Chapter 8

Resource Recovery From E-waste for Environmental Sustainability: A Case Study in Brazil

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1 Introduction

For the purpose of regulating the collection and recycling of electrical and electronic equipment, in 2013 the Brazilian Ministry of the Environment (MMA) published a Call Notice (number 01/2013), calling on companies to unite into management organizations and submit proposals for reverse logistics (RL) of their products, in an attempt to reduce costs and operationalize the collection and recycling system. The government guidelines were applied to a system of reverse logistics of electronic waste (E-waste), calculating their costs and problems, with a view to analyze the economic and financial sustainability and also environmental impacts of the collection and recycling of the residues of electrical and electronic equipment (Placet et al., 2005).

The production of electrical and electronic waste in Brazil, according to Portal Brasil (2016), was 1,247,000 metric tons per year. This is equivalent, for the population of Brazil that year, to 5.93 kg for each inhabitants. An important point of the Portal report is that due to economic problems starting in 2014, the level of 7.0 kg per year will not be reached in 2018. However, the economic potential of the E-waste generated is US$10 billion per year, and has not yet been reached (Portal Brasil, 2016).

In developing countries, solid waste collection and recycling employs more than 64 million people, says the United Nations Environment Program (UNEP) in the Waste Crime-Waste Risks study. It is an economic activity that not only

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generates income but helps to preserve the environment, according to this and other UN studies on the subject, but requires more regulation and investments to strengthen, including in Latin America (StEP, 2012).

The RL activities consist of five basic functions: planning, implementation, and control of the flow of materials, the flow of information from the point of consumption to the point of origin during its life cycle, and recovery of value (Lacerda, 2002).

In the process of RL, the products go through a recycling stage and return to the production chain, or are energetically valorized, if they do not have metals and ceramics (such as that found in electronic boards), until their disposal, going through the "product lifecycle", according to the ABNT (Brazilian Association of Technical Standards)/NBR (Brazilian Technical Standards), and ISO 14044: 20014 Environmental Management and Life Cycle Assessment, respectively (SETAC, 2014).

A particular emphasis has been placed on cell phones, which become accessible every day to a larger portion of the population, creating problems due to the difficulty in effectively complying with the provisions of the PNRS (National Solid Waste Policy) (Brazil, 2013) and its correct disposal. According to the US Environmental Protection Agency (EPA), the lifecycle of these devices is 9–18 months, after which most are discarded or disposed of in household waste. Like most electronics, the cell phone contains metals, polymers, and ceramic material (EPA, 2014).

In Brazil, there were 280 million active cell phone lines (ANATEL, 2013) with an average lifetime of two years for each cellular device and its batteries (Provazi et al., 2012): the timeframe from its production until the moment the first possessor discards it (Tadeu, 2012).

2 Proposal of a Government Model

The modeling proposed by the Brazilian Federal Government, through the Ministry of Environment (MMA) and discussed in a specific report, has the following basic characteristics (ABINEE, 2015a,b,c):

- The system will be structured to deal with consumers of EEE (electrical and electronic equipment), to deal with discards at reasonable volumes for the consumption profile of an individual;
- WEEE (waste electrical and electronic equipment) from legal entities will not be considered in the modeling, as licensed companies are usually hired to correctly dispose of the waste, according to the legislation.
- RL is divided between primary logistics (transport from the consumer's home to the SC (screening center)) and secondary logistics (transportation from the SC until its final destination);
- Distinct primary logistics between small-sized (portable) WEEE and large WEEE (Brazil, 2013).

The costs for dismantling EEE were not included in the government proposal. The recycling of manufactured products depends greatly on the efficiency with which one material can be separated from one another. In the long term, recycling can be made more effective by product design that allows easier disassembly and recycling (Xanthopoulos and Iakovou, 2009). This requires the development of appropriate product analysis tools to enable project teams to assess the potential for disassembly and recycling of alternative products during the early stages of the project (Sodhi and Knight, 1998).

The government assumes a mandatory association between manufacturers and importers in one or more managing organizations to manage the RL system that will interact with regulators, from:

- Use of (direct) supply logistics of certain manufacturers/importers, reducing transport and storage costs;
- Implementation of the system in phases, initially prioritizing regions with higher densities of waste;
- Provision of a network of fixed points of discard/receipt in municipalities with more than 100,000 inhabitants;
- Products considered orphaned (legalized or otherwise legalized) will be dealt with by the manufacturers/importers, with costs shared between the participants of the management organization, allowing the RL costs of these products to be amortized at the end of the WEEE recycling process. There is then a need to trace these products, for a balanced distribution of costs (Brazil, 2013).

3 Possibility of Resources Generation

According to Williams (2003) and analyzing data from state and outsourced companies of garbage collection in Brazil, especially in São Paulo, the average composition of 1 ton of E-waste collected in Brazil is as seen in Table 1.

This amount will be used to estimate the economic potential in Brazil that can be obtained by recycling of E-waste, mainly the material of printed circuit boards (ABREE, 2015).

4 The Model From the Government Proposal

There has been no significant experience of public participation in designing a recycling scheme, according to Keramisoglou and Tsagarakis (2013). The MMA Call for Proposals 01/2013 suggests a logistical strategy and establishes responsibilities for the stakeholders of the process, based on research from FEAM (State of Minas Gerais Environment Foundation) (2009), which is described below:

(1) Transport to the point of disposal:
   - For small products, the consumer transports and delivers his WEEE in the network of fixed points of disposal/reception (receiving centers [RC]);

TABLE 1 Values of Existing Metals in 1 Ton of E-waste (Notebooks, Desktops, Mobiles, DVDs)

Amount	Component	Price (US$/kg)	Total
1.16 kg	Ag	480	556.80
113.3 g	Au	28.360	3213.18
46.6 g	Pd	86.820	4045.81
43 kg	Cu	8.80	378.40
126 kg	Steel	0.06058	7.63
24.10 kg	Al	0.6038	14.55
1.5 kg	Ni	0.5321	6.79
460 kg	Plastics (PET, PE, PP)	0.51468	23.67
Total			**US$8246.73**

(2) Receipt and storage:
- A trade provides fixed points of discard/receipt in which they receive and correctly store WEEE;
- Alternative points of reception, outside the trade, can make up the system at their own discretion and cost of the managing organization (e.g., technical assistance, post office, other logistics partners, among others);
- Consumers with the intention of donating their electronic products for reuse are informed and advised of the possibilities of doing so (Brazil, 2013).

(3) Transport to the SC:
- A trade and management organization carries out the transportation of WEEE to the nearest SC;
- Sharing of transport costs will be handled between the parties in the establishment of the sectoral agreement;
- The SCs may be outsourced by the managing organization;
- There is an opportunity for partnerships with municipalities, cooperatives, recyclers, and others to carry out transport (Brazil, 2013).

(4) Waste sorting:
- A management organization, which is a signatory to the Sectoral Agreement, structures, coordinates, and manages a network of sorting centers (own, established in partnership with municipalities of larger municipalities), and promotes the sorting, storage, and dispatch of WEEE;
- In the SC, the separation of WEEE by type of equipment and sampling by process monitoring is done (ABINEE, 2015a,b,c);

– The important point here is that until arriving with the recycler, only material separations can be made by type, separation, and condition of batteries, and loose parts of plastic or metal (Damasceno et al., 2014).

At this point, the sorting will separate polymers, which will be sold and can be reused for new products; it will also separate, in the case of other appliances, steel or aluminum shells. As for polymers, the first step in verifying the possibility of such a waste being used in coprocessing is the analysis of its physicochemical characteristics, which will determine the purpose of the waste utilization, whether as a partial substitute of raw material (Urbano, 2002) or energy recovery.

According to Urbano (2002), coprocessed wastes are: "Solid and pasty wastes, such as those originating from the following industrial activities: petrochemical, chemical, automotive, auto parts, electro-electronics, steel, metallurgy, metal-mechanics, pulp and paper, among others".

(5) Transport to the recycler:
- The management organization collects the WEEE from the SCs and transports it to the recycler with whom it has established a service contract;
- The management organization shall be remunerated by the recycler according to the value of the WEEE delivered.

(6) Recycling of waste:
- The recycler performs trademark and data mischaracterization (where applicable) checks, makes the traceability, recycles the WEEE, and carries out the mass balance, in agreement with the management organization;
- The recycler restores the recycled material back into the market or organizes the waste's final destination (ABINEE, 2015a,b,c).

The responsibilities are assigned to each of the actors in the process:

- Consumer:
  - Take your waste electrical and electronics (small) to the point of disposal/receipt. In the case of small equipment, there are collection kiosks in shopping malls, or in stores that sell electrical and electronic equipment (Inventta, 2014).
- Trade:
  - Provide a network of fixed points of disposal/receipt;
  - Receive and properly store the waste;
  - Disclose reception points, disposal practices, and reuse alternatives;
  - Share primary freight costs with the managing organization (Inventta, 2014).
- Main management organization:
  - Share RL costs from the waste from the points of receipt, with the manufacturer/importer;
  - WEEE sampling by brand for orphan volume monitoring, information to the auditing bodies and compensation/cost sharing with system partners (Inventta, 2014).

- Secondary management organizations (hired by the lead management organization):
  - Manage and fund the logistics of sorting centers to recyclers;
  - Hire and monitor the recycling service;
  - Provide information on the service of withdrawal of electrical and electronic waste to its customers;
  - Report the flow of the logistics process to the supervisory bodies; and
  - Carry out awareness campaigns (ABINEE, 2015a,b,c).
- Recycler:
  - Carry out the recycling and correct final disposal of the postconsumer product;
  - Provide process performance information; and
  - Return recycled material to the market and transfer the value to the organization manager (organization being a signatory to the Sectoral Agreement).
- Public power:
  - Assign and monitor recycling targets;
  - Regulate and encourage recyclers to gain performance in the process (certification in quality standards ABNT NBR ISO9001:2015 and ISO14001:2015 (standards for quality and environment)).
  - Provide incentives for the manufacture of products with a higher content of recycled, recyclable, and recyclable facilities, whether in the electronics sector or in other sectors, for example through tax reductions (ABINEE, 2015a,b,c);
  - Launch announcements to encourage research and development in order to promote the development of knowledge and technologies related to the RL chain of WEEE;
  - Promote awareness of the issue; and
  - Nominate a monitoring committee for the implementation of the system (Lagarinhos and Tenório, 2013).

(7) Source of resources for the system:

The alternative model selected for RL of Brazilian WEEE, and according to the assumptions adopted, was shared costs between the consumer (primary logistics, not necessarily in financial form, but responsibility for delivery to RL), commerce (to maintain collection points and primary freight), and the manufacturer/importer (primary freight, sorting, secondary freight and processing) (Brazil, 2013).

It is important to emphasize that this definition of attributions and responsibilities is the one issued by the federal government, and opens up a possibility that the consumer can be charged an EEE collection rate at the time of sale. On that basis, ABINEE is drawing up a proposal which contains such a charge. The allocation of costs of RL in this first model proposed by the government would have to be done by tracking the material collected, in order to reimburse each of the participants in the RL chain (ABINEE, 2014a, b).

(8) Responsibility for orphans:

In Brazil, there are strong indications and findings that there is a volume of equipment without a corresponding manufacturer/importer, for various reasons, such as interruption of production or exit from the country. These are called orphan products. This issue is predominant enough to overwhelm those actors that comply with the legislation and join the system (Mahadevan and Deb, 2007). In the proposed model it is suggested that the orphans are monitored by the Public Power (Brazil, 2013).

(9) Collection and recycling targets:

The targets for recycling were established by MMA, and are included in Call Notice Nr. 01/2013. The proposed model notes that only recycling targets by volume (Cunha and Caixeta Filho, 2002) are established. It is suggested that 100% of the volume collected (not the volume sold) in each step is processed, until its final phase of extraction of the metals. However, not all of the collected material can be recycled. For this goal, industrial large-scale chemical processing of metals is needed in Brazil (Brazil, 2013).

(10) The Public Power:

The role of the Public Power in the suggested modeling is nominated as active, that is, it acts in the program more broadly. Its performance is important in promoting the technological development of the chain, in the certification of effectiveness, in the dissemination of the recycling culture, and in the tracking of orphan products.

According to Lagarinhos and Tenório (2013), this is the same situation as CONAMA (National Council for the Environment) Resolution Nr. 258/99 for unusable used tires. IBAMA (Brazilian Institute for Environment) should verify through the information available in the Federal Technical Registration (CTF) the goals and results obtained for the recycling of waste tires. There is, however, nothing from the manufacturers and importers regarding the development of new technologies, population awareness, or the disposal of waste tires (Lagarinhos and Tenório, 2013).

(11) Treatment of WEEE:

Although there is still no Normative Instruction or Resolution to classify WEEE, they are treated as differentiated urban waste, which must be packed and transported correctly, i.e., WEEE is considered a hazardous material after its dismantling and grinding (CONAMA, 2010). The proposed model considers that WEEE will be treated as nonhazardous waste during the RL chain, i.e., its complete removal will only occur in the final recycling cycle.

It is understood that the Public Power, the federal, state, and municipal spheres, have their competencies and scope established by CONAMA at each stage.

One of the conditions imposed on the system is that no physicochemical modification of WEEE is promoted during the handling and transportation to a recycler, and the agent must obtain environmental licensing for handling and processing such waste. In this way, the risk of exposure of harmful material is minimized, due to the fact that there will be no material leaching (the extraction or solubilization of the chemical constituents of the material by the action of a fluid), should the items come into contact with rainwater (Damasceno et al., 2014).

To attempt to quantify the costs involved in this multiple-stage process (Tibben-Lembke, 2002), it is not possible to use the Brazilian research centers, because the scale is quite different from a recycler operating on a large scale. However, a model was obtained using market data (Fleischmann et al., 2000).

As an example, São Paulo's Suzakim Company recycles polymers and ceramics from electronic waste from several companies in São Paulo, reselling them to companies that use recycled material, but does not treat metallic aggregates, which are passed on to other companies for separation of metals. This company recycles E-waste generated by several companies in the state of São Paulo (Suzakim Chemical Industries Ltd., 2015).

According to CONAMA Resolution Nr. 264/99 regarding coprocessing in clinker kilns, only thermosetting polymers, which cannot be recycled, can be used for energy recovery in cement, so metals and thermoplastic polymeric materials and ceramics should be screened, producing material for recyclable plastic products as plastic wood. Ceramics can be used in tile and flooring factories (Suzakim Chemical Industries Ltd., 2015). The metals will be able to undergo a refining process with feasibility of use in the manufacture of new electronics. Fig. 1 is a model based on government guidelines and Leite (2013).

5 Costs of the Government Model

The government model proposes a CR for each city with more than 25,000 inhabitants, and an SC for each 100,000 inhabitants. The costs for a 5-ton collection center and 12-ton SC are shown in Table 2.

As for the sorting centers, the annual capacity of 12,000 tons was chosen, based upon the volumes of WEEE generated, and the capacity of the road vehicles chosen, according to Tables 3 and 4.

The costs for implementing a Reverse Logistics in these ways, based on the state of Minas Gerais in the Southeast region in Azevedo (2009), can be estimated according to Table 5.

Road transport is the least efficient method when comparing the cost per ton per useful kilometer of freight carried for different modes. However, in Brazil there is no possibility of using the other modalities, in view of the incipient railway network, without continuity.

The waterway transportation is underdeveloped in routes along the Brazilian coast (Halliday, 2003).

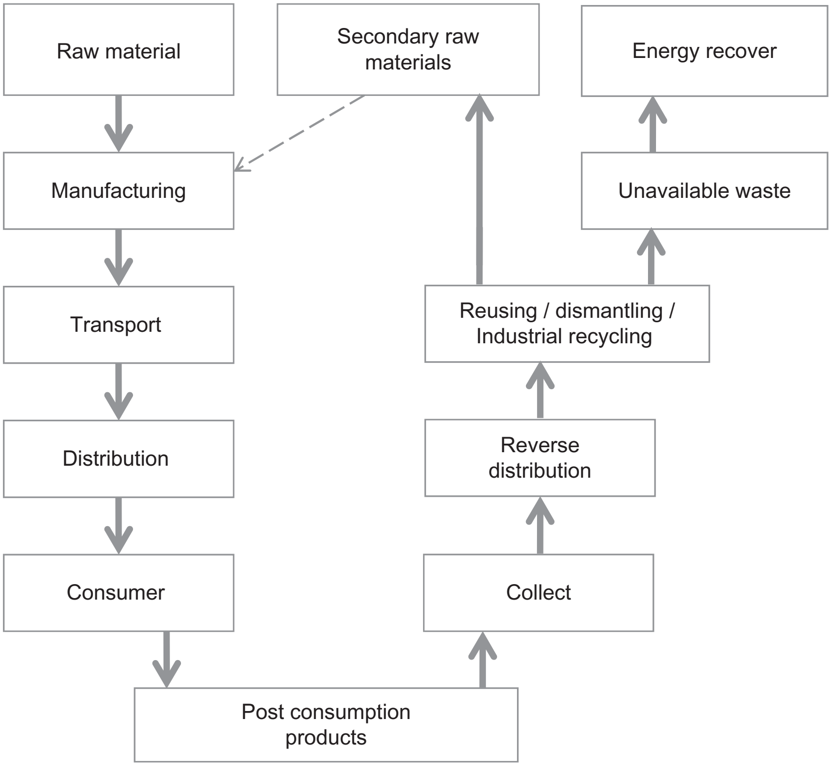

FIG. 1 Block diagram of the reverse logistics of postconsumption.

TABLE 2 Investments (CAPEX) and Operating Costs (OPEX) of Receiving Center—Receiving Point Costs With 5 Tons

OPEX—Receiving Point			
Equipment	*Quantity*	*Unitary Value (US$)*	*Total Annual Value (US$)*
Officials	1	1000.00	12,000.00
Area (m^2)	16	150.00	2000.00
Office material	1	16.60	200.00
Safety (m^2)	16	5.00	960.00
Total value		**US$ 181,920.00**	

Data from Inventta, 2012. Reverse Logistics of Electrical and Electronic Equipment, Technical and Economic Feasibility Analysis. MDIC (Ministry of Industry and Commerce), Brazil (in Portuguese).

TABLE 3 Operating Costs of the Screening Center

Annual Capacity (Tons)	12,000 Tons per Month			
	Quantity	*Unitary Value (US$)*	*Total Value (US$)*	*Percentage*
Officials	18	402.66	7248.00	20%
Taxes	18%	13.86	967.00	20%
Shed	400 m^2	7.53	3013.33	9%
Individual protection equipment	30	100.66	3020.00	34%
Others	20%	591.40	7096.66	17%
Total value		**US$ 256,139.88**		

Source: Inventta, 2012. Reverse Logistics of Electrical and Electronic Equipment, Technical and Economic Feasibility Analysis. MDIC (Ministry of Industry and Commerce), Brazil (in Portuguese).

TABLE 4 Investments (CAPEX) of the Screening Center

Annual Capacity (Tons)	12,000 Ton per Month			
Equipment	*Quantity*	*Unitary Value (US$)*	*Total Value (US$)*	*Percentage*
Forklift	2	13,333.33	26,666.66	44%
Running machine	2	6666.66	13,333.33	22%
Palletizer	2	5000.00	10,000.00	16%
Human traction trolleys	10	400.00	4000.00	7%
Scales	2	1500.00	3000.00	5%
Containers	20	100.00	2000.00	3%
Office	1	1666.66	1666.66	3%
Total value	**US$727,999.80**			

Source: Inventta, 2012. Reverse Logistics of Electrical and Electronic Equipment, Technical and Economic Feasibility Analysis. MDIC (Ministry of Industry and Commerce), Brazil (in Portuguese).

TABLE 5 Results Verified: Tons per Year

Description		Values (US$)
Tons collected	17,055.44	140,644,786.53
Annual cost of CR		181,920.00
Annual cost of freight		920,000.00
CAPEX cost of SC		1,395,333.33
OPEX cost of SC		6,490,186.66
Total		10,446,347.08
Average cost of reverse logistics and preprocessing per ton from the calculated value of processing		**US$612.49**

Source: Inventta, 2012. Reverse Logistics of Electrical and Electronic Equipment, Technical and Economic Feasibility Analysis. MDIC (Ministry of Industry and Commerce), Brazil (in Portuguese).

There is also a differentiation in road transport costs from region to region of the country (Guia do Transportador, 2015) as shown in Fig. 2.

To calculate the freight value of the regional capitals, the average cost per ton above was used for the Southeast Region, resulting in Table 6.

The costs of RL, including the cost of storage locations, and the freight of the regional capitals to São Paulo, were then calculated according to the tonnage and number of trips required per year.

Linear interpolation was used for proportionality between gross domestic product (GDP), population, and E-waste generation (D'Ávila et al., 2007).

The difference in freight values between the different regions was considered. The population and GDP were provided by IBGE (Brazilian Institute for Geography and Statistics) (2011) and IPEA (Brazilian Institute for Applied Economic Research) (2011). Due to the peculiarities of the Amazon region, where much of the transportation is done using the rivers, and because of the difference in the road networks of each state, the freights and movements within each state were not calculated, leaving these values to be covered by the market values in the purchase and sale of the E-waste.

The flow of goods and their value within the state are shown in the following tables. Table 7 shows the the primary calculations.

There was a potential total value in Brazil of US$9814.34 million, or about US$10 billion in potential resources to be used by the country, according this sheet, compatible with the SteP (2012) estimates.

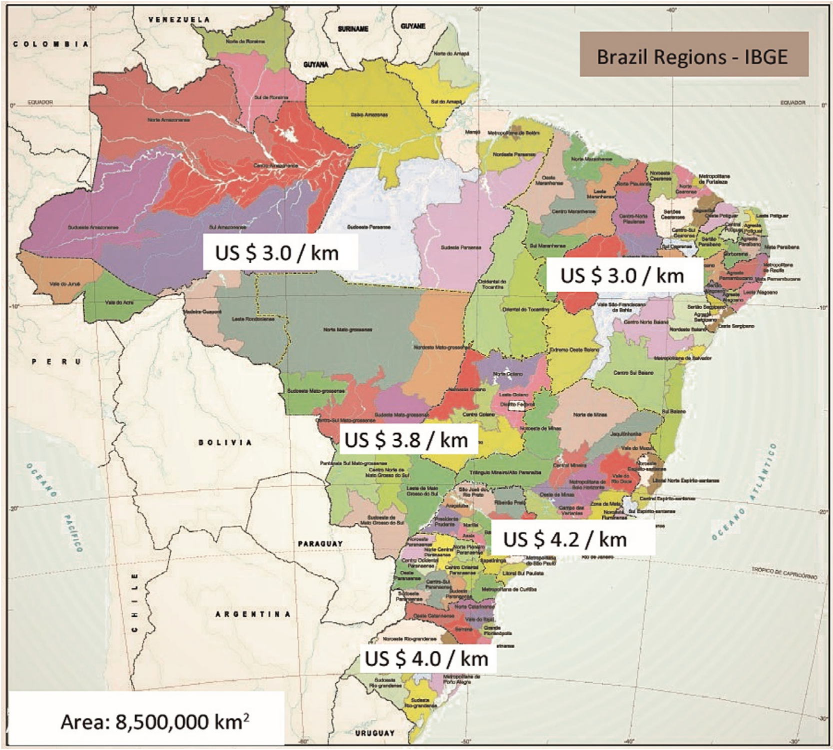

FIG. 2 Prices of road freight from the regions of 25 metric tons.

TABLE 6 Freight Costs to São Paulo From the Regional Capitals

Area of Brazil	Regional Capital	Distance to S. Paulo (km)	Tons/ Year	Voyages/ Year	10^6 US$
North					
Rondônia	Porto Velho	3325	21,047	526	1.75
Acre	RioBranco	3831	24,250	606	2.32
Amazonas	Manaus	4213	26,668	667	2.81
Roraima	Boa Vista	4955	31,365	784	3.89
Pará	Belém	2320	14,686	367	0.85
Amapá	Macapá	3464	21,927	548	1.90
Tocantins	Palmas	1779	11,261	282	0.50

TABLE 6 Freight Costs to São Paulo From the Regional Capitals—cont'd

Area of Brazil	Regional Capital	Distance to S. Paulo (km)	Tons/ Year	Voyages/ Year	10^6 US$
Northeast					
Maranhão	São Luís	3368	21,319	533	1.80
Piauí	Teresina	2934	18,572	464	1.36
Ceará	Fortaleza	2915	18,452	461	1.34
Rio Grande do Norte	Natal	2912	18,433	461	1.34
Paraíba	João Pessoa	2745	17,376	434	1.19
Pernambuco	Recife	2631	16,654	416	1.10
Alagoas	Maceió	2388	15,116	378	0.90
Sergipe	Aracajú	2132	13,496	337	0.72
Bahia	Salvador	1938	12,268	307	0.59
Southeast					
Mnas Gerais	Belo Horizonte	594	44,206	1105	0.92
Espírito Santo	Vitória	944	67,574	1689	2.23
Rio de Janeiro	Rio de Janeiro	440	69,056	1726	1.06
São Paulo	São Paulo	0	74,622	1866	0
South					
Paraná	Curitiba	410	54,532	1363	0.73
Santa Catarina	Florianópolis	697	63,744	1594	1.44
Rio Grande do Sul	Porto Alegre	943	55,362	1384	2.05
Midwest					
Mato Grosso do Sul	Campo Grande	1015	50,743	1269	1.62
Mato Grosso	Cuiabá	1865	59,749	1494	3.51
Goiás	Goiânia	943	46,374	1159	1.38
Distrito Federal	Brasília	1146	147,118	3678	5.31
			Total Million US $		**44.62**

6 Actual Model of the Current WEEE Recycling Market

With the questions raised in the previous model, already much more simplified than the initial one, based on the government assumptions, the research of Prahinski and Kocabasoglu (2006), and analyzing the market and bibliography, the current WEEE flow was modeled as seen in Fig. 3.

The present financial and material flows were analyzed to conclude whether or not a monopoly model would be feasible with a management organization, working on circular economy principles (EMF, 2013).

The debt flows of companies generating WEEE (*italicized* text) are:

- *R$ Y*: the payment made to recyclable waste pickers by delivery to a first recycling company, raw material, without any processing. These are usually informal operations.
- *R$ X*: the payment made to recyclers of raw materials that require an invoice, bill of lading, and/or certificate of environmentally correct destination. Several small companies already act in this line, under contract and licensing of the environmental agency, being duly registered. For example, in São Paulo, the Certificate of Approval of Industrial Waste (CADRI) is required.
- *R$ W*: the payment made to carriers to send material by private transportation to the SC.
- *R$ U*: payment made to public companies for large collections, for which the municipality does not charge, for example through auctions.
- *R$ V*: payment made to the carrier for taking WEE from the RC to the SC.
- *R$ T*: payment made to technical assistance by companies.
- *R$ LX*: payment made by a company that consumes recycled material so that another company can provide the environmentally-correct final disposal of its nonusable waste.

The credit flows of companies in charge of RL (**bold** text) are:

- **R$ R**: payment received by recycling company with own transportation.
- **R$ XY**, **R$ XX**, **R$ XZ**: payment received from companies that will use the recycled material as input.

It is now possible to estimate these values, using the calculations of:

$$R\$Y + R\$X + R\$W + R\$U + R\$V + R\$T + R\$LX$$

Compared with:

$$\mathbf{R\$R + R\$XY + R\$XX + R\$XZ}$$

These estimated values per ton resulting in the data in Table 8.

$$\text{US\$ }1333 + \text{US\$}4000 + \text{US\$}50 + \text{US\$}200 + \text{US\$}100 + \text{US\$}267 + \text{US\$}50 = \text{US\$}5910 \text{ per ton.}$$

TABLE 7 Costs of WEEE Reverse Logistics in the Regions of the Country

Great Regions and Federation Units	PIB	Population	GDP/ Inhab.	GER WEEE	RC	SC	RC Cost	SC Cost	Total	Potential Value of WEEE	RL Cost	Freight to S. Paulo	Balance
	10^6 US$		*2016*	*Tons./ year*			*10^6 US$*	*10^6 US$*	*10^6 US$*	*10^6 US$*	*10^6 US$*	*10^6 US$*	*10^6 US$*
Brazil	*1,464,031*		*US$/ Inhab./ Year*										
North	**77,128**			**126,648**							**73.06**		
Rondônia	9787	1,454,237	6730	21,301	13	2	3.33	2.79	6.12	175.66	7.97	1.75	166.04
Acre	3210	653,620	4911	15,542	5	1	1.28	1.40	2.68	128.17	5.00	2.32	120.85
Amazonas	21,373	3,167,668	6747	21,355	24	2	6.15	2.79	8.94	176.11	11.75	2.81	161.56
Roraima	2438	394,192	6185	19,574	1	1	0.26	1.40	1.65	161.43	5.54	3.89	152.00
Pará	30,336	7,070,867	4290	13,579	74	10	18.95	13.95	32.91	111.98	33.76	0.85	77.37
Amapá	3473	585,073	5960	18,788	3	1	0.77	1.40	2.16	154.94	4.06	1.90	148.98
Tocantins	6510	1,248,158	5216	16,507	7	2	1.79	2.79	4.58	136.13	5.08	0.50	130.55
Northeast	**196,461**			**144,654**							**189.85**		
Maranhão	19,607	6,072,932	3229	13,624	58	6	14.86	8.37	23.23	112.36	25.02	1.80	85.54
Piauí	8574	3,029,916	2830	11,941	19	2	4.87	2.79	7.66	98.47	9.02	1.36	88.09
Ceará	30,044	8,183,880	3671	15,492	74	8	18.95	11.16	30.12	127.76	31.46	1.34	94.95

Continued

TABLE 7 Costs of WEEE Reverse Logistics in the Regions of the Country—cont'd

Great Regions and Federation Units	PIB	Population	GDP/ Inhab.	GER WEEE	RC	SC	RC Cost	SC Cost	Total	Potential Value of WEEE	RL Cost	Freight to S. Paulo	Balance
	10^6 US$		*2016*	*Tons./ year*			*10^6 US$*	*10^6 US$*	*10^6 US$*	*10^6 US$*	*10^6 US$*	*10^6 US$*	*10^6 US$*
Brazil	*1,464,031*		*US$/ Inhab./ Year*										
Rio Grande do Norte	13,181	3,014,228	4373	18,454	18	3	4.61	4.19	8.80	152.19	10.14	1.34	140.71
Paraíba	12,91	3,640,538	3546	14,965	20	3	5.12	4.19	9.31	123.41	10.50	1.19	111.72
Pernambuco	39,113	8,487,072	4609	19,448	73	10	18.70	13.95	32.65	160.38	33.75	1.10	125.54
Alagoas	9848	3,014,979	3266	13,784	27	2	6.92	2.79	9.71	113.68	10.61	0.90	102.16
Sergipe	9274	1,938,970	4783	20,185	15	2	3.84	2.79	6.63	166.46	7.35	0.72	158.39
Bahia	55,909	14,079,966	3971	16,757	119	15	30.48	20.93	51.41	138.19	52.00	0.59	85.59
Southeast	**808,002**			**510,916**							**153.23**		
Minas Gerais	134,517	19,261,816	6984	88,413	127	26	32.53	36.28	68.81	729.11	69.46	0.66	658.99
Espírito Santo	35,776	3,351,327	10,675	135,149	26	7	6.66	9.77	16.43	1,114.53	18.02	1.59	1094.92
Rio de Janeiro	168,074	15,406,488	10,909	138,112	53	23	13.57	32.09	45.67	1,138.97	46.43	0.76	1091.78
São Paulo	469,635	39,838,127	11,789	149,243	206	72	52.76	100.46	153.23	1,230.77	153.23	0	1077.54

South	**236,953**			**228,851**							**109.49**		
Paraná	85,309	10,279,545	8299	70,043	67	14	17.16	19.53	36.70	577.62	37.25	0.56	539.81
Santa Catarina	59,092	5,868,014	10,070	84,992	43	10	11.01	13.95	24.97	700.91	26.00	1.11	673.72
Rio Grande do Sul	92,553	10,582,324	8746	73,816	76	18	19.47	25.12	44.58	608.74	46.16	1.57	561.01
Midwest	**143,488**			**202,656**							**55.64**		
Mato Grosso do Sul	18,157	2,265,021	8016	33,829	14	2	3.59	2.79	6.38	278.98	7.66	1.29	270.03
Mato Grosso	26,943	2,854,456	9439	39,833	22	4	5.63	5.58	11.22	328.49	14.00	2.79	311.70
Goiás	41,309	5,638,608	7326	30,916	37	7	9.48	9.77	19.24	254.96	20.34	1.09	233.52
Distrito Federal	57,079	2,455,903	23,241	98,079	15	4	3.84	5.58	9.42	808.83	13.64	4.21	790.97
								Million US$		**10,009.24**	**581.27**	**585.48**	**9254.06**

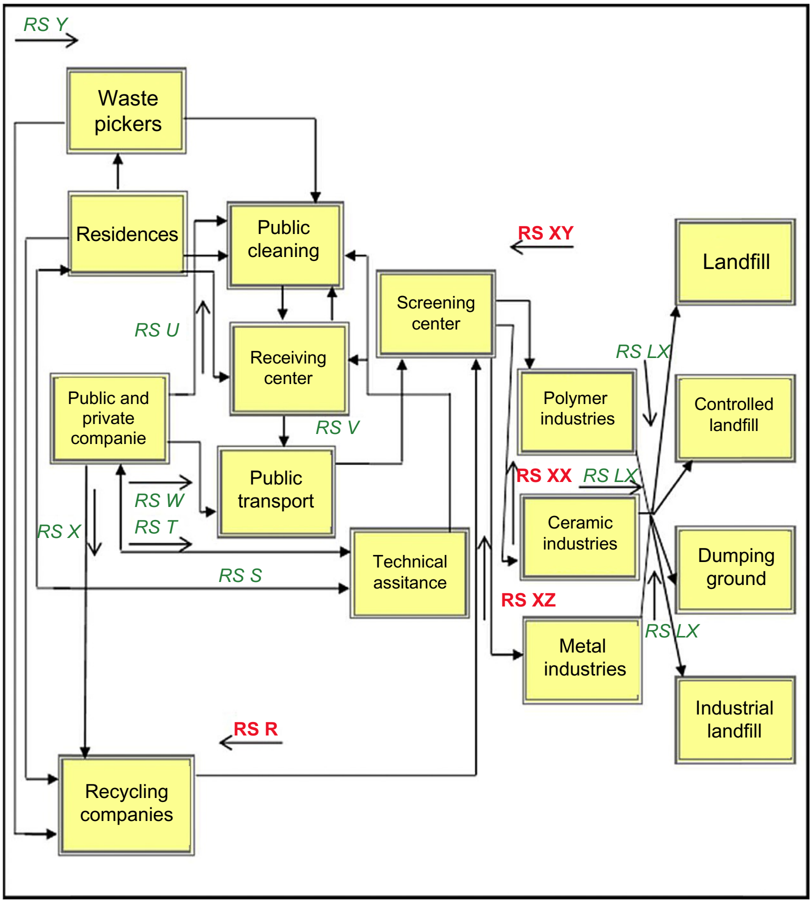

FIG. 3 Current WEEE flow model.

TABLE 8 Amounts Involved in the WEEE Market

Payments	Values/Ton (US$)	Source
R$ Y	1333	E-mile, Sincronics
R$ X	4000	Cimélia, Suzaquim
R$ W	50	Estimate based on the freight table
R$ U	200	Research of federal auctions, electronic auctions
R$ V	100	Table of freights
R$ T	267	Estimate with market queries
R$ LX	50	Estimate with market queries

TABLE 9 Receipts

Receipts	Values per Ton (US$)	Source
R$ R	8000.00	Small recycling companies at Minas Gerais: BH Recicla, BID, Santa Maria, after delivery to the industry - UMICORE
R$ XY	33.00	Royal Polímeros, Replas, MG Polímeros Brasil
R$ XX	33.33	Cimélia, Suzaquim
R$ XZ	3933.33	Sinctronics

Receipts are calculated using Table 9.

As for the **bold** plots, we will have:

$$\mathbf{R\$\,R + R\$\,XY + R\$\,XX + R\$\,XZ} = \mathrm{US\$8000.00 + US\$33.00 + US\$33.33 + US\$3933.33} \\ = \mathrm{US\$8400.00\ per\ ton.}$$

As can be seen, there is a difference in credit to the company(s) in relation to the values of the average mass balance already discussed above (from US$8246.73 per ton maximum). The companies that recycle the WEEE, after the separation of metals, polymers and ceramics, are able to have credit of US$2490.00. This amount would refer to the credit to the company undertaking metals processing, after all the payments.

According to the figures disclosed, the activity is sustainable, because if from the theoretical total of US$8,246.73 of material value, with US$612.49 spent on RL, there is a possible US$7634.24 to be calculated by the metal recycling industry. These values are consistent with payments to Brazilian recyclers until the material has gone to European industries. Since these are values researched in the market, the customs and environmental licensing costs on the export of these WEEE have already been duly included.

The system shown in Fig. 4 is therefore sustainable, without government or private monopoly intervention, only for the prices in the scrap market with capital inflows of **R$ XY** and **R$ R**.

A management company, in the manner proposed by the government, will not be able to monopolize this market, even if they make investments in RC and SC, as there is a tendency for recycling companies to informally separate WEEE seeking higher values of remuneration, and send it abroad as commodities.

If the management company with capital from the manufacturers/importers decides to pay for the RC and SC, and invest in a chemical processing company for the mining of precious metals, the entire system will become self-sustaining, without government investment, and without consumer charges. There will be a

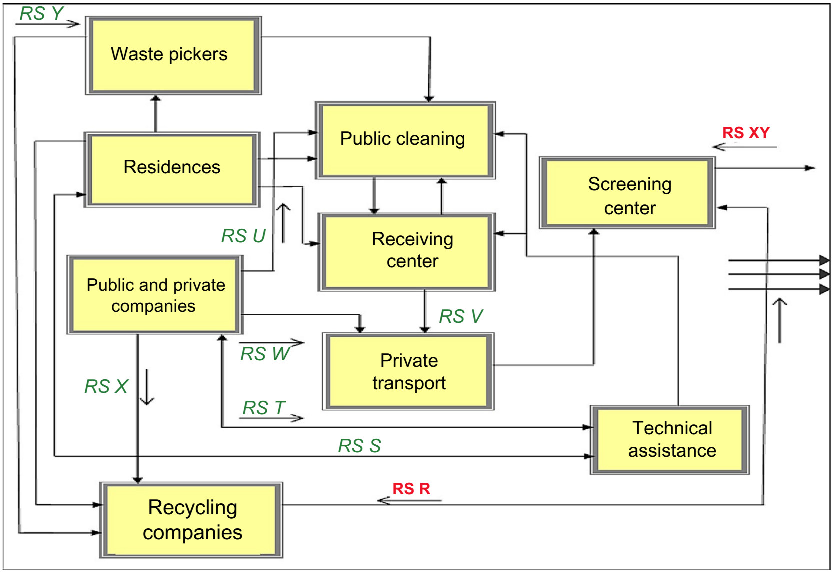

FIG. 4 Competitive proposal modeling of recyclers and waste pickers.

tendency to send WEEE for recycling in Brazil, in legally qualified and qualified industries, increasing the earnings of all agents in the process, according to Fig. 5.

The EEE-producing industry will then have inputs with only processing costs:

- Payment to industrial landfill: **R$ AB** = US$150.00 per ton (Bayer, 2016);
- Payment to recyclers for polymers and ceramics: **R$ XY + R$ XX** = US$276.00 per ton (Suzakim Chemical Industries Ltd., 2015).

With the value of *R$ XXX* (amount equivalent to the metals calculated), after deducting the amounts **R$ AB**, **R$ XY,** and **R$ XX**, the manufacturers would again have inputs for their manufacturing lines, being able to, under the management organization, have access to the Brazilian refining industry, and to establish lower costs than natural extraction. The management organization would be exclusively formed by manufacturers/importers of electronic equipment.

7 Results

7.1 Discussion of Results

In financial terms, this general volume of scrap generates a potential market growth of US$233 million, as presented in Table 10 and according to IPEA (2011).

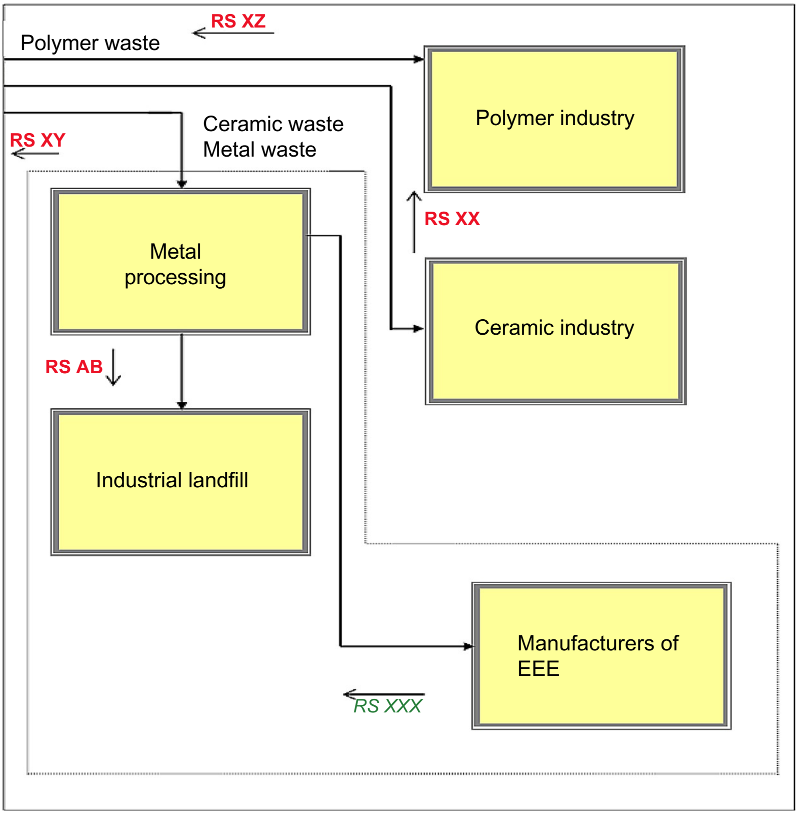

FIG. 5 Model proposed for the action of the management organization formed by manufacturers/importers.

TABLE 10 Economic Potential of WEEE Utilization in Brazil per Year

Material	Estimated Volume of Recycled Raw Material Generated From the RL System (Tons)	Scrap Price Range (US$ per Ton)	Potential Impact on the Market (Million US$)
Aluminum	9800	7.33 to 9.00	24
Copper	9060	3.36 to 4.29	103
Iron	183,400	83.2 to 126.6	57.6
Polymer	56,300	100 to 120	46.3
Glass	9300	33.3 to 63.3	1.5
Total	**267,860**		**232.40**

Source: IPEA, 2011. Institute of Applied Economic Research. Diagnosis of Solid Waste from Reverse Compulsory Logistics; Research Report. Secretary of Strategic Affairs of the Presidency of the Republic, Federal Government (in Portuguese).

TABLE 11 Potential to Reduce CO_2 Emissions

Estimated Reduction CO_2 Generated		
Material (Tons)		*Tons. of CO_2*
Al	29,400	132,300
Cu	27,200	127,840
Glass	24,800	7936
Total		**268,076**
Percentage of WEEE		**26.11%**

Source: Inventta, 2012. Reverse Logistics of Electrical and Electronic Equipment, Technical and Economic Feasibility Analysis. MDIC (Ministry of Industry and Commerce), Brazil (in Portuguese), adapted by the author.

With the strengthening of the recycling of WEEE, the encouragement of the development of recyclable products, and with a higher content of recyclable material through the implementation of ecodesign, the RL system will contribute to the promotion of a more sustainable production: a transversal theme of the Brazilian industrial, technological policy, and foreign trade (Brunner, 2015).

In line with the environmental impacts, the Brazilian potential for reducing CO_2 emissions in the mining industry, due to the use of recycled materials from the WEEE reverse logistics system, should be highlighted, as shown in Table 11.

8 Conclusions

There is a surplus of recovered material that cannot be considered a profit because it depends on the percentage of recycling and processing costs in the chemical processing industry. It serves as an indication, however, that there are values that need to be extracted from urban mining, even for environmental protection (Lima and Oliveira, 2008).

In Brazil, there is no possibility of using recovered metals in the electronics industry because the country does not manufacture integrated electronic circuits that could be used in the production of electronics (ABINEE, 2015a,b,c).

However, this recycling would generate funds, jobs, and reduce environmental degradation. As our calculations show, the recycling of E-waste is financial and ecologically sustainable. This process is cheaper in all phases of traditional mining (ABRELPE, 2015).

As we have seen above, the commercialization of WEEE is economically viable. It is what the Japanese refer to as "true urban mining", and it is also sustainable, as it is no longer used to mine several metals, thereby reducing the degradation of the environment environment.

The last model proposed, modified governmental premises, and reducing the number of CR and TC, would not influence the network of collectors, cooperatives, and recyclers, and there may be, assistance from the government to increase the activity. The market itself, stimulated by increasing amounts to be paid by WEEE, would deal with the transport and logistics involved, alleviating the responsibility of the manufacturer/importer in the process.

The organization or organizations that submit a sector agreement to IBAMA would receive incentives to attract the recycling network and to become involved in chemical processing in Brazil, being willing to deliver precious metals to manufacturers/importers in Brazil, without having RL costs management of the last stage of the extraction of metals and polymers and also the network of reception centers and sorting.

The manufacturer/importer could use good quality material for a much lower price than if it was purchased from the extraction of the ores from nature.

The final recycling group, with the capital established in the sale to the manufacturers/importers, would finance its operation and remunerate the management organization.

According the plans of the Union of Industry of Electrical Conductors, Drawing and Rolling of Non-Ferrous Metals of the State of São Paulo (SINDICELABC) and Brazilian Copper Association (ABC), 10,000–15,000 workers will be required to operate the system from disposal points, passing through the SC and arriving to recyclers that will process the volume of WEEE. This estimate considers the system at full capacity, covering 100% of the national territory.

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