it; create mechanisms for coordination, monitoring, and regulating the application of procedures for the peaceful settlement of disputes. In addition, it encourages its elimination, through environmentally sound management, as close as possible to the site where they are generated. It also seeks to minimize the production of hazardous waste, this involves strong controls during storage, transportation, treatment, reuse, recycling, recovery, and disposal. It promotes the substitution of hazardous substances in production and extended producer responsibility (REP) from the design and production of the product to the treatment of waste. Currently, this agreement has included within its regulations the transport of electrical and electronic waste, cell phones and computers. Likewise, it contains fractions that specifically limit the export of electronic waste including metal waste, electronic assemblies such as printed circuits, accumulators, other batteries and cathode ray tubes.

The Stockholm Convention seeks to limit pollution caused by persistent organic pollutants (POPs), such as brominated flame retardants, as well as heavy metals since at the end of their life cycle, these pollutants can be released and cause adverse effects to the environment and health. The Rotterdam Convention promotes shared responsibility and the joint efforts of countries adhering to it in the field of international trade in certain hazardous chemicals. Its objective is to protect human health and the environment against possible damage and contribute to its environmentally sound use, facilitating the exchange of information about its characteristics, establishing a national decision-making process on its import and export and disseminating those decisions between the members.

The Montreal Protocol was signed with the purpose of regulating the issue of substances that deplete the ozone layer, in which deadlines were established for the elimination and consumption of these substances. To this end, it establishes restrictions on trade with countries that are not part of the protocol, prohibiting the importation and/or exportation of exhausting substances or products that contain them. It also gives importing countries the means and information they need to recognize potential hazards and exclude chemicals that they cannot handle safely. If a country consents to the import of chemical products, the protocol promotes the safe use of these through labeling rules, technical assistance and other forms of support.

At the regional level, in 1994 Mexico signed the Agreement on Environmental Cooperation of North America (ACAAN). This agreement reflects the commitment of Mexico, Canada, and the United States to environmental improvement in the region. As a result of the ACAAN, the Commission for Environmental Cooperation of North America emerged, formed by the three federal environmental entities of the signatory countries of the North American Free Trade Agreement (NAFTA).

Since 2004 the three countries have worked within the framework of the CEC to develop projects for the adequate management of E-waste. The Commission considers that the electrical and electronic waste represents an environmental and commercial issue both for the waste generated and for the flows with use and unknown destination to other regions such as Africa or Asia. Therefore the problem of electrical and electronic waste in North America must be addressed jointly, given the geographical proximity and the permeability of the borders. The differences in national legislations and the complex institutional coordination represent significant challenges that can be faced in the context of the CEC to contribute to the control of illegal flows of electrical and electronic waste, and the efficient application of local regulations to improve their management, in other aspects.

In relation to RELAC, it is not a normative instrument, but rather an associative, nonprofit project. Its objective is to promote, articulate, and disseminate initiatives that promote solutions for the prevention, proper management, and correct final treatment of electronic waste in Latin America. Its fields of action are prevention, reuse, and recycling. Its foundation is focused on identifying the social, economic, and cultural particularities of Latin America and the Caribbean and responding to them in the electronic waste treatment initiatives that are implemented in the countries of Latin America. It seeks to recognize, highlight, and respond to the social, economic, and cultural peculiarities of Latin America and the Caribbean in the electronic waste treatment initiatives that are implemented. For this, it is committed to reconditioning initiatives to reduce the digital divide and promotes the social business, to promote the possibilities of equal access to market initiatives for the treatment of electronic waste. The national framework established for the management of electronic waste starts from the Political Constitution of the United Mexican States, the General Law of Ecological Equilibrium and Environmental Protection (GLEEEP), the General Law for the Prevention and Integral Management of Solid

Residues (GLPIMSR), from which follows the Regulations of the General Law for the Prevention and Integral Management of Waste (RGLIMSR), and the official regulations. In Mexico, electronic wastes, according to the LGPGIR, are classified as especial management wastes (EMW), so the law establishes the obligation to develop management plans and specific programs for their disposal The General Law for the Prevention and Integral Management of Residues as an instrument of environmental policy establishes a general classification for waste: hazardous waste, special handling, and urban solid waste; the first and last classification are residues whose identity is unquestionable; however, as regards the residues of special handling, their definition and understanding has not been very clear, which makes the handling of E-waste more complex in Mexico. This could be handled as dangerous, of special management or as an urban waste, when it is generated in a house, so the areas of competition involved are the three levels of government. The GLPIMSR establishes environmental policy instruments to regulate waste management plans that require it, for this purpose, Mexican Official Standards are generated that establish criteria for the development of management plans. It establishes a framework of shared responsibility among several industry players, as well as general principles for waste management, valorization, shared responsibility, and integral management, under criteria of environmental, technological, economic, and social efficiency. In Mexico, the federal entities have the power to formulate, conduct, and evaluate the state policy, as well as to prepare the programs on electronic waste. They are also responsible for authorizing the integral management of these, and identify those that may be subject to management plans. For this reason, Fig. 18.8 presents a scheme to give its identity and indicates the level of

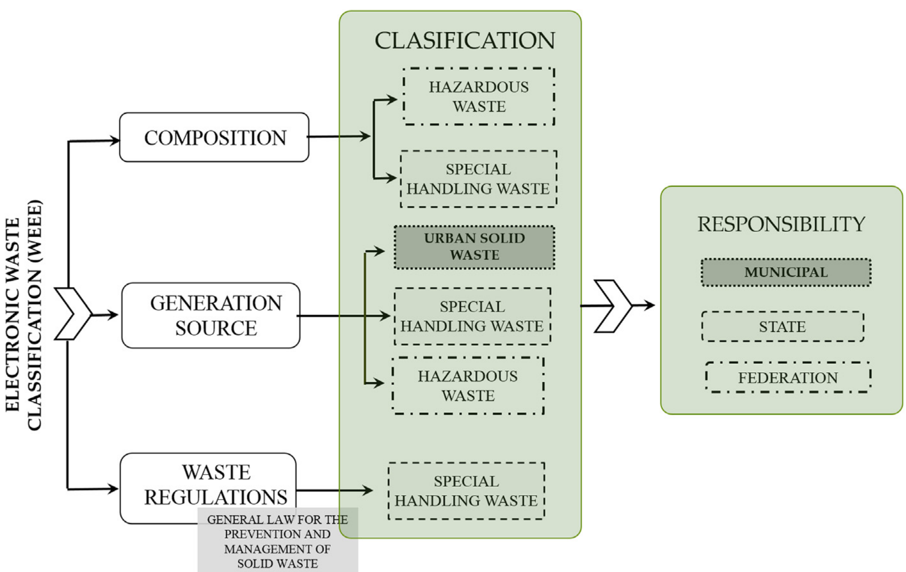


Figure 18.8 E-waste according to composition, source, and regulations.

competence in terms of authority to be involved in the regulations and waste management strategies, based on their classification, which is associated with the source of generation, composition, and regulations. Depending on the source and type of products, E-waste in Mexico is classified in three different forms: hazardous wastes (industrial), special wastes when generated in great quantities and municipal solid waste when generated by households. However, most E-waste is improperly disposed with municipal solid wastes.

In relation to the large generators of waste of special handling, among which electronic waste is found, Standard 161 in Mexico establishes classification criteria and determines that they are obliged to submit management plans (SEMARNAT, 2018a,b). This Standard 161 identifies the "Technological waste of computer industries and manufacturers of electronic products", such as computers, cell phones, televisions and cathode ray tube monitors, liquid crystal and plasma screens, printers, photocopiers and multifunctional, as well as audio and video players, and cables for electronic equipment.

However, for microgenerators such as individuals, households, small commercial establishments, offices, and schools, among others, there is no regulation, nor a program for the management of postconsumer electronic waste.

18.6 Current practices

Mexico is among the Latin American countries that has a higher percentage of separation and use of electronic waste. Among public programs, private companies, university programs, and the informal sector, 358,000 Mt of electronic wastes are collected nationwide, representing 36% of the total (Baldé et al., 2017). For the Secretary of the Environment, the integral management of electronic waste in Mexico faces important challenges, among which are the following:

- Combat the informal market.
- Control imports (mainly with the United States).
- Generate sufficient WEEE processing capacity.
- Create quality systems in your treatment.
- Avoid the presence of WEEE in final disposal sites.
- Open burning.
- The lack of norms or instruments for its management.

(SEMARNAT, 2018a,b: 17)

A federal government program for the switch to digital television in 2014–15 had unplanned consequences for E-waste management practices. The federal government delivered 13.8 million flat-panel televisions and caused millions of obsolete television sets to be discarded. Cathode ray tube television sets should be delivered to special collection centers, but the centers did not operate efficiently and managed to collect only a minimum percentage (5%) of the total of obsolete television sets. Bernache and Chávez (2015) report that in June 2015, after 1 year of the start of the television delivery program, there was no waste management strategy for analog televisions, people had nowhere to turn to deliver their old televisions. The answers they observed were: keep them at home; sell them to chachareros; incorporate them into domestic garbage; and throw them in the street or in vacant lots (solar). The federal government did not have a management plan for analog televisions, which led to the informal market for metals, mainly copper, which these analog devices contain. The three types of hazardous waste that can be contained in an analog television set are lead oxide (Pb), cadmium (Cd), and polybrominated flame retardants. The total amount of electronic waste resulting from the transition to digital television in Mexico was 278,000 tons. In addition to encouraging the informal activities of scrap dealers and pepenadores, due to the lack of a collection program, the waste stream from old televisions destabilized several recycling programs that were carried out in some states of the republic, "reciclatrones". Because in 2015 large amounts of televisions and monitors were received, which had a high cost to send them to their final destination and processing.

18.6.1 Universities

Several universities across the country have developed their campus programs focusing on E-waste collection and the subsequent transportation to authorized recycling centers.

In response to the problem of inadequate waste management some universities in México have organized collection activities of electronic waste, including the University of Guadalajara, the University of Veracruz, the Autonomous University of Baja California and the Autonomous Metropolitan University (UAM), and Universidad Michoacana de San Nicolás de Hidalgo in Morelia.

In the case of UAM, during three electronic waste collection programs conducted in 2013, 2014, and 2015, a total of 442 kilograms was collected. Such a program increases collection of E-waste is an indicator of social participation and awareness (SEDEMA, 2016).

An example is the program of selective collection of E-waste called "*Reciclatron*" which has been implemented in the Autonomous University of Nayarit (UAN)—Mexico with the aim of promoting in the university community and society, mechanisms to promote organized cooperation to improve the environment. The objective of this program is to promote a sustainability culture in higher education, and at the same time develop in students the abilities of leadership, cooperation, and responsibility in actions that favor the environment. A relevant result of the program during the four periods in which it was carried out, a total of 28.8 tons of electronic waste was collected and taken to a certified recycler. The results show that the program was also a success in terms of the environmental awareness of participants of students, employees, and professors.

18.6.2 E-waste collection campaigns in the state of Jalisco, Mexico

A recent study estimated a production of electronic waste of 21,983 tons for the state of Jalisco and 13,190 for the metropolitan area of Guadalajara. These amounts of thousands of tons per year are a serious problem since a large part of this E-waste is improperly disposed in landfills or disposed of with municipal solid waste. In a joint effort of civil society organizations, municipalities, state government, universities, and recycling companies, five *Electroacopio* campaigns were carried out in Jalisco as of 2010. These campaigns have involved up to 49 municipalities that have organized education programs and environmental workshops, have trained groups of volunteers and have installed temporary collection centers for electronic waste. In this type of campaigns, the relationship between society and government is emphasized. In this effort, social and public stakeholders have been integrated since the first campaign in 2010. It is important to note that up to 2014, a total of 456.2 tons of electronic waste have been collected (Bernache and Chávez, 2014). The 2014 campaign adopted the official name of "*ElectroAcopio* Jalisco". This campaign was organized following the logic established previously. The organization work begins 6 months in advance, the Organizing Committee was formed, in which The Ecovía Project, Vías Verdes A.C. and the Secretary of the Environment and Territorial Development (SEMADET) play a central role. The SEMADET held the Call for the participation of the town councils. From that Call, in November 2013, sessions were held to agree on dates, programs, advertising campaigns, transport routes, and logistics of the campaign. A new company was also selected to work in 2014, Belmont Bt Recycling Solutions (hereinafter referred to as Belmont). The company received all the REEs collected in the campaign and contributed with transportation and personnel for the loading and transfer of the E-wastes from the 11 regional collection centers that were established in the state of Jalisco (Bernache and Chávez, 2014). It is important to emphasize that in this campaign there was no purchase-sale of waste and there was no economic transaction between the parties.

The Organizing Committee also has a Technical Committee, made up of a group of university researchers, as well as the *Ecovía Project* experts. This Committee carries out technical advisory activities, evaluates the recycling companies, and also collaborates in the design and operation of the records and analysis of data resulting from the campaign. In this campaign, in addition to the weighing, registration of collection amounts in each location, and type of REE collected, a survey was also developed on consumption, management, and disposal of electronic waste that was administered to a sample of 581 participating citizens.

Three companies participated in the *electroacopio* campaigns in different times: in the first three campaigns (2010–12) the company that receives the electronic waste collected was *Recicla Electrónicos* located in the city of Querétaro.

In the last two campaigns, two companies located in the city of Guadalajara that have experience in disassembling and commercializing electronic waste materials participated. The company *MAC Grupo Ecológico* worked on the 2013 Collection Campaign. On the one hand, MAC has the advantage that at its plant, in addition to the REE treatment, it also carries out the recycling of mercury vapor bulbs and large domestic appliances such as refrigerators, stoves, and washing machines among other white goods. The company has important certifications, including the e-Stewards certification, which recognizes it as an environmentally responsible company in the recycling of E-wastes. However, the MAC company reported that

Table 18.2 *ElectroAcopio* intermunicipal campaigns in the state of Jalisco.

Intermunicipal campaign	Number of municipalities involved	Tons of E-wastes collected
2011	23	100.2
2012	30	104.4
2013	46	110.6
2014	49	90.3

they could participate in 2014 but that they would establish a fee for transporting and processing electronic waste.

Given that the results of the 2013 collection reflected a small volume of bulbs and white goods collection and given the complexity of their management, it was decided to choose a different management of these wastes, which opened the door to the possible participation of other companies to be depositaries of the collected in the program. In this sense, it was agreed to approach the company Belmont to know if it was interested in participating. The company Belmont is the only other company in Jalisco that holds the e-Stewards certification. There was a first approach with Belmont and the company agreed to participate under the terms that were established in a letter of commitment. The total amounts ORFE-waste collected in each campaign is presented in (Table 18.2).

The decrease in the amount of E-waste collection in the 2014 campaign may be explained by the following reasons. First, some important municipalities for their contribution did not have a good organization of the campaign and their collection was significantly less than previous campaigns. Second, the sector of the population that has participated in these campaigns previously has less waste to deliver. Third, in some municipalities there were situations in which "scrap merchants" who buy old equipment passed precisely a few days before the campaign and left little to deliver. One last reason is that a problem arose with the weighing in a regional route, since it was not possible to verify the exact tonnage delivered by three municipalities, so we could be underestimating the total tonnage received in this campaign.

When the trucks loaded with E-waste entered the plant of the recycling company, the employees classified the different types of E-waste and recorded the weight in kilograms of each type of electrical and electronic waste. The results of this record were: TVs added 28%, monitors 16%, and printers 15%. The set of "other electronics" added 38% of the total weight. Fig. 18.9 shows the proportion of each type of E-waste received in the *ElectroAcopio* 2014, according to its weigh.

On the other hand, records were taken of the number (frequencies) of each type of E-waste reported by citizens in the delivery format, which was filled when it arrived at the Collection Center. The participants reported that they were delivering an REE number by type. According to this report, we have the main types of E-waste were cell phones (23%), followed by monitors (19%), Desktop (16%), and

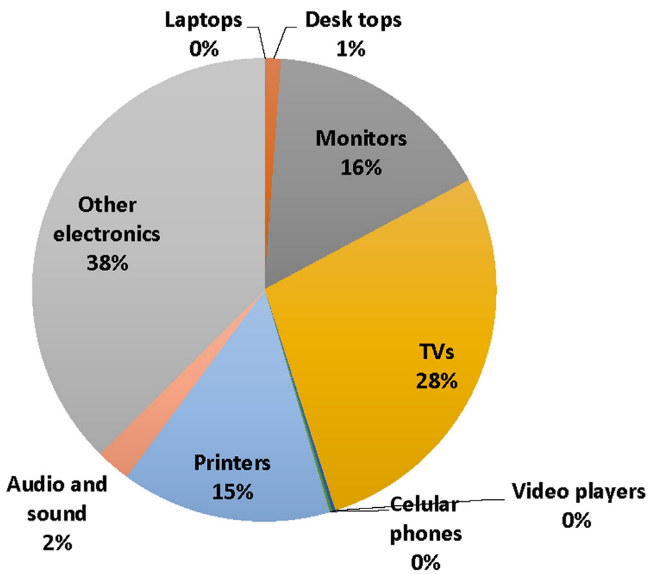


Figure 18.9 Percent of E-waste according to weight (2014).

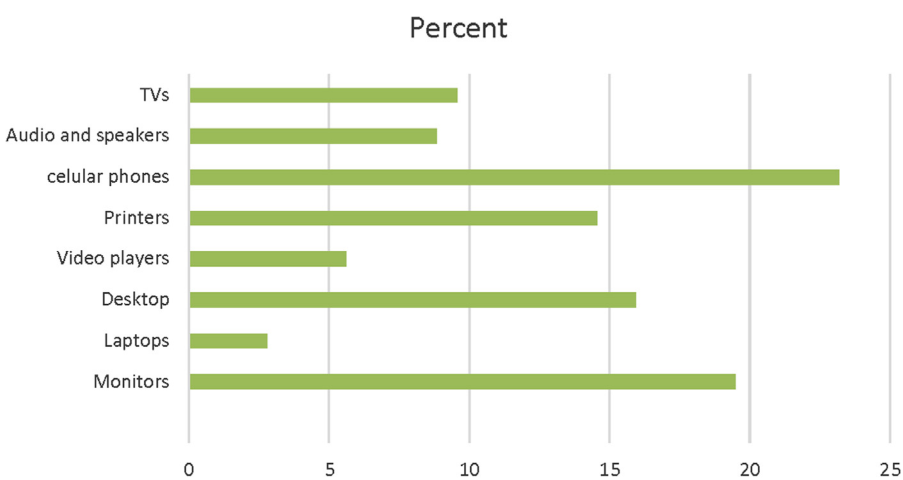


Figure 18.10 Types of E-waste, percent of frequencies (2014).

printers (15%). Fig. 18.10 shows the percentage distribution profile of E-waste delivered by citizens.

The graph shows that the monitors and televisions are two types of waste that have similar characteristics: together they reach 28% of the electronic waste units delivered, so they are a type of waste to avoid its inadequate disposal. In both cases (computer monitors and TVs) the main concern is the disposal of the cathode ray

Table 18.3 Nonparticipant resident E-waste disposal practices.

Question: Those persons that do not participate in the electronic waste collection campaign? How they dispose of their electronic wastes?	Percentages
Throw it to the garbage	58
Store them at home	13
Sell it to chatarreros	28
Other actions	1

tube which contain lead oxide residues that spread when the tube is broken during disposal. At the same time that the electronic waste collection campaign was carried out, a Knowledge and Management Survey of the E-waste was administered (Bernache and Chávez, 2014). Participation in the survey was 581 people from the 49 participating municipalities. Regarding the participation of citizens in the Campaign, the students were the ones who participated the most (30%) of the total, in second place were the employees with 19% and in third place were the housewives (18%). A fact that draws attention is that teachers only participated in a 5%, when it would have been expected a participation with greater presence of this type of professionals for their strategic activities in the training of students from basic education. The results indicate that the most common electrical and electronic devices in Jalisco homes are cell phones (35%), followed by television sets (27%), and desktops (17%), sound devices (13%) and video game consoles (8%) Regarding the management of devices that work but no longer used, 52% report that they keep them, or give them to relatives (16%), or donate them (13%). Regarding the management and disposal of E-wastes, an open question was asked and the answers are surprising since many report that they keep them for storage, but also throw other devices during the annual cycle or sell them to scrap metal. When asked more specifically about the management of E-wastes by their neighbors who do not participate in the *ElectroAcopio* campaign, the responses indicate that they are mainly thrown away in the MSW collection, as shown in Table 18.3.

When asked about the reason why other people from their colony do not participate in the *ElectroAcopio* Campaign, 43% indicated that it is due to a lack of timely information about the dates and places of the collection centers. While 45% of respondents answered that they do not give importance and care about the environment, this is a lack of education and environmental culture. Finally, regarding the motivation of those participating in the *ElectroAcopio* Campaign, the three main reasons are the following: 33% of respondents are motivated by an improvement in the environment, 28% say that their actions avoid pollution, and in third place 13% to promote good practices in the handling of electronic waste. In the period from 2010 to 2014, the campaigns for collection and recycling of electronic waste were consolidated in the state of Jalisco (Bernache and Chávez, 2015). The participation of 49 municipalities (out of a total of 125 municipalities) in this effort is important since it goes beyond the collection of physical waste. The environmental education programs, the workshops with practical activities, and environmental education for children and young people are also a transcendent component of these campaigns. Regarding advances in social participation, it can be said that the participants' environmental culture shows progress toward the integral management of E-waste. However, there are also traditional behaviors that lead to inadequate provision of E-wastes during the annual cycle, when there are no collection campaigns and access to an adequate route for the disposal of electrical and electronic waste generated in the context of the household life.

E-waste collection campaigns are very important and are a necessary step on the road to integral waste management. These are small steps and with discreet advances, but in a very positive orientation and leaving a mark on the citizens to inculcate the handling and recycling of this special type of waste that are generated, abundantly, by the contemporary consumer society.

It is necessary to point out that some town halls had problems with the organization of their campaigns. There were two main problems. On the one hand, several municipalities did not have an adequate organization at their headquarters and the dissemination was not timely or sufficient so the collection was much less than in previous campaigns. On the other hand, in some cases the weighing did not follow the protocol, the weighing receipts were not delivered and on a regional route that included at least three municipalities that did not report their weights well and this causes us to underestimate the total amount of the collection of REE in 2014, this underestimation is in the range of tons.

Finally, *electroacopio* campaigns in Jalisco stopped in 2015 before the irruption of thousands of tons of electronic waste product of the obsolete analog television that resulted from the program of transition to digital television in Mexico. By 2018, initiatives have returned, albeit on a smaller scale, to collect and give proper treatment to electronic waste.

18.7 Scavangers

In this group of informal workers there are several types: from the groups that pepenadores work in transfer plants and in final disposal sites, as well as those who buy waste in the streets and other actors. In the city of Mexico, *Colonia Renovación* is well known for carrying out storage, dismantling, and commercialization of electronic waste. In general, the informal sector in Mexico City could be handling 5000 to 10,000 tons per year (PNUD, 2018).

18.8 Industrial activities

There are four types of companies that are involved in the management and recovery of electronic waste (Table 18.4).

Table 18.4 Types of companies.

Processing level	Activities
0	Collection, transportation and storage
1	Gross selection of nonelectronic components
2	Selective separation of electronic components
3	Refinement

Source: PNUD, 2018.

In Mexico there are 153 registered companies dedicated to the handling and processing of electronic waste: 60% is classified as processing level 0 and 36% includes level 2 activities (PNUD, 2018).

The states with the highest number of companies dedicated to handling electronic waste are three: Jalisco with 25%, Baja California with 18%, and Guanajuato with 11%, while the State of Mexico and Mexico City participate with 8.5% and 7.8%, respectively. The rest is distributed in 10 other states of the republic.

Mexico, according to PNUD (2018), has an estimated generation of 383,424 tons E-waste in 2016; the industry has an installed capacity to handle up to 325,859 tons per year. Companies with processing level 2 (selective separation of electronic components) are located mainly in the states of Jalisco, Baja California, and Mexico City, which contributes to a handling of 50,431 tons per year.

18.9 Conclusion

E-waste production in Mexico is high, the country is ranked number three in the continent, only surpassed by United States and Brazil. The amounts given for a range that goes from 383,424 up to 1.1 million tons of E-waste. We consider that the first amount corresponds to postconsumer E-waste, and the second amount to all types of E-waste, considering wastes from production in electronic factories and large scale generators.

The organization of massive campaigns, locally organized provides events of collect E-waste, in Mexico, and it also provides the opportunity to collect and recover components that can be recycled. It prevents that these E-wastes being disposed mixed with municipal solid waste, therefore avoiding a negative impact on the environment. Events like *Reciclatron* o *ElectroAcopio* show that a collaborative effort to improve practices of E-waste management can be develop, involving, citizens, civil organizations, municipal and state environmental officials, and universities.

University campuses are another location for new initiatives, such a E-waste collection from computer rooms and laboratories. A number of associations of professors, employees, students, and other actors have emerged during the last decade, consolidating E-waste collection programs and taking those wastes to proper treatment and disposal. Such is the case with Universidad Autonoma Metropolitana in Mexico City, the Nayarit Autonomus University in Tepic, the Universidad Michoacana de San Nicolás de Hidalgo in Morelia, and some more.

In states with important presence of electronic industries, such as Jalisco, Baja California and Guanajuato, a growing number of E-waste processing plants have emerged.

The scope of the informal work conducted by scavengers is not well known at the time. We know that the informal sector has been involved in collection, separation, and commercialization of E-waste and material components. Colonia Renovation in Mexico City is an extended informal network of shops, street venues, organized commercialization, and control of their territory.

Searching alternatives for the management of E-waste, it is necessary for the intervention of all sectors and actors involved in the life cycle of E-waste from its generation. So this study sought to identify the level of knowledge of the generator regarding environmental problems due to the generation, consumption, and disposal of domestic products, and their perception of the problem and current management systems. In addition to obtaining a vision of the impact due to consumption and disposition practices in the search to establish background and possible strategies that support the need to implement measures for the use and recovery of this waste.

References

Araújo, M.G., Magrini, A., Mahler, C.F., Bilitewski, B., 2012. A model for estimation of potential generation of waste electrical and electronic equipment in Brazil. Waste Manag. 32 (2), 335−342. Available from: https://doi.org/10.1016/j.wasman.2011.09.020.

Baldé, C.P., Forti, V., Gray, V., Kuehr, R., Stegmann, P., 2017. The global E-waste monitor 2017: quantities, flows, and resources. In: United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/ Vienna.

Bernache and Chávez, 2014. Informe para la Secretaría de Medio Ambiente y Desarrollo Territorial. La Campaña de ElectroAcopio 2014 en el Estado de Jalisco. Manuscrito no publicado. Guadalajara, México. 15 pp.

Bernache and Chávez, 2015. Los residuos de la transición a la Televisión Digital Terrestre en México. VI Simposio Iberoamericano en Ingeniería de Residuos Sólidos. Tecnológico de Costa Rica. Cartago.

Cucchiella, F., D'Adamo, I., Koh, S.L., Rosa, P., 2015. Recycling of WEEEs: an economic assessment of present and future E-waste streams. Renew. Sustain. Energy Rev. 51, 263−272. Available from: https://doi.org/10.1016/j.rser.2015.06.010.

DOF (Diario Oficial de la Federación), 2015. Ley General para la Prevención y Gestión Integral de los Residuos. Cámara de Diputados del Congreso de la Unión. Última reforma 22/01/2019. Consultado en línea. https://www.gob.mx/cms/uploads/attachment/file/27266/Ley_General_de_Residuos.pdf.

Georgiadis, P., Besiou, M., 2009. Environmental strategies for electrical and electronic equipment supply chains: which to choose? Sustainability 1 (3), 722−733. Available from: https://doi.org/10.3390/su1030722.
Huang, K., Jie, G., Zhenming, X., 2009. Recycling of waste printed circuit boards: a review of current technologies and treatment status in China. J. Hazard. Mater. 164, 399−408.
Kahhat, R., Kim, J., Xu, M., Allenby, B., Williams, E., Zhang, P., 2008. Exploring E-waste management systems in the United States. Resour. Conserv. Recycl. 52 (7), 955−964. Available from: https://doi.org/10.1016/j.resconrec.2008.03.002.
Mihai F.C., Gnoni M.G., Meidiana C., Ezeah, C., Elia V., 2019. Waste electrical and electronic equipment (WEEE): Flows, quantities and management, a global scenario. Chapter 1 in Prasad M.N.V. and Vithanage, Meththika (Eds). Electronic Waste Management and Treatment Technology, Elsevier Science & Technology Books 1−34. Available from: https://doi.org/10.1016/B978-0-12-816190-6.00001-7.
Ohajinwa, C.M., van Bodegom, P.M., Osibanjo, O., Xie, Q., Chen, J., Vijver, M.G., et al., 2019. Health risks of polybrominated diphenyl ethers (PBDEs) and metals at informal electronic waste recycling sites. Int. J. Environ. Res. Public Health 16 (6), 906. Available from: https://doi.org/10.3390/ijerph16060906.
Orlins, S., Guan, D., 2016. China's toxic informal E-waste recycling: local approaches to a global environmental problem. J. Clean. Product. 114, 71−80.
PNUD, 2018. Industria formal e informal del reciclaje de residuos electrónicos en México. Infografía industrial del reciclaje. Available from: Obtenido en: http://www.residuoscop.org/wp-content/uploads/2018/06/Infograf%C3%ADa-Industria-Reciclaje.pdf.
Promexico, 2016. Industria Electronica. Diagnostico sectorial. Unidad de Inteligencia de Negocios de ProMéxico Secretaria de Economía. Mexico D.F.
Román Moguel, Guillermo, 2007. Diagnóstico sobre la generación de residuos electrónicos en México. Informe Final. Instituto Nacional de Ecología, desarrollado por el CIIEMAD del Instituto Politécnico Nacional, México, D.F.
SEDEMA (Secretaría de Medio Ambiente de la Ciudad de México). 2016 Reciclatrón: Jornada de acopio de residuos electrónicos y eléctricos. <http://www.sedema.df.gob.mx>.
SEMARNAT, 2018a. NORMA Oficial Mexicana NOM-161-SEMARNAT-2011, Que establece los criterios para clasificar a los Residuos de Manejo Especial y determinar cuáles están sujetos a Plan de Manejo; el listado de los mismos, el procedimiento para la inclusión o exclusión a dicho listado; así como los elementos y procedimientos para la formulación de los planes de manejo. Diario Oficial de la Federación, 1 de febrero 2013.
SEMARNAT, 2018b. Buenas prácticas para el manejo integral y ambientalmente adecuado de residuos de aparatos eléctricos y electrónicos: Marco General. Programa de las Naciones Unidas para el Desarrollo, Proyecto #92723 "Manejo Ambientalmente Adecuado de Residuos con Contaminantes Orgánicos Persistentes" (ResiduosCOP). México.
Sinha, K.D., Kraeuchi, P., Widmer, R., 2009. Producer responsibility for E-waste management: key issues for consideration: learning from the Swiss experience. J. Environ. Manag. 90 (1), 153−165.
Vega, O.A., 2012. Efectos colaterales de la obsolescencia tecnológica. Revista Facultad de Ingeniería, UPTC 21 (32), 55−62.
Widmer, R., Oswald-Krapf, H., Sinha-Khetriwal, D., Schnellmann, M., Böni, H., 2005. Global perspectives on E-waste. Environ. Impact Assess. Rev. 25, 436−458.