# Environmental Information System for Waste Electrical Electronic Equipment (WEEE) Management: Case Study of Pernambuco (Brazil)

Lúcia Helena Xavier[1], David Lee[2], Dietmar Offenhuber[3], Carlo Ratti[2], Alexsandro Diniz[1], Rodrigo Medeiros[4]

## Abstract

The National Policy on Solid Waste (NPSW) brought a new dimension to waste management in Brazil. According to the requirements of this law, producers, traders, recyclers, importers, distributors, and consumers are each held responsible for waste outcomes. The establishment of reverse logistics systems, also proposed by the law, begins from the management of diffuse interests in support of environmentally sound disposal of waste. However, no form of monitoring or implementing process improvements is possible without knowledge of the managed resources and control of the activities. Energy usage from fuel consumption is a central concern for sustainable waste management through reverse logistics systems (RLS). The distances travelled, the type of fuel, and the defined routes are some of the criteria to be evaluated in energy performance improvement. Thus, as preliminary results of a survey of international cooperation between Brazil and the United States, we propose a method of operating waste collection systems, with the support of an environmental information system (EIS) and integration of electronic waste management stations from a cooperative of waste pickers located in Pernambuco (Brazil). Our findings suggest the importance of the EIS prototype in compliance with legal requirements and the potential for improvement of the proposed solution.

## 1. Introduction

The sustainability challenges facing Brazil require balancing environmental compliance, economic performance, and social equity. In a recent study carried out in 50 Brazilian companies, it was noticed that most institutions consider environmental sustainability as a business issue only with respect to legal and economic penalties [1]. The authors also discussed the disclosure of companies´ environmental actions, and their findings suggested that waste management is the most relevant issue, along with atmospheric emissions, for those companies.

In sustainable waste management systems, different agents are responsible for specific tasks in order to guarantee environmentally suitable return and treatment (e.g. recycling, reuse, refurbishing, remanufacturing and landfill disposal). In the majority of Latin American countries, systems for dealing with waste electrical and electronic equipment (WEEE) have formed spontaneously through the actions of informal waste pickers, people who collect, sort and sell different post-consumer materials [2].

As a result of the Brazilian National Policy on Solid Waste (NPSW), enacted in 2010 by the Law n. 12,305, states and municipalities are required to prepare waste management plans as well as reverse logistics systems (RLS) procedures. The law also requires the inclusion of waste pickers in these planned systems. Other laws and decrees are also in place, accounting for regional specificities and local infrastructure arrangements.

[1] Joaquim Nabuco Foundation - Fundaj, Recife, Brazil, lucia.xavier@fundaj.gov.br; alexsandro.diniz@fundaj.gov.br

[2] Senseable City Lab – MIT, Boston, United States, david733@alum.mit.edu; ratti@mit.edu

[3] Northeastern University, Boston, United States, dietoff@gmail.com

[4] Federal University of Pernambuco – UFPE, Recife, Brazil, rodrigopessoamedeiros@gmail.com

Nowadays, solid waste management employs a plethora of regulatory mechanisms and technological tools, but not as many efficient or adapted information systems. Amongst other requirements, the NPSW proposes the development of a broad Information System (IS) named SINIR (National Information System on Solid Waste), in order to allow data management, monitoring, and decision-making regarding waste management. This system is currently under construction, and data collection and quality are among the main challenges in its implementation.

The core of the waste management Information System, in general, is the data input and availability on the collection, storage, and disposal phases of post-consumer materials and products. However, although the Brazilian legislation does not specify the necessary information for waste management, lack of trust in data from sources such as waste picker associations and cooperatives remains a weakness of these information systems. Therefore, it is necessary to make the collection and recording of these data as automated as possible, in order to increase the reliability and credibility of information and improve data quality and decision significance [1, 4, 5].

To that end, we propose a method for partially automated data collection and management, applying tracking and mass balance concepts to the activities of waste picker cooperatives and associations. Our paper focuses on an important common point in regulation: the inclusion of waste pickers in the waste management process through process and technology innovation.

## 2. Background

### 2.1. WEEE management in Brazil

WEEE is not solely a recent field of study [6, 7], but it is possible to note the evolution of related themes over the last two decades. From the years 2000 to 2010, approximately, most studies focused on the social effect of recycling actions, as well as legal and technical aspects [8-11], likely in response to European Directives requirements of the time. From 2010 onward, research shifted to focus on strategic overview and managerial themes [12-14].

In accordance with this tendency [15], presented a recent study based on the importance of defining the amount of WEEE generated as a strategic tool for waste management in Brazil. Additionally, [16] focused on technical and managerial approaches to e-waste management in Brazil. Both studies were based on the NPSW requirements.

One of the main concerns in the design of RLS in Brazil is the distances to be travelled. In a country of continental proportions, it is quite important to invest in efficient use of precious resources such as time and energy. In this context, [17] presented an interesting discussion about e-waste management trough reverse logistics tools and the energy consumption during post-consumer movements in Europe. The dimensional challenges of shipping between European countries are comparable to cargo movement across Brazilian states. The state of Pernambuco, for example, spans almost 100,000 $km^2$, stretching about 700 km from east to west, and about 300 km from north to south.

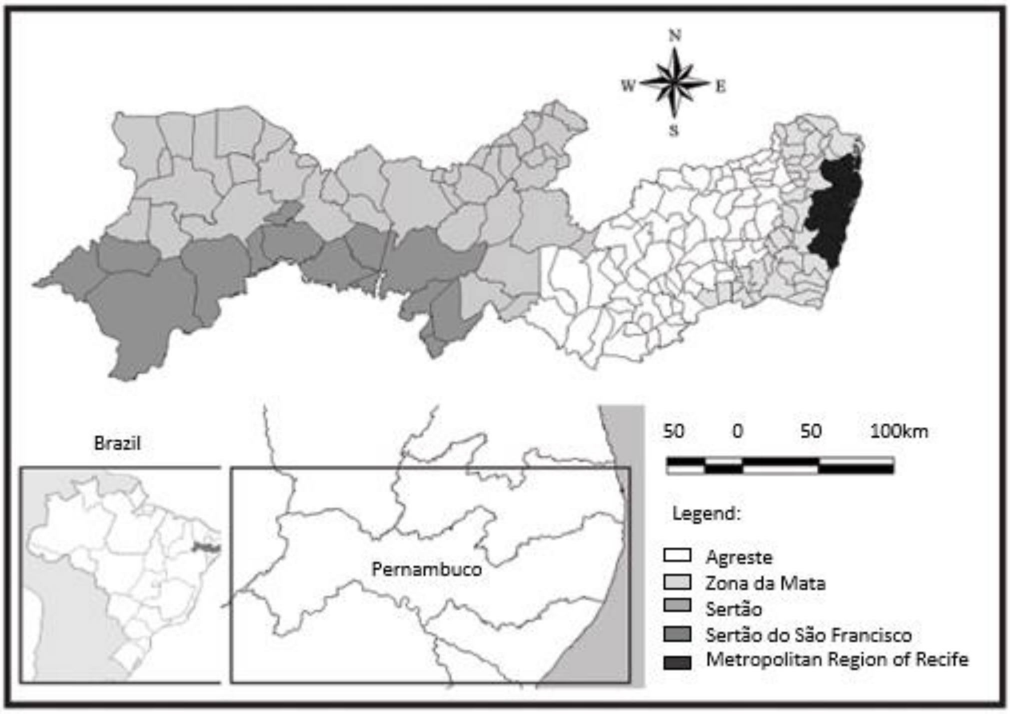


*Figure 1. Pernambuco and the Metropolitan Region of Recife (Brazil) [18].*

According to [19], of the 27 Brazilian states, only nine have specific state laws on e-waste management. According to this report, there are seven different business models for e-waste management successfully applied in Brazil (Table 1).

| Model | Nationality | Characteristics |
|---|---|---|
| Itautec (S/A) | Brazilian | Executes the whole recycling process in Brazil and then exports directly to a foreign company to extract the valuable materials. |
| Philips do Brasil | American | Collection, transport and recycling capacity over than 300 ton per year, from 40 collection points in the country. |
| Carrefour | French | Provide collection and delivery of e-waste to recycling partners: OXIL and Diassolog, in order to establish a model for its shared responsibility. |
| Oxil | Brazilian | Receives e-waste from 50 manufacturing companies around the country. As well as electronics, OXIL recycles refrigerators, extracting CFCs, and printer cartridges |
| Reciclo Ambiental | Brazilian | Collects and transports e-waste material from the client and delivers it to its own facility. Provides process tracking and brand protection. |
| Umicore | Belgian | Plays an important role in exporting e-waste, guarantees the correct destination, and assures payback for the e-waste recycling. |
| Oxigênio | Brazilian | A unique model in the country – a civil organization with public interest that can receive resources from all levels of government. |

*Table 1. Business models for e-waste management in Brazil.*

The main stages of the disposal of Waste Electrical Electronic Equipment (WEEE) systems are: the recovery of dispersed material in specialized collection centers; delivery to environmentally appropriate disposal points for reuse, reconditioning, repair, remanufacturing or recycling; and reinsertion into production chains. During the disassembly of post-consumer electronic equipment, it is possible to assign value to materials and components for marketing purposes along the reverse supply chain.

The assigned value is the result of product composition (valuable or hazardous materials, etc) and the processing cost of components and materials. However, large electronic equipment often has low added value; due to designs unconducive to recycling, they are difficult to re-integrate into the production chain.

The tasks and costs involved in post-consumer product warehousing, disassembling and treatment may be considered the operational axis of an RLS. As discussed by [20], disassembly is considered a crucial step in returned product disposal, and also an expensive sequence of tasks that must be carefully planned. Because of the complexity of electrical and electronic equipment, the integrity of materials, parts and components could result in either economic profit or extra disassembly costs.

Figure 2 shows a conceptual model for a reverse logistics system to be applied to different post-consumer products and materials from electrical and electronic origins.

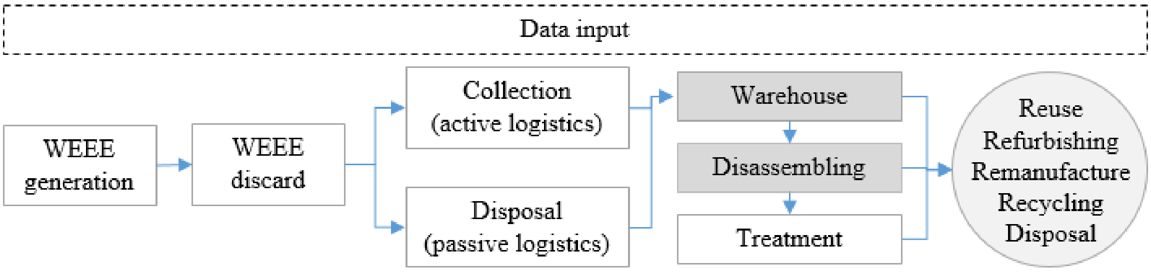


*Figure 2. Conceptual model of Environmental Information System for Waste Electrical Electronic Equipment (WEEE) management.*

The RLS we propose will feature tracing mechanisms for post-consumer stages, and can be expanded to cover all post-production steps, as well as mass balance based on the identification of the product and its materials. Products with simple composition, such as plastic or cardboard packages, glass, plastic bottles, and books and magazines, are easily disassembled and reincorporated into the recycling chain by means of reverse logistics. However, e-waste are, in most cases, complex products consisting of three or more types of materials; some of these have more severe potential environmental impact, such as printed circuit boards, CRT tubes, and mercury vapour lamps [21].

Supplying the waste management information system with more and higher quality information will improve the reliability of this system. In turn, this reduces uncertainty and increases the credibility of decision-making. Depending on the reverse logistics stage from where the material returns, the decision-makers may include the government, manufacturers, retailers, importers, distributors, and consumers – collectively known as Agents of Reverse Manufacturing (ARM).

After recovery, the product moves to the ARMs responsible for sorting and separating parts and/or constituent materials. Those ARMs who are interested in reselling the material must give an account of the origin of this material. Thereafter, we can trace whether a product was disposed of in a proper environmental manner.

### 2.2. EIS for WEEE management

The costs in RLS can be inflated due to logistical inefficiency, unpredictability and unreliable data. Some research has shown satisfactory results regarding the application of innovative tools that contribute to efficiency improvement and cost reduction, such as the use of RFID for reverse logistics [22] and e-waste management [23].

Nevertheless, in Brazil there are no e-waste studies on this concern. To this end, we use the concept of mass balance – the ratio of the weight of each material that can be extracted from a given material in terms of its total weight.

The method proposed for RLS monitoring requires automatic data input in order to provide reliability and credibility. These data may be provided by tag scanners, GPS devices, weight scales, and image capture. A central server manages the overall database system, and may have regional or national coverage. Local servers are responsible for local databases specific to the ARM responsible for their stage, for example a local waste picker association or cooperative, as well as the material categories and volumes managed. This method embraces and facilitates environmental knowledge, legal compliance, and technology in an environmental IS that may support the actual Brazilian SINIR and also include international best practices on WEEE management.

## 3. Research methodology

After literature review on the main studies related to the subject, we considered the following lines of action: (i) identification of needs for associations and cooperatives of collectors entering the recycling market; (ii) definition of system requirements in accordance with operational and legal requirements; (iii) testing the prototype in field studies, and (iv) verification of the material system through mass balance and tracking, with report generation.

## 4. Results

### 4.1. Waste management at MRR

The Metropolitan Region of Recife (MRR) (Figure 1), located in the State of Pernambuco, has one of the lowest Human Development Indices in Brazil [24]. A recent report [25] shows a larger contingent of waste pickers working in this region of the country, possibly because of the precariousness position in which a significant portion of the population lives. Many individuals need to compose or supplement their income from the collection and sale of recyclable material. These workers have a monthly income equivalent to USD 200.00, approximately.

Since the current strategy for their inclusion in the waste system relies on their involvement in waste picker cooperatives or associations, our method considers these organizations as the units of analysis for our data collection, including their membership characteristics, routes, and waste categories and amounts collected. Considering the local aspects of e-waste management and the legal requirements, we proposed a simple system to organize collection and treatment logistics, as well as provide reliability to the data collection.

The system is designed with the technical, educational and spatial constraints faced by waste picker cooperatives and associations. All parts are off-the-shelf products that are connected using open-source software available without license fees. The system is limited to the minimum components necessary to collect actionable data for the purposes of an EIS that integrates with other agents in the reverse logistics chain and complies with current legislation. Waste collection routes are recorded through a smartphone application used in the collection vehicle, in order to estimate transportation cost and impact (Figure 3).

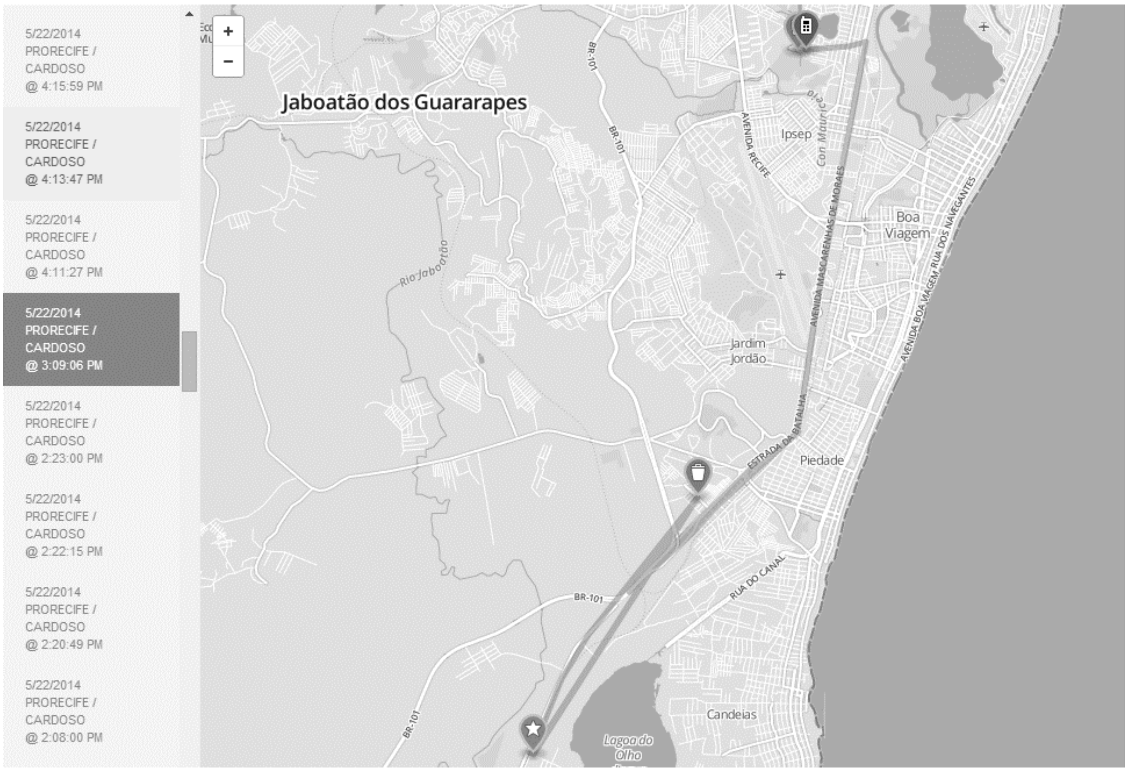


*Figure 3. Metropolitan Region of Recife (PE, Brazil) and a route detected by the smartphone application.*

The routes performed by waste pickers in the MRR were not so efficient as it could be. They use to repeat some sections and spend more time and fuel consumption (in the case of trucks collecting), than would be expected. Improvements could be provided by considering some variables such as: the responsible person and the location of collecting points, distances to be travelled, type of material to be loaded in the truck or collected by manual charts and the average time spent for the daily performance of the tasks. Besides managerial criteria, low cost technological alternatives were proposed to compound the RLS in the RMM.

Recorded weights and images of the collected e-waste provide the basis for calculating mass balances, with increasing accuracy as more and more material is documented. The proposed system collects most input automatically through the image capture webcam, scale for weighing the material or product, and bar code reader for identification and storage of information. All recorded information goes to a database that, according to legal requirement, must be available for inspection and monitoring of the process, and eventually, reverse logistics traceability of the post-consumer product (Figure 4).

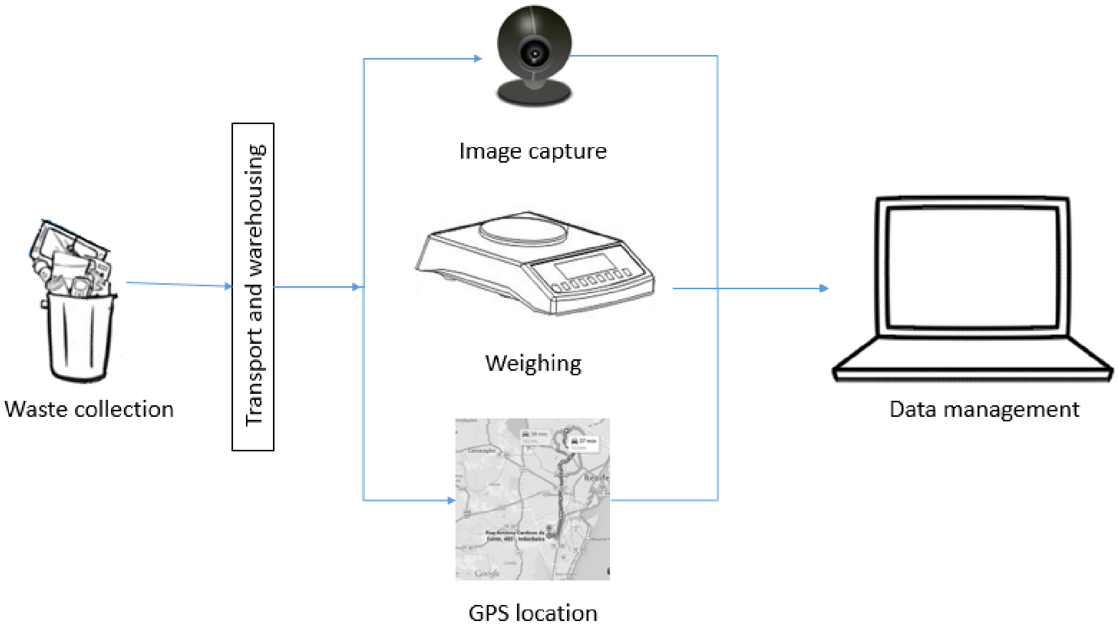


*Figure 4. General model proposed for e-waste management*

As expected, the system will also allow for optimization of routes traveled and reduced fuel consumption. In the future, it may also incorporate estimated $CO_2$ emissions. For example, since many waste pickers in Latin America still use vehicles powered by manual effort (e.g. hand carts), these could be considered as zero emission processes.

## 5. Conclusion and Discussion

The findings suggest that both environmental and energy aspects of e-waste reverse logistics may be improved through an efficient and reliable EIS. This system prototype considers the integration of different devices (scale, GPS device, and computers) in order to provide reliable data and support decision-making in a sustainable way. Information reliability is the main concern for policymakers, industry trade unions, and informal recyclers, while improving energy consumption in RLS would be an added benefit from previous sustainable decisions.

Our EIS setup represents a first step to capturing relevant data about collection, treatment and valorization in an environment that is a significant part of the value chain, yet is still dominated by informal practices and management. While this system needs to be tested extensively in the everyday practice of waste picker cooperatives, it allows capturing data about an until-recently little-known, yet ubiquitous part of the waste system.

Future research will consider specific requirements for other supply chains. By combining environmental services and technological support, we hope to reduce energy consumption and in waste collecting processes. Direct impacts could include using fewer trucks through better logistics planning of collection points and routes taken by the cooperatives.

## References

[1] Rosa, F.S., Guesser, T., Hein, N., Pfitscher, E.D., Lunkes, R.J. "Environmental impact management of Brazilian companies: analyzing factors that influence disclosure of waste, emissions, effluents, and other impacts". *Journal of Cleaner Production*, In Press, 2013.

[2] RELAC, 2014. Plataforma Regional de Residuos Electrónicos en Latinoamérica y el Caribe. http://www.residuoselectronicos.net/

[3] NPSW, 2010. National Policy on Solid Waste. Law n. 12,305. http://www.planalto.gov.br/ccivil_03/_ato2007-2010/2010/lei/l12305.htm

[4] Fox, C., Levitin, A., Redman, T. "The notion of data and its quality dimensions". *Information Processing & Management*, vol. 30, 1, pp. 9-19.

[5] Chung, S.S. "Using plastic bag waste to assess the reliability of self-reported waste disposal data". *Waste Management*, v. 28, no. 12, pp. 2574–2584, 2008.

[6] Ernst, T., Popp, R., Eldik, R. "Quantification of heavy metals for the recycling of waste plastics from electrotechnical applications".*Talanta*, vol. 53, 2, 1 2000, pp. 347-357

[7] Ongondo, F.O., William, I.D., Cherrett, T.J., How are WEEE doing? "A global review of the management of electrical and electronic waste". *Waste Management*, Vol. 31, 4, pp. 714-730, 2011.

[8] Cui, J., Forssberg, E. "Mechanical recycling of waste electric and electronic equipment: a review". *Journal of Hazardous Materials*, vol 99, 3, 2003, pp. 243-263

[9] Tange, L., Drohmann, D. "Waste electrical and electronic equipment plastics with brominated flame retardants – from legislation to separate treatment – thermal processes". *Polymer Degradation and Stability*, vol. 88, 1, 2005, pp. 35-40

[10] Darby, L., Obara, L. "Household recycling behaviour and attitudes towards the disposal of small electrical and electronic equipment". R*esources, Conservation and Recycling*, Vol. 44, 1, 2005, pp. 17-35.

[11] Marco, I., Caballero, B.M., Chomón, M.J., Laresgoiti, M.F., Torres, A., Fernández, G., Arnaís, S. Pyrolysis of electrical and electronic wastes. J of Analytical and Applied Pyrolysis, vol. 82, 2, pp. 179-183, 2008.

[12] Kuo, T.C. "Combination of case-based reasoning and analytical hierarchy process for providing intelligent decision support for product recycling strategies". *Expert Systems with Applications*, Vol. 37, 8, pp. 5558-5563, 2010.

[13] Gutiérrez, E., Adenso-Díaz, B., Lozano, S., González-Torre, P. "A competing risks approach for time estimation of household WEEE disposal". Waste Management, vol. 30, 8–9, 2010, pp. 1643-1652.

[14] Ongondo, F.O., William, I.D., Dietrich, J., Carrol, C., "ICT reuse in socio-economic enterprises". *Waste Management*, Vol. 33, 12, pp. 2600-2606, 2013.

[15] Araújo, M.G., Magrini A, Mahler C.F., Bilitewski B. "A model for estimation of potential generation of waste electrical and electronic equipment in Brazil". *Waste Manag* 2012; 32(2): 335-42.

[16] Mazon, M.T., Azevedo, A.M.M., Pereira, N.M., Silveira, M.A. Does Environmental Regulation Foster the Diffusion of Collaborative Innovations? A Study on Electronics Waste Regulation on Brazil. Procedia - Social and Behavioral Sciences, Vol. 52, 2012, pp. 259-268.

[17] Barba-Gutiérrez,Y.,Adenso-Díaz,B., Hopp, M."An analysis of some environmental consequences of European electrical and electronic waste regulation". *Resour, Conserv and Recy*, vol. 52, pp. 481-95, 2008.

[18] Dantas-Torres, F., Brandão-Filho, S.P., "Geographical expansion of visceral leishmaniasis in the State of Pernambuco", *Revista da Sociedade Brasileira de Medicina Tropical*, vol. 39, no. 4, 2006.

[19] InfoDev Report, 2012. Wasting no Oportunity – The Case for Managing Brazil´s Electronic Waste. World Bank. http://www.infodev.org/infodev-files/resource/InfodevDocuments_1169.pdf

[20] Adenso-Díaz, B., García-Carbajal, S., Gupta, S.M. A path-relinking approach for a bi-criteria disassembly sequencing problem", *Computers & Operations Research*, Vol. 35, 12, pp. 3989-3997, 2008.

[21] Yamane, L.H., Moraes, V.T., Espinosa, D.C.R., Tenório, J.A.S. "Recycling of WEEE: Characterization of spent printed circuit boards from mobile phones and computers". *Waste Management*, vol 31, 12, 2011, pp. 2553-2558.

[22] Lee, C.K.M., Chan, T.M Development of RFID-based Reverse Logistics System. *Expert Systems with Applications*, Vol. 36, 5, pp. 9299-9307, 2009.

[23] Lee, C-H., Lin, C-Y., Ma, H-W., Ng, S-H. The Incentive Mechanism with RFID Technology for Suppliers to Design Environmentally-Friendly Electrical and Electronic Equipment. *Procedia - Social and Behavioral Sciences*, vol 57, 9 2012, pp. 339-345

[24] PNUD, 2010. Rankng IDHM Municípios, 2010. http://www.pnud.org.br/atlas/ranking/Ranking-IDHM-Municipios-2010.aspx

[25] IPEA, 2013. Situação Social das Catadores e dos Catadores de Materiais Recicláveis e Reutilizável. http://www.ipea.gov.br.