The impact of waste of electrical and electronic equipment public police in Latin America: analysis of the physical, economical, and information flow

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17.1 Introduction

The waste electrical and electronic equipment (WEEE)-stream comes mostly from households rather than from business sector. In the Netherlands only 19% comes from this sector (Huisman et al., 2012) meanwhile in Sao Paulo—Brazil, 30% comes from commercial enterprises (ABDI, 2013); however, in general there is underreporting worldwide, so its exact origin remains uncertain (Baldé et al., 2017). Nowadays, purchasing household appliances increases not only due to basic needs satisfaction but also for comfort seeking in developing countries (Rao & Ummel, 2017). This is reinforced by technological changes, programmed or perceived obsolescence, which make the appliances life shorter and therefore generate more WEEE (Kumar et al., 2017; Wang et al., 2013). Electrical and electronic equipment (EEE) have negative environmental impact at all life cycle phases. While refrigerators have a greater impact in the use stage (Xiao et al., 2015), cell phones have an impact on the production and disposal stages (Yang et al., 2004; Yu et al., 2010; Park et al., 2006) without disregarding its contribution on material extraction, use, and disposal (Yu et al., 2010; Park et al., 2006). Although, disposal is one of the most studied problems in order to reduce its impact and improve the efficiency of resources, including energy (Bian et al., 2016).

Seeking to transform from a linear to a circular economy (CE) one implies to have a wider perspective in mind not only the end of life stage but also whole stages of the life cycle, facing challenges such as waste generation, lack of resources, and sustainable economic benefits for stakeholders (Lieder and Rashid, 2016; Parajuly and Wenzel, 2017; Ghisellini et al., 2016). Different business

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models of CE are implemented such as cradle to cradle, take back management like reverse logistic, refurbishment, including resale, repair, deposit system, remanufacturing, and rematerialization including recycling and cascading use (Ellen Macarthur Foundation, 2012; Bakker et al., 2014; EU, 2016; Islam and Huda, 2018).

The extended responsibility of the producer (EPR) (Lindhqvist, 2000) that aims to enhance the circularity of products and materials. EPR arises as one of the cornerstones of the transition toward a CE (Zero Waste Europe, 2017). It is the most applied environmental policy principle in Latin America (OECD, 2014). This principle seeks to assign physical, financial responsibility to the producer because it is able to make changes at the source, bringing strong incentive to reuse, recycle, or dispose products at the end of life (Lindhqvist, 2000; Manomaivibool and Hong, 2014). This principle is made effective through administrative, economic, and informative policy instruments (Tojo et al., 2008), which allow the integral management of the physical, economic, and information flows of WEEE.

In developing countries, household electronic appliances increase with income (Rao and Ummel, 2017). In addition, the amount of WEEE is more directly correlated to country's GDP than to population (Kumar et al., 2017), which implies that socio-economic condition strongly affects the EEE Life Cycle.

In the context of a geographically region, Latin American covers 20 different countries sharing similar socio-cultural features with a population close to 610 million people, representing approximately 9% of the world (World Bank, 2017a,b). The regional average GDP per capita is close to US $12000, considered medium-high, yet it combines three differentiated country groups. A great socio-economic contrast can be observed because some groups have high, others have medium high, and others have low income; this contrast can be a reflex of each country's internal socio-economic structure, evidenced in the average inequality index, which is high, 48 (World Bank, 2015). The final expenditure of households represents 69% of the GDP, an average in global sense. Television is the appliance showing higher penetration followed by the refrigerator, washing machine, stereo system, and the Internet access equipment; the later exhibits a regional penetration of 49.1%, higher than the world average by 5% (ITU, 2017). The regional amount of WEEE generated is 5.3 kg/inh/year, lower than the world average and represents 9% of the worldwide (Baldé et al., 2015).

Around 30% of Latin American countries have WEEE legislation (Baldé et al., 2015; Misiones online, 2017; RELAC, 2017). Notably there is a remarkable subregistry of the generated and recycled amounts because the informal chains prevail in the collection, dismantling, and recycling (Ardi and Leisten, 2016; Cao et al., 2016; Islam et al., 2016; Liu et al., 2016). Latin American legal frameworks are rigid and show lack of integrated, collective, and coordinated management system schemes (GSMA, 2014). In most of Latin America countries, there are no management policies for WEEE or road maps indicating the actions to be taken by the State, involving all stakeholders, to obtain better long-term results (SRI, 2017). Those countries who lead these policies are Colombia, being a pioneer in the establishment of comprehensive WEEE management policy (SRI, 2017; MADS, 2017), Brazil that has established action plans for WEEE and its selective collection and Peru with its WEEE management plans (ITU, 2016).

Other common feature in Latin America is the lack of infrastructure for collection, dismantling, recycling, and recovery of current WEEE, that is, not be sufficient for the increasing amounts of these, which stimulates informality. It is estimated that Brazil loses USD 13 billion annually because of the infrastructure lack to treat solid waste that includes WEEE (GSMA, 2014). The existing collection infrastructure is concentrated in the main cities, covers only up to the preprocessing that involves the dismantling and often does not include mechanical separation. That is why the end-processing technologies that include the pyro/hydro/bio metallurgical treatment and allows the recovery of valuable materials are in foreign hands, associated to the export of circuit cards and other components (MADS, 2017; Kumar et al., 2017).

Given the aforementioned specific characteristics, we want to estimate "what are the impacts of administrative, economic and information policy instruments, on the physical, economic and information flow of WEEE" that produce an increase of valuable, toxic material, and those that go to landfill, as well as energy consumed, to demonstrate the effects at different stages of the life cycle. Including in the panorama that the management policies and plans have been formulated, only in three representative Latin American countries, and considering there is a lack of instruments for its implementation the model contributes to estimate the scenario that gives greater results within the socio-economic context of the region.

Under this perspective, the chapter is structured as follows: Section 17.2 presents the state of the art and shows the analysis of the administrative, economic, and informative policy instruments that have been proposed or used to increase reuse, collection, recycling, and recovery materials, related to the EPR principle and CE. In addition, it explains the use of system dynamics (SD) as an appropriate technique to establish the relationships between the different actors and the policy instruments impact on the variables selected in the different flows. The context describes the situation of three countries in the region that reflect the socio-economic differences and different levels of implementation of legislation, which allow modeling the relevant characteristics.

In Section 17.3, we present the selection criteria that were applied in order to define the appliances to be studied, obtaining five devices: television, refrigerator, computer, cell phones, and light bulbs. In Section 17.4, the simulated management model of WEEE is described together with the physical, economic, and information flows. In Section 17.5, policy instruments are applied to different scenarios and the impact of these is determined in the stages of the life cycle of WEEE.

In the results section the importance of intervening several phases of the life cycle at the same time is highlighted; specifically, in the usage phase three energy efficiency technological changes are modeled in refrigerators and the model determines the impacts on energy consumption and purchase decision of a new ones. Finally, in the last section the conclusions.

17.2 State of the art

17.2.1 *Extended responsibility of the producer and EPR policy instruments*

CE suggests an economic model regulated according to the laws of the nature, networks of interacting components, exchange of material and energy flows, recycling patterns, and environmental mimicry (Ghisellini et al., 2016). The CE seeks to apply principles to close the loop of products life cycles through greater reuse, recycling, and recover, with the purpose of protecting the environment, resources, and the economy (Lieder and Rashid, 2016). It also aims to extend the lifespan of materials through longer use and the increase of secondary raw materials incorporation (OECD, 2014). This concept is relevant to the WEEE management model because implies a complex mixture of material, some with hazardous content, which can cause major environmental and health problems. Moreover, the production of modern electronics requires the use of scarce resources: around 10% of total gold worldwide is used for EEE production (EC, 2017). EPR is one of the key principles for the transition of the economy circular (Zero Waste Europe, 2017).

EPR has two environmental objectives: one to encourage the eco-design and second to ensure adequate end of life through better collection, treatment, reuse, and recycling. The implementation of EPR in Europe have strengths basically on the improvement of the collection and recycling rates and costs, reduction of the burden on public budgets for municipal. The market and quantity for high quality recovered material has increased, contributing to resource security and potential opportunities to promote the eco-design (Watkins and Pantzar, 2017). EPR is identified as an effective policy instrument to engage producers in the broader efforts on sustainable material management. There are various types of EPR schemes, mandatory and voluntary; assigning the physical, financial, and information responsibility that is made effective through different policy instruments.

In a study made by Tojo et al. (2008), in the European Union the physical responsibility of the WEEE has been differently assumed. By the producer in four countries, by the government in one country, by the producers and traders in five countries, by the traders and the government in ten countries, by the producers, traders, and the government in two countries, and there is not enough information in three of them. In contrast, the producer assumes financial responsibility in eight countries, the producer and traders in five countries, and the traders and the government in six countries.

The policy instruments seeking to increase the waste management efficiency in specific socio-economic contexts have been applied in a regional fashion (see Table 17.1). In the European Union, administrative, economic, and information instruments have been applied (Tojo et al., 2008). In Asia, several policies have been proposed to improve the management of WEEE focused on determining financial and physical responsibility, as well as the incorporation of the informal sector (Yu et al., 2014; Cao et al., 2016; Shinkuma and Huong, 2009; Mashhadi and Behdad, 2017). One of the most relevant policies implemented since 2016 is the Chinese fund policy that states that producers and importers must pay disposal fees,

Table 17.1 Applied, proposed, and needed policy instruments in WEEE.

	Policy instruments/authors	1	2	3	4	5	6	7	8	9	10
Administrative instruments	Substance restriction	x						x			x
	Source separation	x									
	Producers take-back (and emerge internet sales)	x	x				x			x	
	Collection/reuse/collection, recycling/recover targets (and resource scarcity)	x					x		x		x
	Minimum recycled material content standards	x									
	Landfill restriction/diversion targets	x					x				x
	Environmentally sound treatment/disposal standards (included hazardous waste)	x	x	x			x	x	x		
	Track WEEE export at proper recycling facilities				x		x			x	
	More restriction of WEEE trade into bilateral agreements			x			x	x			
	WEEE recycling programs in rural areas			x							
	Role and responsibility of actors (included informal recyclers)						x	x			x
	Reusability index					x					
Economic instruments	Landfill tax	x									x
	Waste Disposal Tax	x			x					x	x
	Recycling Credit Scheme	x	x								
	Subsidies for secondary Materials/ quarry tax	x									
	Pay as you throw	x						x			
	Deposit-refund systems	x	x					x			
	Subsidies to eco-design or incorporate recover material				x		x			x	
	Tax/subside to improve technical progress and recycling rate to recyclers							x	x		
	Governmental responsibility by orphan products		x								
	Funding to infrastructure and human training						x	x	x		
	Waste Tax into the energy consumption bill										x
Informative	Eco-labeling scheme	x									x
	Green shopping guidance	x									
	Marking of products and components	x									
	Information campaign to residents	x		x				x			
	Information to treatment facilities	x						x			
	Transparent data and cost management						x		x		x

Constructed by the authors based on these sources: (1) Tojo et al. (2008); (2) Yu et al. (2014); (3) Cao et al. (2016); (4) Shinkuma and Huong (2009); (5) Mashhadi and Behdad (2017); (6) OECD (2014); (7) Kumar and Dixit (2018); (8) Wang et al. (2018); (9) Gu et al. (2017); (10) This research.

while qualified dismantlers and disposers obtain subsidies under the allocation and supervision of the government but remanufacturing is not included in the agreement. Since 2016, approximately 109 formal WEEE recycling enterprises have obtained official license for the treatment and disposal of WEEE (Liu et al., 2017). The effects of this policy have been studied by Zhou et al. (2017), Gu et al. (2016), Gu et al. (2017), Liu et al. (2016), Li et al. (2017), and Wang et al. (2018). It has enhanced the competitive advantage of formal recyclers, although informal recyclers, besides promoting the healthy development of WEEE recovery industry, dominate the market (Liu et al., 2016; Zhou et al., 2017). In Chile, the fund for recycling was created, with educational purposes for the citizens, the scavenger, and the infrastructure (MMA Chile, 2017).

These policy instruments must resolve what other authors have identified as barriers: policies and regulation, infrastructure, knowledge, socio-economic, socio-cultural, technological, and financial barriers (Kumar and Dixit, 2018). Also, challenges and constraints of EPR and general implementation are an unclear role and responsibilities of the actors, lack of data, free-riders, lack of enforcement mechanism, lack of collective schemes, lack of incentive of environmental design, unknown disposal cost, informal sector, recycling and material recovery targets, and the auditing and compliance of material flows within the system (OECD, 2014; Morris and Metternicht, 2016; Islam and Huda, 2018). In the same Table 17.1, the instruments that will be simulated in the different scenarios are shown, which will be discussed in Section 17.5.

17.2.2 System dynamics

SD as a simulation technique allows to model complex, closed-cycle systems and analyze the variables and implications for the system (Sterman, 2000), which is why it has been applied in several environmental, economic, and social studies (Ardi and Leisten, 2016; Georgiadis and Vlachos, 2004). SD has a qualitative and quantitative approach. The scope of the system, the variables and their relationship make up the causal loops diagram (Sterman, 2000), which represents the real model. Through arrows, the causality between the variables is shown and positive circularity is formed when the variables go in the same direction, in contrast, the negative sign in loop variables generate the balance of the system. In addition, stock and flow diagram is established (Sterman, 2000), where stocks are accumulators that are influenced by flows, as well as connectors and auxiliary variables. The quantitative approach is carried out through computer simulation models with specialized software, in this case Vensim, which generate results that are studied in the analysis phase through different "*what if*" scenarios that allow to reduce the uncertainty in the decision-making throughout the simulation period.

Several studies have applied SD with various purposes associated with changing the behavior toward recycling, including the informal population, determining policy impacts, and closing material cycles. Specifically, Georgiadis and Vlachos (2004) studied the impact of the environmental policy and the corporate image of environmental practices on market behavior. Spengler and Schröter (2003) and Georgiadis and Besiou (2008, 2010) studied EEE using SD to investigate closed-loop material flows, focused on supply chain management and the influence of consumer behavior. Besiou et al. (2012) studied the impact of the waste picker's activities in the WEEE recovery system using the environmental, economic, and social dimensions of sustainability. Nguyen et al. (2015) understand smartphone usage in Singapore by exploring the leverage points and resistance to change. Ardi and Leisten (2016) assessed the role of informal sector in WEEE management system. Sinha et al. (2016) modeling approach investigated the dominant paths and drivers for closing the metal flow loop through the concept of eco-cycle in the global mobile phone product. Rodríguez et al. (2013, 2015) and Rodríguez and Estupiñán (2018) applied different policies in the life cycle of EEE in order to reuse, recycling, and recover more materials. Fan et al. (2018) predicted the recycling behaviors of various user groups using the E-waste recycling in Taiwan. Yao et al. (2018) explored the influences of different recycling scenarios for mobile phone in China.

17.3 Contextualization and electrical and electronic equipment scope

In Latin America, socio-economic differences are wide, so, putting into context three different studies reflecting the reality of the region is proposed, namely, Sao Paulo, Bogotá, and La Paz. Brazilian city is the most populated of the country; Colombia and Bolivia cities were selected due to their importance in the country's economy, and the most representative characteristics are shown in Table 17.2. These cities were determined because of their different levels of informality in the management of WEEE; besides the actors and the physical, economic, and informative responsibilities are differentiated and diverse; therefore in these context the modeling results distinguishes the best policies.

Several Latin American countries have implemented primal EPR schemes, especially those that are part of the OECD: Chile, Mexico, and Brazil. In addition, Argentina and Colombia have also worked on EPR schemes (OECD, 2014). Countries like Bolivia, Costa Rica, Ecuador, Guatemala, Panama, Peru, and Uruguay follow those implementation efforts. Countries studying or promoting its application are El Salvador, Honduras, Nicaragua, Paraguay, and the Dominican Republic. Most of these initiatives are motivated on achieving development plans, climate change, and sustainable development goals (RELAC, 2017). Likewise, only regulatory policy instruments are applied and express the need for economic and informative instruments (OECD, 2014), since physical and financial responsibility is still more alongside the government.

In Latin America due to socio-economic conditions, the decision to dispose of EEE is postponed, so they are stored in households or sent to reuse, due to the perceived material value by users. Once the disposal decision is made, preference is given to the informal channel, since the consumer has little information about the formal recycling options and formal infrastructure lacks nearby disposal places (MADS, 2017). In addition, the informal sector often offers economical retribution

Table 17.2 Characteristics of countries studied.

Representative country	**Brazil**	**Colombia**	**Bolivia**
City studied(Population 2017)	Sao Pablo(12,106,920)	Bogotá(8,181,047)	La Paz(1,890,000)
GDP miles of millions US$ (World Bank, 2017a).	High(more US$17,836)	GDP medium high(US $17.836–US$10,000)	GDP medium(less US $10,000)
Similar GDP countries (World Bank, 2017b).	Argentina, Brazil, Chile, Costa Rica, Panamá, and Uruguay	Colombia, Ecuador, México, Perú, República Dominicana, and Uruguay	Bolivia, El Salvador, Guatemala, Haití, Honduras, Nicaragua, and Paraguay
Informal economy (Americas Society, 2015)	36.5%	54.5%	70%
WEEE Generation 2014 (Balde et al., 2017)	7.0 kg/inh/year1412 kt/year	5.3 kg/inh/year252 kt/year	4.0 kg/inh/year45 kt/year
WEEE Legislation	National Policy on Solid Waste (Law 12.305/2010). Decree 9.177/2017 Compulsory Reverse logistics (Brasil, 2010).	WEEE National Policy. Law 1672/2013 and decree 284 of February 2018 (SIR, 2017)	Integral Waste Management Law 755/2015. Supreme Decree 2954/2016
WEEE infrastructure	38 Licensed Recycler, 4 Hazardous waste treatment, 16 Informal Recycler, 10 Technical assistances, 13 Scrap metal, 6 Sale of used, 2 Recycling store (MDIC, 2017)	36 WEEE Managers with license and 13 managers export (MADS, 2017)	ONG Fundare y Fundación Viva, 5 operators (Fundación viva, 2017)
Physical and Economic Responsibility	Government(ABDI, 2013; MDIC, 2017)	Government and private Company through the postconsumer programs.	Government initiatives, NGOs and private companies
Energy Efficiency policy instruments (BID, 2015)	Ecolabels from 1984Dec 132/2006 to illumination	Voluntary Ecolabel from 2000. Obligatory from 2015 (Ley 1715/2015)	The government delivered efficient bulbs in 2008) (Greenpeace, 2010)

Table 17.3 Criteria for selecting the study EEE.

EEE	Penetration in homes	Technological change	Hazardous materials	EEE weight (kg)	Valuable materials with high demand
TV	High	High	High	Medium	High
Fridges	High	High	High	High	Low
Computers	Medium	High	Low	Medium	High
Mobile	High	High	Low	Low	High
Light Bulbs	High	High	High	Low	Low

Constructed by the authors based on these sources: DANE (2017); Delfín et al. (2009); MDIC (2017); ABDI (2013); Grant Thorton (2011); EU (2011); Wang (2014); Cucchiella et al. (2015); Zhang et al. (2017); Chancerel et al. (2015); Van Eygen et al. (2016).

in exchange for WEEE and picks them up door-to-door. Nevertheless, more than recycling there is dismantling, yet the lack of recovery standards affects the health and environment (de Oliveira et al., 2012; Ghisolfi et al., 2017). The informal sector has an advantage because it avoids formalization costs and extracting the materials requires less technification. Colombia and Bolivia informal data are inaccurate. Brazil exhibits the following figures: collection from households is 50% informal, 15% public, 2% formal, and 33% falls into reuse. In contrast, those who come from companies have a higher proportion of 62% reuse and informality falls to 19%, formal increases to 5% and public is 14% (MDIC, 2017).

Household EEE somehow reflects the socio-economic differences of the region, so they are selected according to the following criteria: (1) the EEE household penetration is high when it is greater than 70%; (2) technological change is high when there is functionality or energy consumption innovation in a period shorter than the device's useful life; (3) hazardous materials are high if they are part of the substance of ROHS Directive (Pb, Hg, Cd, Cr^{6+}, PBB, BDE, DEHP, BBP, DBP, DIBP) (EU, 2011); (4) product's weight is high if greater than 40 kg and is low if less than 3 kg (Wang et al., 2013); and (5) quantity and demand of valuable materials is high when any of the 78 fundamental raw materials are found among their components (EC, 2017). Specially Co, Ga, In, Ta, Au, Pd, Ag, and REE and whose demand is greater than 30% relative to world mining production (Zhang et al., 2017), or metal has a concentration greater than 0.25 g per unit of product (Cucchiella et al., 2015). The application of these criteria is shown in Table 17.3.

17.4 Model

Three base models are simulated independently to model each country characteristics. Model includes the retailing, use, and end of the life cycle stages of the EEE, as shown in Fig. 17.1. The causal diagram allows visualizing how the variables of

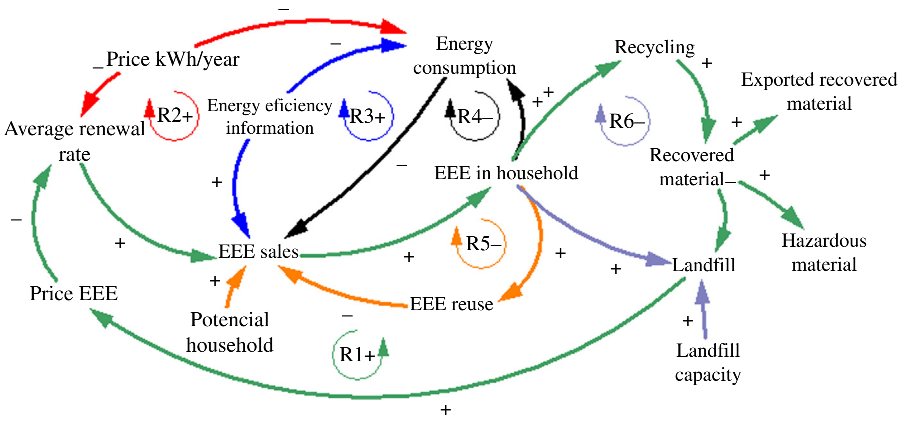

Figure 17.1 Causal loops diagram of EEE in stage marketing, use, and end of life.

the WEEE management system are related and it represents the real situation through the most significant variables. This has four basic elements: the variables, the relationship between these, represented through an arrow, the arrow direction from the cause to the effect and the sign of the loop that shows the positive or negative relationship between the variables. Fig. 17.1 shows six loops or closed cycles of interrelation between the variables. The R1 green cycle shows that an increase in EEE sale, there would be more EEEs in households. Therefore there will be more quantities for recycling and thus greater opportunity to recover material, so less material will go to the landfill and therefore its capacity will be exhausted. Thus, the WEEE tax is increased and the price of the new EEA increases, so that the rate of renewal of new equipment is lower and whenever this rate increases, the sales will be higher. Moreover, since there is a positive relationship between the variables, then the loop is positive. The R2 red loop is associated with energy prices, R3 blue for energy efficiency information, R4 black for energy consumption, R5 yellow for reuse, and R6 purple for recycling. These relationships are explained in the physical, economic, and information flow, which are described below.

The simulation scope covers a 40-year horizon, starting in 2001. These flows are affected with different policy instruments to see their influence on the outcome variables.

17.4.1 Physical flow

The physical flow shows the EEE forward movement through the stages: production, use, and up to the end as WEEE. In the production stage, data production, imports and exports data are obtained mostly from the Trade Map platform and from national statistical institutions in each country: IBGE (Brazil), DANE (Colombia), and INE (Bolivia). Households EEE in use are determined by the penetration rate, households that acquire EEE for the first time, households that renew the EEE by perceived obsolescence or by programmed obsolescence and also by those repaired, donated, thus extending their useful life. 30% of household appliances and some light bulbs contemplate reuse. The WEEE stock contemplates the formal and informal channel, and their ability to retrieve material is differentiated. The recovered materials can be incorporated into the productive cycle, guaranteeing a CE.

17.4.2 Economic flow

When the EEE average renewal rate is estimated, socio-economic aspects of each country are taken into account, as this depends on the price, the cost of repair in case of minor damage, the purchasing power determined by household income and finally access to financing or discounts that can be provided either by retailers or financial institutions. Another involved economic variable is an ex ante tax on the consumer for EEE disposition, which value is adjusted according to the excess capacity of the sanitary landfill.

Brazil is the unique country with available collection costs and WEEE dismantling information, as shown in Table 17.4. A clear difference is made for medium-sized EEE that are collected in a consolidation center (CC) by traders and then taken to dismantling plants, while large EEE also have the option to go to dismantling directly from the consumer.

The energy cost is a factor that could affect the purchase decision and consumer usage habits, which is directly reflected in the electricity consumption bill. When the energy cost increases, the user is willing to make changes in his consumption habits or even looks for more energy-efficient EEEs.

17.4.3 Information flow

Aiming to achieve full-informed consumer's decision-making when purchasing or renewing appliances, energy efficiency labels were defined as an informative tool.

Table 17.4 Unit costs of WEEE disposal (US$/ton).

Costs	Medium, with CC	Large, without CC	Large, with CC
Primary transportation	479.3	1010.4	414.5
Separation and storage	362.7	0.0	272.0
Secondary transportation	90.7	0.0	129.5
Dismantling	621.8	440.4	440.4
Public relations	25.9	25.9	25.9
Data monitoring	25.9	25.9	25.9
Total	1606.2	1502.6	1308.3

Convention: 1US$: 3.86 $Real, CC.

Source: Adapted from Agência Brasileira de Desenvolvimento Industrial (ABDI), 2013. Logística Reversa de Equipamentos Eletroeletrônicos Análise de Viabilidade Técnica e Econômica. Retrieved from: <https://corporativo.abdi.com.br/conhecimento/Publicaes1/Log%C3%ADstica%20reversa%20de%20Equipamentos%20Eletroeletr%C3%B4nicos%20-%20res%C3%ADduos.pdf>.

In the European Union, the scale goes from A +++ to C, in accordance with Directive 2010/30/EU; in North America it is determined by Energy Star, and in Brazil and Colombia the scale goes from A to G, and Bolivia still does not have this instrument yet (IDB, 2015). Three categories were defined for the simulation model: T1 with a consumption of (+59%) with respect to type T2, which has average values and T3 with consumption of (−42%).

17.4.4 Validation

The model is validated through comparison with secondary information used for the first 15 years. Raw data come from different studies and sources related in Table 17.2; additional sources are used in the description of the model. Informal sector information sources are very descriptive since it represents the majority of the sector but not accurate. Once governmental global and the formal sector data is acquired, an estimate of the informal sector is obtained as the complementary of the formal. Likewise, dimensional consistency is performed; parameters verification was cross-checked with real data to observe their consistency and additional simulations with extreme data were made finding a logical behavior of the system.

17.5 Scenarios

Six scenarios were simulated with different policy instruments in order to discern the impacts of these in the amount of TV, fridges, computers, mobile, and light bulbs in use; energy consumption, landfill material, recovered material, and hazardous material. Those scenarios are selected because they implement the more applied, proposed, and needed policy instruments in WEEE related in Table 17.1.

17.5.1 Scenario 1: prohibition of hazardous substances

Different authors considered that more than 3% of the WEEE components are hazardous (Zhang et al., 2017; Cucchiella et al., 2015). Fluorescent luminaires contain mercury and according to the Minamata Convention that came into force in August 2017, "there should be no processes that use mercury", and although many Latin American countries have not signed yet, there are specific laws that eliminate their use by 2026 (MCIT, 2017). Likewise, refrigerators contain gases that deplete the ozone layer and generate high environmental impact. According to the Montreal Convention, by 2020, the use of HCFCs must be reduced by 99.5% and eliminated by 2030 (UNEP, 2006), which will be reinforced by the Kigali amendment.

17.5.2 Scenario 2: improvement in the collection and recovery

Seeking to overcome the infrastructure barriers, the nonincorporation of the informal sector, the lack of collection and recovery goals, policy instruments such as funds for infrastructure and education are established in this scenario. As well as the determination of the each role responsibilities of the actors facing the physical, economical, and information flow, the latter two being poorly developed, so the current baseline is not known with certainty. The implementation of these administrative and economic instruments will achieve improvements in the collection of 50% and in the recovery of 40% for Brazil, which are different for the other countries, since their baselines are different. Thus, Colombia will increase the collection up to 45% and recovery up to 30%, and Bolivia would achieve 15% in collection and 30% in recovery.

17.5.3 Scenario 3: energy efficiency

Brazil has energy efficiency labels since 1984. In 2006, interministerial ordinances determined minimum efficiency values for compact fluorescent lamps, in 2007 for refrigerators, and in 2010 for incandescent lamps (Cepal, 2015). In 2000, Colombia introduced voluntary labeling and in 2015 mandatory national labeling regulation (IDB, 2015). On the other hand, Bolivia has not implemented this initiative to empower the user at the purchasing time. This information policy instrument covers the refrigerator, since it is responsible for more than 30% of consumption in a household (UPME, 2006). The aim is that users move from a less efficient to a more efficient technology.

17.5.4 Scenario 4: increase in the price of energy

Historically, in times where energy consumption is greater than supply, energy rationing is generated: in Brazil, it occurred in 2001 (Cepal, 2015); in Colombia, it happened in the period 1993 (UPME, 2006). In Bolivia in 2008, the government bought and delivered efficient lighting to reduce consumption (Greenpeace, 2010). In these periods, the value of kW/h increases to discourage consumption, so in this scenario this economic policy instrument is applied, and the KWh is increased by 20%.

17.5.5 Scenario 5: end of life tax

In order for the user disposes the WEEE through the formal channel, he must pay an ex ante tax when he buys the new EEE. At the time the WEEE is delivered, the user receives a discount voucher for the next purchase. The value of the tax can be increased according to the available capacity of the sanitary landfill, which although it is currently prohibited to receive WEEE in most countries, this is still happening (IDB, 2013). The model estimates the depletion of the capacity of the landfills of Sapopemba, Doña Juana, and Alpacoma in 2043, 2037, and 2025, respectively.

17.5.6 Scenario 6: synergy of all the previous instruments

Given that policy instruments are applied in different stages of the life cycle, synergy is expected when these are applied together. The substance restriction acts in the design of the product and the improvement in the collection and recovery of materials. Although it implies the intervention in different stages of the life cycle, it centers its results in the end-of-life. Likewise, energy efficiency and increase in the price of energy applies in the use phase.

17.6 Results and discussion

Table 17.5 shows the application results of the different scenarios. The variation with respect to the base scenario is shown.

The model indicates that the policy instruments generating the best results in the recovery of materials are those aiming to obtain end-of-life results, which are applied in the E2 scenario. It allows increases between 6.4% and 10.9%. This scenario is the one that allows the greatest collection of hazardous material and the one that reduces the material that reaches the landfill. In Bolivia, higher results are achieved in relation to the baseline, given that it is the country with a more incipient base.

One of the instruments that generates most change in energy consumption is the energy efficiency labels E3, which although in this case only applies to refrigerators, allows intratechnological mobilization, that is, the user makes an informed decision at the time purchase and acquires a new refrigerator more efficient than the one he owned. Likewise, the increase in the price of kWh, E4, generates a reduction in consumption, but it is minimal in relation to that obtained by energy efficiency labels. Indirectly restricting hazardous substances (HCFC and Hg) that are present in the refrigerators and light bulbs, makes the consumer look for the change of EEE and contributes to a rational decision of buying those available with greater efficiency. The result of the scenario allows the greatest reduction in energy consumption, since it not only includes refrigerators but also light bulbs. Bolivia is the one to achieve greater reductions over the 40 years, since it is considered that in the baseline it had less efficient technologies than Colombia and Brazil. Nevertheless, all countries have the same tendency to reduce consumption when applying the policies.

The substances prohibition, E1, increases the EEE in use, since the user perceives the need for change and applies the perceived obsolescence, despite the fact that the programmed goods obsolescence may be greater. In this way, it generates a reduction in the lifetime of the EEE, increases the amount of WEEE, therefore increases the material recovered, and increases the material in the landfill, as the recovery processes are not completely efficient. The low technification implies that the hazardous material that is recovered is relatively low. This phenomenon, where perceived obsolescence takes precedence over the programmed one, is accentuated in the scenario of an increase in energy prices, where the EEE in use increase up to 2.9%. This fact is more visible in Brazil because its population has a greater purchasing power, which means that the speed of replacement is greater.

The scenario E5, where the tax for the adequate disposal of WEEE is introduced, generates a decrease in the acquisition of EEE by up to 3.5% and causing a slight

Table 17.5 Results of scenarios in countries of study.

Country	Scenario	Light bulbs in use (%)	EEE in use (%)	Total energy (%)	Material in landfill (%)	Recovered material (%)	Hazardous material (%)
Brazil	E1	0.1	0.4	− 7.6	6.5	7.2	0.5
	E2	0.0	0.0	0.0	− 2.1	8.9	6.9
	E3	0.0	0.8	− 6.4	5.9	6.5	0.5
	E4	2.9	2.9	0.1	17.1	16.1	13.9
	E5	0.0	− 2.2	− 0.8	− 0.5	− 0.4	− 0.5
	E6	3.2	0.5	− 7.6	20.0	33.3	21.4
Colombia	E1	0.1	0.7	− 8.8	3.3	3.5	0.5
	E2	0.0	0.0	0.0	− 1.5	6.4	3.5
	E3	0.0	0.9	− 7.4	2.7	2.9	0.4
	E4	2.3	2.4	− 0.3	16.6	16.0	9.3
	E5	0.0	− 3.1	− 0.9	− 0.3	− 0.4	0.0
	E6	0.6	− 0.6	− 9.8	16.3	25.3	13.2
Bolivia	E1	0.3	0.5	− 11.5	8.6	5.8	1.4
	E2	0.0	0.0	0.0	− 1.1	10.9	10.9
	E3	0.0	1.7	− 7.9	7.5	5.0	1.2
	E4	1.7	0.9	− 0.2	12.5	5.3	3.4
	E5	0.0	− 3.5	− 1.2	− 0.6	− 0.4	− 0.2
	E6	2.1	− 2.8	− 12.5	17.9	23.6	15.7

reduction for landfill, recovered, and hazardous material. Bolivia is the country most susceptible to the result of increasing the price of acquisition of the good by the tax, associated with having a lower socio-economic condition and greater restriction in the sanitary landfill.

Best results of the model are obtained in the scenario where all the simulated policy instruments intervene, E6, since each of these generates impacts in different stages of the life cycle of the EEE. It is possible to recover material between 216% and 395% higher than the best individual scenario E2, likewise higher hazardous material is recovered, between 44% and 377% of the baseline. Unfortunately, the material that reaches the landfill grows a lot, which is why it is necessary to increase the efficiency of the recycling and recovery processes. In the synergy scenario, energy consumption is similar to the E1 scenario, which implies that if energy efficiency labels are introduced for other EEE not only for fridge, energy consumption would decrease even more. Therefore it would be better to include other EEE that have an important energy consumption, associated to the penetration at homes and the hours of use, like the TV sets.

It must be guaranteed that higher efficient EE are found in the market so that the change generates improvement. Therefore the policies should be aimed at the design, not only focused on energy consumption, but on the ease of disassembly, hazardous, scarce and valuable materials recovery, parts replacement, replacement and reduction of polluting substances, and reduction of the amount of material used. That is, encourage eco-design, with policies that have worked or would work in the long term (Gottberg et al., 2006; Dalhammar, 2016), reaffirming the opportunity for an EPR stronger and broader implementation (Watkins and Pantzar, 2017).

The flow of information is necessary for the control of the physical and economic flow, and must cover all the actors involved in the management system, with the purpose of monitoring, measuring, analyzing, and evaluating the system. Then, continuous improvement associated to the obtained results, anticipating decisions of reinforcement or change will be enabled. This will eliminate underreporting and the continued effort to obtain real data from the physical flow and in contrast, the information system will guarantee quantitative, continuous, timely, and reliable information, achieving benefits such as those proposed in the two cases of study in China (Sun et al., 2018).

The instruments, proved by the model, to adopted the EPR in Latin America are the prohibition of hazardous substances, securing funds for infrastructure, imposition of collection and recovery targets, definition of the roles and responsibilities of the actors in the physical, economic and information flow, as well as, energy efficiency labels and the end of life tax. These instruments ratify the advantages achieved in Europe by applying EPA schemes as they state by Watkins and Pantzar (2017). In addition, the dynamic model is robust because in its scope it contemplates the TV, fridge, computer, mobile, and light bulbs, take into account different stage of the life cycle, the behavior of the user, and the informality of the system. For that reason, this SD model shows more complexity and it is better describes the reality than previous studies.

Moreover, once its successful implementation is achieved, there will still be many orphan products, generated by old brands that have been kept at households, discontinuance of EEE assembling brands or because it is not within the scope determined by the producers, so it will be the government who must determine if it will assume such responsibility. Leaving this issue pending to study.

The informal sector should be incorporated in the collection and not necessarily in the WEEE pretreatment and treatment, given the technology levels and cost involved in recovery industries. Therefore policies should prefer specialized promoters with high technological capacity of recovery and installed capacity. Therefore the informal sector should be incorporated in the collection processes, favoring their expertise and taking advantage of the high collection rate by offering money to the user in exchange for WEEE and the opportunity of door-to-door collection (Besiou et al., 2012; Ardi and Leisten, 2016; Ghisolfi et al., 2017). In addition, given the level of informality of the regional economy, this alternative would guarantee recoverers formalization, emulating the formalization of the recovered solid waste that was made in Bogota, thus guaranteeing social results (Rodríguez et al., 2016). Actions that must be deepened through more specific studies.

Keeping the aim on the CE it is necessary to carry out studies in reuse, given the socio-economic context of the population, which generates great social, economic, and environmental benefits. For the model, a reuse of 30% was simulated, but this figure is higher when considering WEEE coming from business and not only from households. In addition, jobs generated by repair or revision and adaptation schemes for reuse must be considered.

17.7 Conclusions

An information flow of the EEE management system is required to control the physical and economic flow. In addition, the application of a set of policy instruments, recognizing that priority must be those that favor the development of a technological infrastructure to achieve higher rates of recovery of materials, the recoverers' formalization and their specialization in the collection processes, taking advantage of their expertise. Besides, the incorporation of energy efficiency labels in the use in EEE of higher energy consumption, penetration, and use in homes. In addition, formalizing the reuse due to the social progress could provide and above all stimulate the eco-design actions of products to strengthen the other stages of life cycle. The information system will allow quantified real information of the economic, social, and environmental benefits but not only projected data.

In order to obtain the benefits of the EPR and CE, the need for collaborative work among all actors is recognized, especially from the producers. In addition, the differences between the behavior of the different countries analyzed is given by the socio-economic characteristics that impact the replacement speed of the devices, the higher the income, the greater the change and the generation of WEEE, and the technological infrastructure. However, for the remaining aspects, the trends are the same, considering that there are different levels of maturity in the region, but the same solutions are required. Noting that countries that have had successful initiatives they influence of others in the region. Thus it can be inferred that the same policy instruments work but their results are differentiated by initial conditions and socio-economic differences.

It is recommended to model other policy instruments that enhance reuse, design, and all preventive actions that may affect the first stages of the EEE life cycle, as well as analyzing the impact of these policies in rural areas, whose socio-cultural and economic conditions are different. Using the SD model guarantees the circularity of the variables that represent the real world and allows a multipurpose analysis taking into account the different actors.

References

Agência Brasileira de Desenvolvimento Industrial (ABDI), 2013. Logística Reversa de Equipamentos Eletroeletrônicos Análise de Viabilidade Técnica e Econômica. Retrieved from: <https://corporativo.abdi.com.br/conhecimento/Publicaes1/Log%C3%ADstica%20reversa%20de%20Equipamentos%20Eletroeletr%C3%B4nicos%20-%20res%C3%ADduos.pdf>.

Americas Society - Council of the Americas - AS COA, 2015. Weekly chart: Latin America's informal economy. Retrieved from: <http://www.as-coa.org/articles/weekly-chart-latin-americas-informal-economy>.

Ardi, R., Leisten, R., 2016. Assessing the role of informal sector in WEEE management systems: a system dynamics approach. Waste Manag. 57, 3–16.

Bakker, C., Wang, F., Huisman, J., Hollander, M. Den, 2014. Products that go round: exploring product life extension through design. J. Clean. Prod. 69, 10–16.

Baldé, C.P., Wang, F., Kuehr, R., Huisman, J., 2015. The global e-waste monitor – 2014. United Nations University, IAS – SCYCLE, Bonn, Germany.

Baldé, C.P., Wang, F., Kuehr, R., Huisman, J., 2015. The Global E-Waste Monitor – 2014. United Nations University, IAS – SCYCLE, Bonn, Germany.

Baldé, C.P., Forti V., Gray, V., Kuehr, R., Stegmann,P. 2017. The Global E-waste Monitor – 2017, United Nations University (UNU), International Telecommunication Union (ITU) & International Solid Waste Association (ISWA), Bonn/Geneva/Vienna.

Besiou, M., Georgiadis, P., Wassenhove, L.N.V., 2012. Official recycling and scavengers: symbiotic or conflicting? Eur. J. Oper. Res. 218 (2), 563–576.

Bian, J., Bai, H., Li, W., Yin, J., Xu, H., 2016. Comparative environmental life cycle assessment of waste mobile phone recycling in China. J. Clean. Prod. 131, 209–218.

BID, 2015. Guía E. Programas de Normalización y Etiquetado de Eficiencia Energética. Retrieved from: <https://publications.iadb.org/bitstream/handle/11319/7326/Guia-E-programas-%20normalizacion-etiquetado-eficiencia-energetica.pdf?sequence = 1>.

Brasil, 2010. Decreto n° 7.404, De 23 De Dezembro De 2010. Regulamenta a Lei n°12.305, De 2 De Agosto De 2010. Política Nacional de Resíduos Sólidos. Official Retrieved from: <http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/Decreto/D7404.htm>.

Cao, J., Lu, B., Chen, Y., Zhang, X., Zhai, G., Zhou, G., et al., 2016. Extended producer responsibility system in China improves E-waste recycling: government policies, enterprise, and public awareness. Renew. Sustain. Energy Rev. 62, 882−894.

Cepal, 2015. Informe nacional de monitoreo de la eficiencia energética del Brasil. Retrieved from: <https://repositorio.cepal.org/bitstream/handle/11362/38863/1/S1500636_es.pdf>.

Chancerel, P., Marwede, M., Nissen, N.F., Lang, K.D., 2015. Estimating the quantities of critical metals embedded in ICT and consumer equipment. Resour. Conserv. Recycl. 98, 9−18.

Cucchiella, F., D'Adamo, I., Lenny Koh, S.C., Rosa, P., 2015. Recycling of WEEEs: an economic assessment of present and future E-waste streams. Renew. Sustain. Energy Rev. 51, 263−272.

Dalhammar, C., 2016. Industry attitudes towards ecodesign standards for improved resource efficiency. J. Clean. Prod. 123, 155−166.

DANE, 2017. Encuesta Nacional de Calidad de Vida. Retrieved from: <https://www.dane.gov.co/files/investigaciones/condiciones_vida/calidad_vida/Boletin_Tecnico_ECV_2017.pdf>.

Delfín, M., Guzman, D., Garay, E., Yañez, P., Delfín, M., 2009. Diagnóstico de Residuos Electrónicos en Bolivia. Retrieved from: <http://www.residuoselectronicos.net/archivos/panama/fichasasistentes/FICHAS%20PDF/0904_DiagnosticoRAEE_%20Bolivia.pdf>.

EC, 2017. Communication from the commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on the 2017 list of Critical Raw Materials for the EU. Retrieved from: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri = CELEX:52017DC0490>.

Ellen Macarthur Foundation, 2012. The Circular Economy System Diagram. Retrieved from: <https://www.ellenmacarthurfoundation.org/circular-economy/interactive-diagram>.

EU, 2011. Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment Text with EEA relevance. Retrieved from: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri = celex%3A32011L0065>.

EU, 2016. Closing the loop: new circular economy package. Retrieved from: <http://www.europarl.europa.eu/RegData/etudes/BRIE/2016/573899/EPRS_BRI(2016)573899_EN.pdf>.

Fan, C., Fan, S.K.S., Wang, C.S., Tsai, W.P., 2018. Modeling computer recycling in Taiwan using system dynamics. Resour. Conserv. Recycl. 128, 167−175.

Fundación Viva, 2017. Reciclaje de Residuos Eléctricos y Electrónicos. Retrieved from: <https://fundacionviva.org/memorias/2017/Memoria_FVIVA17-WEB.pdf>.

Georgiadis, P., Vlachos, D., 2004. The effect of environmental parameters on product recovery. Eur. J. Oper. Res. 157 (2), 449−464.

Georgiadis, P., Besiou, M., 2008. Sustainability in electrical and electronic equipment closed-loop supply chains: a system dynamics approach. J. Clean. Prod. 16 (15), 1665−1678.

Georgiadis, P., Besiou, M., 2010. Environmental and economical sustainability of WEEE closed-loop supply chains with recycling: a system dynamics analysis. Int. J. Adv. Manuf. Technol. 47 (5−8), 475−493.

Ghisellini, P., Cialani, C., Ulgiati, S., 2016. A review on circular economy: the expected transition to a balanced interplay of environmental and economic systems. J. Clean. Prod. 114, 11−32.

Ghisolfi, V., De Lorena, G., Chaves, D., Ribeiro, R., Helena, L., 2017. System dynamics applied to closed loop supply chains of desktops and laptops in Brazil: a perspective for social inclusion of waste pickers, 60, 14–31.

Gottberg, A., Morris, J., Pollard, S., Mark-Herbert, C., Cook, M., 2006. Producer responsibility, waste minimisation and the WEEE Directive: case studies in eco-design from the European lighting sector. Sci. Total Environ. 359 (1–3), 38–56.

Grant Thorton, 2011. Estudo de viabilidade. Viabilidade técnica económica em logística reversa na organizacao da colecta e reciclagem de residuos de lampadas no Brasil.

Greenpeace, 2010. Análisis de Derecho Comparado sobre la Prohibición de Focos Incandescentes. Retrieved from: <http://www.greenpeace.org/mexico/global/mexico/report/2010/3/derecho_comparado.pdf>.

Gu, Y., Wu, Y., Xu, M., Wang, H., Zuo, T., 2016. The stability and profitability of the informal WEEE collector in developing countries: a case study of China. Resour. Conserv. Recycl. 107, 18–26.

Gu, Y., Wu, Y., Xu, M., Wang, H., Zuo, T., 2017. To realize better extended producer responsibility: redesign of WEEE fund mode in China. J. Clean. Prod. 164, 347–356.

GSMA, 2014. eWaste en América Latina. El aporte de los operadores móviles en la reducción de la basura electrónica—Estudio de casos.

Huisman, J., van der Maesen, M., Eijsbouts, R.J.J., Wang, F., Baldé, C.P., Wielenga, C.A., 2012. The Dutch WEEE Flows. United Nations University, ISP – SCYCLE, Bonn, Germany.

Islam, M.T., Abdullah, A.B., Shahir, S.A., Kalam, M.A., Masjuki, H.H., Shumon, R., et al., 2016. A public survey on knowledge, awareness, attitude and willingness to pay for WEEE management: case study in Bangladesh. J. Clean. Prod. 137, 728–740.

International Telecommunication Union – ITU, 2016. Sustainable management of waste electrical and electronic equipment in Latin America. Retrieved by <https://www.itu.int/en/ITU-T/climatechange/Pages/publications.aspx>.

International Telecommunication Union – ITU, 2017. Country ICT Data (until 2016). Percentage of individuals using the Internet. Retrieved from: <https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx>.

Islam, M.T., Huda, N., 2018. Reverse logistics and closed-loop supply chain of waste electrical and electronic equipment (WEEE)/E-waste: a comprehensive literature review. Resour. Conserv. Recycl. 137 (May), 48–75.

Kumar, A., Holuszko, M., Espinosa, D.C.R., 2017. E-waste: an overview on generation, collection, legislation and recycling practices. Resour. Conserv. Recycl. 122, 32–42.

Kumar, A., Dixit, G., 2018. Evaluating critical barriers to implementation of WEEE management using DEMATEL approach. Resour. Conserv. Recycl. 131, 101–121.

Li, Y., Xu, F., Xiong, Z., 2017. Governance mechanisms of dual-channel reverse supply chains with informal collection channel. J. Clean. Prod. 155, 125–140.

Lieder, M., Rashid, A., 2016. Towards circular economy implementation: a comprehensive review in context of manufacturing industry. J. Clean. Prod. 115, 36–51.

Lindhqvist, T., 2000. Extended producer responsibility in cleaner production. IIIEE Dissertation 2000:2. Lund: IIIEE, Lund University.

Liu, H., Lei, M., Deng, H., Keong Leong, G., Huang, T., 2016. A dual channel, quality-based price competition model for the WEEE recycling market with government subsidy. Omega 59, 290–302.

Liu, Z., Tang, J., Li, B. yi, Wang, Z., 2017. Trade-off between remanufacturing and recycling of WEEE and the environmental implication under the Chinese fund policy. J. Clean. Prod. 167, 97–109.

Manomaivibool, P., Hong, J.H., 2014. Two decades, three WEEE systems: how far did EPR evolve in Korea's resource circulation policy? Resour. Conserv. Recycl. 83, 202–212.

Mashhadi, R.A., Behdad, S., 2017. Optimal sorting policies in remanufacturing systems: application of product life-cycle data in quality grading and end-of-use recovery. J. Manuf. Syst. 43, 15–24. Available from: http://doi.org/10.1016/j.jmsy.2017.02.006.

Ministério da Indústria, Comércio Exterior e Serviços – MDIC, 2017. Projeto para a Melhoria da Logística Reversa de Resíduos Elétricos e Eletrônicos (REEE) no Brasil.

Ministerio de Ambiente y Desarrollo Sostenible – MADS, 2017. Política nacional para la gestión integral de los residuos de aparatos eléctricos y electrónicos (RAEE), Bogotá, Colombia.

Ministerio de Comercio, Industria y Turismo - MCIT, 2017. Decreto 2133 de 2016. Control a la importación y comercialización de mercurio y los productos que lo contienen. Retrieved from: <http://es.presidencia.gov.co/normativa/normativa/DECRETO%202133%20DEL%2022%20DE%20DICIEMBRE%20DE%202016.pdf>.

Ministerio Medio Ambiente- MMA Chile, 2017. Reglamento del Fondo para el Reciclaje. Retrieved from: <http://portal.mma.gob.cl/transparencia/mma/doc/DS_No7-de-2017-Reglamento-del-Fondo-para-el-Reciclaje.pdf>.

Misiones online, 2017. Argentina tiene pendiente el debate por una ley específica de gestión de residuos electrónico. Retrieved from: <http://misionesonline.net/2017/06/16/argentina-pendiente-debate-una-ley-especifica-gestion-residuos-electronico/>.

Morris, A., Metternicht, G., 2016. Assessing effectiveness of WEEE management policy in Australia. J. Environ. Manage 181, 218–230.

Nguyen, N.C., Bosch, O.J., Ong, F.Y., Seah, J.S., Succu, A., Nguyen, T.V., et al., 2015. A systemic approach to understand smartphone usage in Singapore. Syst. Res. Behav. Sci. .

OECD, 2014. Global forum on environment: promoting sustainable materials management through extended producer responsibility (EPR). Tokyo, Japan. Retrieved: <http://www.oecd.org/environment/waste/Global%20Forum%20Tokyo%20Issues%20Paper%2030-5-2014.pdf>.

de Oliveira, C.R., Bernardes, A.M., Gerbase, A.E., 2012. Collection and recycling of electronic scrap: a worldwide overview and comparison with the Brazilian situation. Waste Manag. 32, 1592–1610.

Parajuly, K., Wenzel, H., 2017. Potential for circular economy in household WEEE management. J. Clean. Prod. 151, 272–285.

Park, P.J., Lee, K.M., Wimmer, W., 2006. Development of an environmental assessment method for consumer electronics by combining top-down and bottom-up approaches. Int. J. Life Cycle Assess. 11 (4), 254–264.

Rao, N.D., Ummel, K., 2017. White goods for white people? Drivers of electric appliance growth in emerging economies. Energy Res. Soc. Sci. 27, 106–116.

RELAC, 2017. Plataforma Regional de Residuos Electrónicos en Latinoamérica y el Caribe. Retrieved: <http://www.residuoselectronicos.net/>.

Rodríguez, L.A., González, N., Reyes, L., Torres, A., 2013. Management system of waste electrical and electronic equipment. System dynamics approach. Revista S&T, Sistemas y Telemática, 11 (24), 55–71. ISBN 1692-5238. <http://www.icesi.edu.co/revistas/index.php/sistemas_telematica/issue/view/179>.

Rodríguez, L.A., Estupiñán, E., Jaimes, S., 2015. Product policy impact in the lifecycle of light bulbs though system dynamics. International System Dynamics Conference. Boston, USA. July 2015. <https://www.systemdynamics.org/assets/conferences/2015/proceed/index.html>.

Rodríguez, L.A., Escalante, E., Reyes, L., 2016. From Recoverers to Recycling Organization, Socio-Economic and Environmental Considerations on Residential Waste Management. In: 34th International Conference of the System Dynamics Society. Conferencia presentada en Ámsterdam, Países Bajos. <https://www.systemdynamics.org/assets/conferences/2016/proceed/index.html>.

Rodríguez, L.A., Estupiñán, E., 2018. "Public Policy Impact in the Life Cycle of the Electrical and Electronic Equipment Waste. Colombia exemplifies Latin America Status" International System Dynamics Conference 2018, Reykjavik, Islandia.

Sinha, R., Laurenti, R., Singh, J., Malmström, M.E., Frostell, B., 2016. Identifying ways of closing the metal flow loop in the global mobile phone product system: a system dynamics modeling approach. Resour. Conserv. Recycl. 113, 65–76.

Shinkuma, T., Huong, N.T.M., 2009. The flow of E-waste material in the Asian region and a reconsideration of international trade policies on E-waste. Environ Impact Assess Rev. 29 (1), 25–31.

SRI - Sustainable Recycling Industries. (2017). Practical guide for designing WEEE management policies in developing countries now available. Retrieved of https://www.sustainable-recycling.org/weee-policy-guidebook-launched/

Spengler, T., Schröter, M., 2003. Strategic management of spare parts in closed-loop supply chains – a system dynamics approach. Interfaces 33 (6), 7–17.

Sterman, J.D., 2000. Business Dynamics: Systems Thinking and Modeling for a Complex World.. McGraw-Hill, New York, NY.

Sun, Q., Wang, C., Zuo, L., Lu, F., 2018. Digital empowerment in a WEEE collection business ecosystem: a comparative study of two typical cases in China. J. Clean. Prod. 184, 414–422.

Sustainable Recycling Industries – SRI, 2017. Practical guide for designing WEEE management policies in developing countries now available. Retrieved from: <https://www.sustainable-recycling.org/weee-policy-guidebook-launched/>.

Tojo, N., Neubauer, A., Bräuer, I., 2008. Waste management policies and policy instruments in Europe: an overview. International Institute for Industrial Environmental Economics.

UPME, 2006. Determinación del consumo final de energía en el sector residencial urbano y comercial y determinación de consumos para equipos domésticos de energía eléctrica y gas. file:///E:/PHD/Articulos%20PHD%20LARB/UPME_415_Determinacion%20del%20consumo%20final%20de%20energia%20%20en%20sectores%20residencial%20%20urbano%20y%20comercial.pdf.

Van Eygen, E., De Meester, S., Tran, H.P., Dewulf, J., 2016. Resource savings by urban mining: the case of desktop and laptop computers in Belgium. Resour. Conserv. Recycl. 107, 53–64. Available from: https://doi.org/10.1016/j.resconrec.2015.10.032.

Wang, F., Huisman, J., Stevels, A., Baldé, C.P., 2013. Enhancing E-waste estimates: improving data quality by multivariate input-output analysis. Waste Manag. 33 (11), 2397–2407. Available from: http://doi.org/10.1016/j.wasman.2013.07.005.

Wang, F., 2014. *E-Waste: Collect More, Treat Better. Tracking Take-Back System Performance for Eco-Efficient Electronics Recycling*. Dissertation, Delft University.

Wang, J., Wang, Y., liu, J., Zhang, S., Zhang, M., 2018. Effects of fund policy incorporating extended producer responsibility for WEEE dismantling industry in China. Resour. Conserv. Recycl. 130 (June 2017), 44–50.

Watkins, E., Pantzar, M., 2017. EPR in the EU plastics strategy and the circular economy: a focus on plastic packaging.

World Bank, 2015. GINI index. Retrieved from: <https://data.worldbank.org/indicator/SI.POV.GINI?>.

World Bank, 2017a. A. GDP per capita, PPP (current international $). Retrieved from: <https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD>.

World Bank, 2017b. Population total. Retrieved from: <https://data.worldbank.org/indicator/SP.POP.TOTL>.

Xiao, R., Zhang, Y., Liu, X., Yuan, Z., 2015. A life-cycle assessment of household refrigerators in China. J. Clean. Prod. .

Yang, J.X., Wang, R.S., Fu, H., et al., 2004. Life cycle assessment of mobile phone housing. J. Environ. Sci. 16 (1), 100–103.

Yao, L., Liu, T., Chen, X., Mahdi, M., Ni, J., 2018. An integrated method of life-cycle assessment and system dynamics for waste mobile phone management and recycling in China. J. Clean. Prod. 187, 852–862.

Yu, J.L., Eric, W., Ju, M.T., 2010. Analysis of material and energy consumption of mobile phones in China. Energy Policy 38 (8), 4135–4141.

Yu, L., He, W., Li, G., Huang, J., Zhu, H., 2014. The development of WEEE management and effects of the fund policy for subsidizing WEEE treating in China. Waste Manag. 34 (9), 1705–1714.

Zero Waste Europe, 2017. *Extended Producer Responsibility—Creating the Frame for Circular Products*. Zero Waste Europe, Brussels.

Zhang, S., Ding, Y., Liu, B., Chang, C.C., 2017. Supply and demand of some critical metals and present status of their recycling in WEEE. Waste Manag. 65, 113–127.

Zhou, W., Zheng, Y., Huang, W., 2017. Competitive advantage of qualified WEEE recyclers through EPR legislation. Eur. J. Oper. Res. 57, 641–655.

Further reading

BID, 2013. Situación de la gestión de residuos sólidos en América Latina y el Caribe <https://publications.iadb.org/handle/11319/7177?locale-attribute = es&>.

Ministerio de Ambiente y Desarrollo Sostenible – MADS, 2018. Listado de puntos de recolección de residuos posconsumo. Retrieved from: <https://www.datos.gov.co/Ambiente-y-Desarrollo-Sostenible/Listado-de-puntos-de-recolecci-n-de-residuos-posco/m79k-beyn/data>.

PNUMA, 2006. Tratados internacionales para la protección a la capa de ozono. <http://www.pnuma.org/ozono/Documentos/DiaOzono/tratados%20internacionales%20ozono.pdf>.