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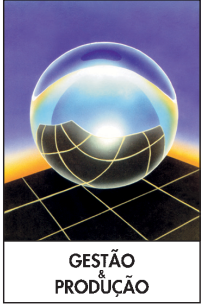

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Risk analysis in the operation of waste electrical and electronic equipment recycling plants

Análises de risco na operação de usinas de reciclagem de resíduos eletroeletrônicos (REEE)

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Abstract: when inappropriately carried out, management of waste electrical and electronic equipment (WEEE) may potentially damage the environment and affect the health of workers. The identification and evaluation of environmental and occupational health risks are essential tools in the prevention of accidents and environmental protection. Despite extensive regulation, WEEE management organizations in Brazil fail to recognize the importance of appropriately address risks associated with their processes and activities. This study developed and tested a methodology to analyze environmental and occupational health risks. The aim was to produce a tool to help WEEE management organizations in decision-making in high priority scenarios. The results show that most environmental impacts and occupational risks classified as significant are associated with the production processes sorting and disassembly of WEEE. However, potential environmental impacts are associated with the transportation of WEEE and coproducts. Accident risks represented 69% of the sum of all risk levels associated with occupational health.

Keywords: WEEE; Risks; Risk management; Environmental impacts; Occupational health.

Resumo: *O manuseio de resíduos eletroeletrônicos (REEE), se executado de forma inadequada, possui grande potencial para causar severos danos ao meio ambiente e à saúde dos trabalhadores que executam estas tarefas. A identificação e avaliação de riscos ambientais, de saúde e segurança do trabalhador são ferramentas essenciais para prevenir acidentes e garantir um ambiente saudável. Embora no país exista extensa legislação acerca do assunto, não há por parte das empresas recicladoras, o reconhecimento e tratamento necessário dos riscos associados a estas atividades. Este trabalho, desta forma, propõe uma metodologia de levantamento e análise de riscos ambientais e de saúde e segurança ocupacional com o intuito de auxiliar as organizações na tomada de decisão, priorizando os riscos mais graves. Os resultados mostraram que a maioria dos impactos ambientais e dos riscos ocupacionais classificados como significativos estão relacionados às atividades de produção (processos de triagem e desmontagem de REEE). Contudo, o estudo revela que um ponto crítico de potencial impacto ambiental está vinculado às tarefas de transporte de REEE e de coprodutos. Já em relação à saúde do trabalhador, o Risco de Acidentes é destaque representando 69% do somatório dos graus de riscos identificados.*

Palavras-chave: *REEE; Riscos; Gerenciamento de risco; Impactos ambientais; Saúde de segurança no trabalho.*

1 Introduction

According to the United Nations University (UNU-AIS), waste electrical and electronic equipment (WEEE) tops the list of waste generated in the world (UNU-IAS, 2015). In 2014, 41.8 million tons of WEEE were generated in the planet, accounting for 5.6 kg/inhabitant year on average. The highest amount of WEEE was recorded in Europe, with 5.6 kg/inhabitant year, followed by Oceania (15.2 kg/inhabitant year),

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North America (12.2 kg/inhabitant year), Latin America (6.6 kg/inhabitant year), Asia (3.7 kg/inhabitant year), and Africa 1.7 kg/inhabitant year) (UNU-IAS, 2015).

More specifically in Brazil, Souza et al. (2016) discussed the sharp increase in amounts of WEEE. It has been estimated that 1.4 million tons of WEEE are produced every year in the country, representing 7.7 kg/inhabitant in the period (UNU-IAS, 2015). For Cucchiella et al. (2015), these values result from fast-paced technological development. But Chi et al. (2011) claim that counterfeit electronic equipment is yet another cause of the increase in WEEE produced across the globe, since enforcement authorities face considerable difficulties to restrain illegal trade.

In the effort to control the generation of WEEE more effectively, the European Union signed a treaty providing for the reuse of electronic and electrical equipment and the development of alternative methods to recycle WEEE. The aim was to reduce the amount of WEEE to 4 kg/inhabitant year, which has been met in most of the signatory countries (Ylä-Mella et al., 2015). The presence of precious metals in WEEE explains the interest in recycling this kind of waste, though these metals also raise management and environmental issues. For example, Tanskanen (2013) investigated the components of Nokia cell phones and discovered the economic potential in recycling these devices. Analysis revealed that the percent composition of cell phones made by that manufacturer includes iron alloys (27%), thermoplastic materials (27%), batteries (15%), copper alloys (11%), glass and ceramic (8%), thermostable plastics and rubber (5%), magnesium alloys (3%), and other materials (4%).

Nevertheless, despite this interesting recycling capacity, high cost of labor and strict environmental regulations stand as hurdles to recycling of WEEE in developed countries. There, this waste is disposed of in landfills or exported to developing countries, where they are recycled (Cobbing, 2008).

The current flow of WEEE between "source" and "destination" countries has been the object of research that discussed the generation, transportation, and fate of this kind of waste (Li et al., 2013). In this regard, China provides interesting examples of the treatment given to WEEE (Zheng et al., 2013). At the same time that the country imports 70% of the world's WEEE, it is one of the main producers of this kind of waste. A more specific, illustrative instance of environmental degradation in China is the city of Guyu, where the inappropriate management of WEEE affected soil, water, and air quality due to the presence of heavy metals, dioxins, and furans (Robinson, 2009). The levels of these substances were well above the maximum acceptable values established by the World Health Organization (WHO), causing the contamination of the food produced in the area. In addition to contamination of the environment, health hazards faced by local population increased, since at least one member of approximately 80% of the families in the region works in WEEE recycling plants under inappropriate conditions (Robinson, 2009). Research also shows that recycling in China is carried out in rural areas, with no appropriate infrastructure. It is important to note that the activity employs roughly 20 million workers in the country (Zheng et al., 2013; Li et al., 2011; Chi et al., 2011).

Compared with developed nations, the main issue to address is that, due to less strict environmental and occupational health regulations, developing countries have to face significant environmental liabilities. In developing economies, labor activities associated with recycling are carried out with little if not no concern at all about health and safety of workers (Cobbing, 2008).

Similarly to the environmental issues around the generation of WEEE, there is little concern about the management, treatment, and fate of this waste in developing nations (Cobbing, 2008). For Carvalho & Silva (2002), direct contact with it poses chemical risks, since the human body may absorb the toxic substances present in these materials. Such risk may increase if the worker sustains skin wounds, which are some of the main contamination routes. The wrong handling and inappropriate fate of WEEE directly influence the extent of the environmental impacts this waste causes, such as the contamination of soil, surface water, and groundwater, with health risks to human populations living around recycling plants (Widmer et al., 2005; Kiddee et al., 2013).

The vast body of environmental standards and regulations in place in Brazil addresses environmental licensing and management of solid waste. Environmental Act 12305, paragraph 33, enforces the adoption of reverse logistics systems by manufacturers, distributors, and points of sale (Brasil, 2010). Similarly, labor regulations in the country are applicable to WEEE management activities. Official order 3219 and the respective enforcement instruments regulate the identification, analysis, and control of hazards (Brasil, 1978). These regulations determine that organizations have to develop, implement, and monitor their own environmental hazard programs.

Several instruments to manage environments hazards have been developed in recent years. One of such tools is the multiple-criteria decision analysis, which has been used in many studies published to date. It is applicable in decision-making involving 1) the selection of sites for disposal banks, treatment, and fate of WEEE (Achillas et al., 2010; Souza et al., 2016; Chaudhary & Vrat, 2017); 2) the definition of the best treatment technologies and disposal sites for solid waste (Madadian et al., 2013); 3) the comparison of materials in the development of sustainable products

(Meyer & Katz, 2016); and 4) performance assessment (Yeh & Xu, 2013; Wibowo & Deng, 2015).

In a study using multiple-criteria decision analysis, Herva & Roca (2013) discussed the advantages of combining tools like ecological footprint, life cycle analysis, and environmental risk assessment. The authors concluded that, used in combination, these techniques shed light on the main factors determining environmental sustainability, such as exhaustion of resources, environmental impact, and human health issues based on more comprehensive assessments of relevant matters in decision-making.

In this scenario, the present study introduces an integrated methodology to evaluate environmental and occupational hazards using the multiple-criteria decision analyses. The aim is to develop a tool to help organizations in decision-making based on the most severe and significant environmental risks.

2 Methodology

Contrasting with industrial, trade, and services sectors, where integrated methodologies are often used to identify and analyze risks, this quantitative case study intends to fill a knowledge gap in WEEE management, where this technique is rarely used.

2.1 Case analysis and selection unit

The WEEE management company evaluated is located in the municipality of Campo Bom, State of Rio Grande do Sul, 57 km away from the state's capital city, Porto Alegre. The company's main activity is the management WEEE, which includes dispatching materials and waste to client companies that specialize in recycling and reuse. At the moment this research was carried out, the organization employed seven workers.

The organization wholesales metallic waste and scrap (class 46.87-7-03 defined in the National List of Economic Activities, CNAE). Regulation NR4 (Brasil, 1978) establishes that the hazard associated with this activity is risk level 3. Figure 1 shows the basic activities of the company considered to determine the risk classes assessed.

We considered as production processes all activities between collection of waste in sources through treatment and fate. Briefly, after collection, the amounts of WEEE transported to the organization are recorded. Next, WEEE is sorted into generic classes such as computer monitors, central processing units, notebooks, cell phones, tablets, DVD equipment, and CD players, for example. The sorting and disassembling processes include (i) the careful segregation of potentially recyclable items from materials requiring appropriate treatment and fate and (ii) the dismantling of compound items like computers and hard drives. Dispatch includes the storage of sorted coproducts that will be transported to partner companies or disposed of. The main materials segregated and sold by the organization are plastics, metals, and circuit boards.

2.2 Identification of environmental hazards, factors, and impacts, and health damage

All processes in the organization were mapped, and all environmental impacts and factors associated with activities were identified based on item 6.1.2 in

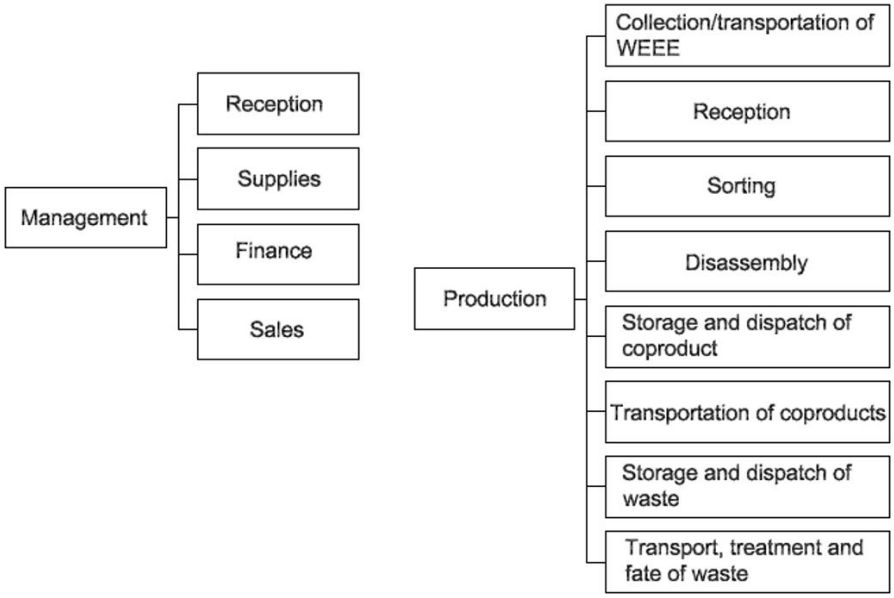

Figure 1. Basic processes carried out in the organization studied.

NBR ISO 14001 (ABNT, 2015). The characterization of activities considered both emergency and routine procedures and events, like consumption, generation, leaks, spilling, and fires.

The identification of health hazards and occupational health problems was carried out for all processes as determined in item 4.3.1a of OHSAS 18001 (BSI, 2007). The following nomenclature was used to describe occupational safety and health (OHS) risks: *accident risks* and *ergonomic*, *physical*, *chemical*, and *biological risks*.

A cause-effect relationship was used to integrate methodologies. Regarding the environment, an aspect was considered a cause, while impact was the main effect on the environment. Regarding occupational health, risk was the cause, while occupational health problem was the effect on workers.

2.3 Evaluation of environmental factors and impacts, and health damage

Four variables were used to evaluate factors and risks: (i) operational situation, (ii) range, (iii) severity, and (iv) frequency (or probability). The methodology adopted was based on documents published by the Environmental Management System of UNISINOS (SGA, 2017) and research carried out by Moraes et al. (2010) and Vasconcelos et al. (2015). The criteria used are described in items 2.3.1, 2.3.2, 2.3.3 and 2.3.4.

A few details about the methodology require clarifying:

a) The methodology was developed taking into account the specific conditions observed in the company, that is, the profile of the user of the methodology;

b) The application and validation of the methodology were conducted by a transdisciplinary team, which included the researchers and the management staff of the organization;

c) The methodology considered the probability and severity of specific risks in the organization, as well as opinions and interpretations from the transdisciplinary team. For this reason, the methodology is subjective in character in function of the composition of the team;

d) This methodology may be adopted by other organizations, though the profile of the new user has to be evaluated prior to implementation.

2.3.1 Operational situation

This criterion represents the relationship of routine, non-routine, and emergency activities with each environmental aspect and/or risk to OHS. Scoring was associated with the descriptions given in Chart 1.

2.3.2 Range

This criterion indicates the potential reach of environmental impact and/or the degree of medical assistance required for affected workers. This criterion is defined based on the descriptions given in Chart 2.

2.3.3 Severity

Severity represents the intensity of the change and the reversible character of the associated impact or risk to OHS. Chart 3 lists the severity criteria.

2.3.4 Frequency

This criterion describes the periodicity or probability of environmental aspects and OHS risks. Scoring was based on first- and second-hand data collected, including: 1) the frequency in which natural resources are used and waste is produced; 2) history of work accidents and emergencies; 3) frequency of exposure to environmental risks (*accident risks* and *physical*, *chemical*, *biological*, and *ergonomic risks*). Chart 4 shows the probability criteria used.

2.4 Prioritization of environmental aspects and impacts and of health hazards and risks

The priority of risks to the environment and OHS was determined using Equation 1:

$$GR = \sum(SO, ABR, SEV, FREQ) \quad (1)$$

where: *GR* = risk level; *SO* = operational situation; *ABR* = range; *SEV* = severity; *FREQ* = frequency.

Chart 5 shows the risk levels and priorities of action in each case. Environments aspects and impacts and significant risks to OHS (moderate and critical) were included.

Chart 1. Operational situation criteria.

Score	Description
Normal (0)	Expected situations associated with operational routine (electrical energy use).
Abnormal (5)	Non-routine events such as risk of slight/intermediate damage to the environment and/or health of workers (small leaks).
Emergency (10)	Unexpected events that may cause severe damage to the environment and/or health of workers (fire, leaks, spills, explosion).

Chart 2. Range criteria.

Score	Description	
	Environment	**Occupational safety and health**
Local (1)	Local impact (small leaks).	Paramedic care and/or emergency care given by the organization's own staff (dizziness, low blood pressure, back pain, limb twisting).
Near (2)	Impact spreads beyond the event site and is restricted to the organization's property boundaries (starting of a fire).	Transportation to a hospital in a conventional car (skin wounds, minor fractures).
Intermediate (3)	Impact within a 100-km radius around the organization's property boundaries (contamination due to the inappropriate fate of waste).	Transport to a hospital in an ambulance (amputations, severe intoxication, lesions on the back caused by falls).
Distant (4)	Impact beyond a 100-km radius around the organization's property boundaries (electrical energy consumption, transportation of hazardous waste to another state in the country).	Actions requiring the transportation of victims of the accident to another state in the country or another country (severe lesions in the respiratory system, mucosae, and skin, occupational cancer).

Chart 3. Severity criteria.

Score	Description	
	Environment	**Occupational safety and health**
Mild (1)	Easily revertible low-cost impacts (small oil leaks in the company).	Occupational health problems not requiring sick leave (dizziness, mild headaches).
Moderate (2)	Impacts within the organization's property boundaries mitigated or recovered using the organization's own structure (starting of a fire).	Treatable injuries and/or occupational health problems that can be treated and require sick leave under 15 days.
Serious (3)	Impacts within the organization's property boundaries that can be mitigated using in-house and external structures (contamination with Class I waste spills).	Injuries and severe occupational health problems whose effects may be reverted or that may heal requiring sick leave over 15 days.
Severe (4)	Severe environmental impacts that require outside structure to be recovered or mitigated (large fires).	Casualties and high-morbidity, severe injuries and occupational diseases with sequelae such as occupational health, acute fatal diseases, and systemic diseases.

Chart 4. Probability criteria.

Score	Criteria
Extremely remote (1)	Event that never occurs in a company or whose probability to occur is one in over one year (fires, deaths).
Remote (2)	Event that may occur at least once a year in the organization (accidents requiring sick leave over 15 days).
Possible (3)	Event that may occur at least once a month in the organization (dispatch of Class I waste to be treated in another organization or to disposal).
Frequent (4)	Event that may occur at least once a week in the organization (fuel consumption).
Very frequent (5)	Event that may occur at least once a day in the organization (electrical energy consumption, inappropriate posture of worker).

Chart 5. Risk levels and priorities of action.

Score	Risk levels	Priorities of action
$GR \geq 15$	Critical (Significant)	Priority (1), high priority actions (6 months)
$9 < GR < 15$	Moderate (Significant)	Priority (2) intermediate priority actions (12 months).
$GR \leq 9$	Negligible (Not significant)	Priority (3) non-priority actions (24 months)

3 Results and discussion

The results obtained are shown and discussed as follows: 1) results of the survey of environmental aspects and impacts; 2) results of the survey of occupational health damage and hazards; 3) the correlation between risk management and OHS.

3.1 Environmental aspects and impacts generated by processes

The environmental aspects and impacts generated by the activities and processes carried out in the organization were used to construct risk matrices (as shown in Chart 6).

In total, nine matrices were prepared for the process described in Figure 1. Chart 7 presents the numbers of aspects and impacts identified, and the analysis of significance.

Of the total number of aspects listed in Chart 7, 17 were considered critical, requiring high priority of action. All were identified as emergency operational situations, like fire, spilling due to traffic accident, and atmospheric emissions due to a broken monitor.

Considering significant aspects classified as requiring intermediate priority of action, the list includes consumption of electrical energy, generation of WEEE and atmospheric emissions due to the use of fuel like diesel oil.

Although Chart 7 shows that most significant environmental aspects (in percent values) are associated with production processes (sorting and disassembly, where 50% of the environmental aspects are significant), management reached score 386, which is the maximum score observed (Figure 2), considering the sum of all risk levels (GR) obtained using Equation 1. This is due to the wide variety of environmental aspects that may occur. Although they are not considered to cause serious impact by comparison with production processes, the aspects identified in management included consumption electrical energy consumption, generation of WEEE as well as ink cartridges, plastics, paper, water, fluorescent bulbs, fuel, lubricant oil, tires and parts (in the use of vehicles), and waste generation, effluents, and emissions. Besides that, impacts associated with potential emergencies such as accidents involving vehicles, fuel spilling, and fires were identified and analyzed. Some of these aspects, mainly those associated with vehicles, do not take place in the production process.

Similarly, the processes associated with transportation of WEEE and/or coproducts also scored high values. This confirms that one of the critical points in the management of environmental risks includes road transportation, which is the main freight system used in Brazil. The transportation of products, coproducts, and waste also stood out in the survey of environmental aspects and impacts in a study about life cycle analysis published by Moraes et al. (2010).

The results of risk levels (Equation 1) show that generation of WEEE represents 38% (1,022 points) of the environmental aspects in the organization, followed by fire (28%, 740 points), consumption (19%, 519 points), spilling and leaking (10%, 258 points), and emissions (5%, 126 points). This analysis also

Chart 6. Risk matrix of the identification and analysis of environmental aspects and impacts in the disassembly sector of the organization.

Characterization		Analysis and significance						
Aspect / Risk to OHS	**Impact / Damage**	**Operational situation**	**Range**	**Severity**	**Frequency**	**Risk level**	**Priority**	**Significance**
Electrical energy consumption	Diminished availability of non-renewable or scarce natural resources	0	4	5	3	12	2	S
Generation of hazardous waste (cutting disks, batteries)	Hydrological contamination	0	3	5	3	11	2	S
	Soil contamination	0	3	5	3	11	2	S
Generation of WEEE	Hydrological contamination	0	3	5	3	11	2	S
	Soil contamination	0	3	5	3	11	2	S
Fire	Changes in air quality	10	2	1	3	16	1	S
	Hydrological contamination	10	2	1	3	16	1	S
	Soil contamination	10	2	1	3	16	1	S
	Greenhouse effect – CO_2 emissions	10	2	1	3	16	1	S
	Risk to physical facilities	10	2	1	3	16	1	S
Sum of risk level values for this section of the matrix						136 points		

Chart 7. Analysis of environmental aspects and impacts for the processes carried out in the organization.

Process	Environmental aspects identified	Significant environmental aspects
Management	26	5 (19%)
Transfer of WEEE to Reception	19	5 (26%)
Reception	16	6 (38%)
Sorting	10	5 (50%)
Disassembly	12	6 (50%)
Storage and dispatch of coproduct	14	5 (36%)
Storage and dispatch of waste	14	5 (36%)
Transportation of coproducts	18	3 (17%)
Storage, treatment, and fate of waste	19	4 (21%)
Total	148	44 (30%)

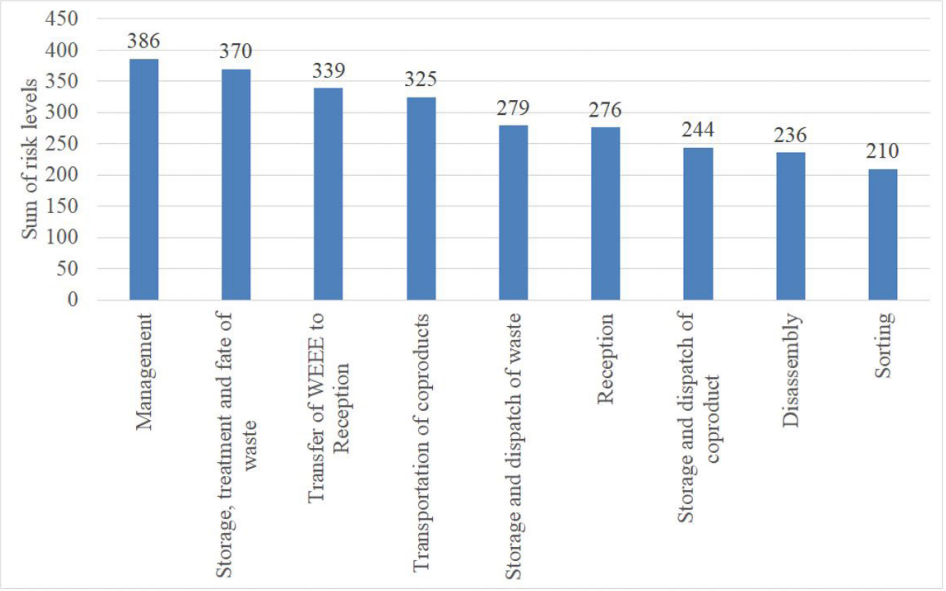

Figure 2. Scores obtained using the sum of risk classes (environmental aspects and impacts) fore each production process.

confirmed the importance of controlling aspects associated with the generation of waste and effluents in the industry sector considered in this study. These environmental impacts include change in soil and water quality, for example, which were also discussed in the research carried out by Robinson (2009).

3.2 Risks and damage associated with processes

Nine matrices were constructed for the processes. Chart 8 illustrates the section of the matrix constructed for risks in disassembly.

Chart 9 shows the results obtained considering all analyses of occupational risks for each process.

The process with the highest number of significant, high-priority risks was disassembly. Of the 15 risks identified, six (40%) were classified as critical. All risks in disassembly were classified as *accident risks*: fire, lightning, electrical shock, work with sharp, pointed objects, work with heavy objects, sharps hauled at eyes.

Figure 3 shows the sum of risk levels calculated adding all risk level values using Equation 1 for each process. Disassembly scored the highest number of points, demonstrating the potential risks faced by workers in that activity.

Production processes scored the highest points (Figure 3). Workers allotted to these processes are exposed to hazards such as cuts, crushing, falls from various heights, hauling of sharps at the body and eyes, and electric shock. These workers are also exposed to *physical* (noise and vibration) and *chemical risks* (contact with contaminants and inhalation of toxic gases from broken monitors. Ergonomic risks, which are associated with posture and weight, came last. This amount of risks associated with WEEE explains the concern about health of workers, as discussed by

Chart 8. Section of the risk matrix prepared to identify and analyze risks to OHS in disassembly.

Identification		Analysis and significance						
Aspect / risk to OHS	**Impact / damage**	**Operational situation**	**Range**	**Severity**	**Frequency**	**Risk level**	**Priority**	**Significance**
Accident risk: fire	Burns, death	10	3	0	4	17	1	S
Accident risk: work with sharp, cutting objects	Surface and deep wounds	5	3	5	3	16	1	S
Accident risk: objects hauled at eyes	Cuts, eye lesions, blindness	5	3	5	3	16	1	S
Ergonomic risk: weight lift	Muscle distension, low back pain	0	2	5	2	9	3	Non-significant
Chemical risk: exposure to toxic gases (broken monitor or other WEEE)	Respiratory problems	5	2	2	3	12	2	Significant
Chemical risk: direct contact with contaminated WEEE	Dermatitis, rash	0	2	5	3	10	2	S
Sum of risk levels for this section of the matrix						80 points		

Chart 9. Analysis of risks and damage to occupational health for processes.

Process	Risks identified	Significant risks
Management	9	6 (67%)
Transportation of WEEE to Reception	12	7 (58%)
Reception	15	9 (60%)
Sorting	15	9 (60%)
Disassembly	16	10 (63%)
Storage and dispatch of coproduct	15	9 (60%)
Storage and dispatch of waste	15	10 (67%)
Transportation of coproducts	12	7 (58%)
Transport, treatment, and fate of waste	12	7 (58%)
Total	121	74 (61%)

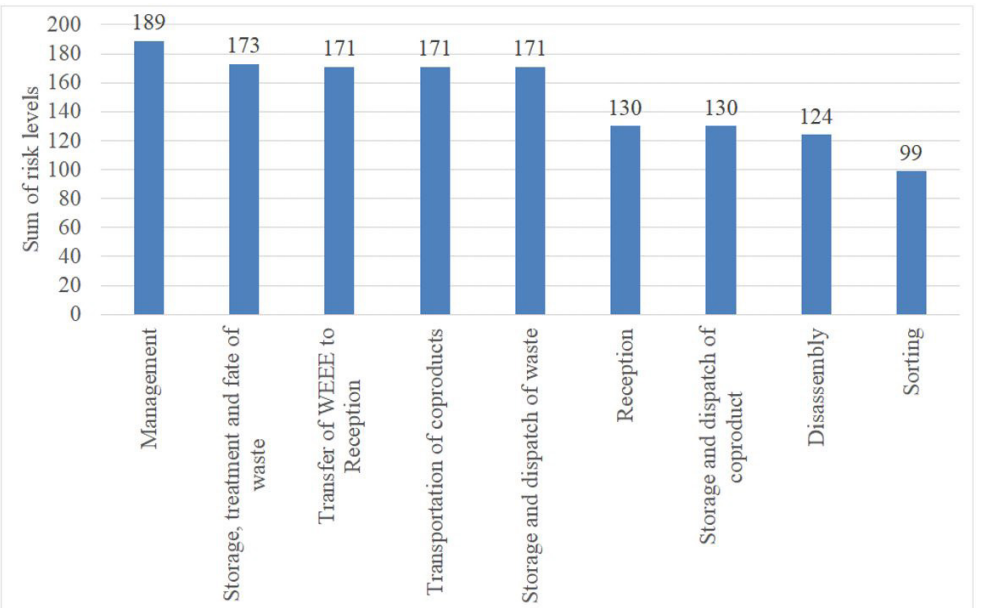

Figure 3. Scores obtained using the sum of risk level values (risk to OHS) for each production process identified.

Cobbing (2008), Carvalho & Silva (2002), Robinson (2009), Zheng et al. (2013), Li et al. (2011), and Chi et al. (2011).

The results obtained also indicate the importance of combined risks (Carvalho & Silva, 2002). WEEE may include sharps, and it is possible that the contact with heavy metals, which are usually also found in this kind of waste, may increase occupational health hazards due to the risk of contamination. Therefore, the combination of risks justifies the adoption of control measures in the tasks carried out in the management of WEEE.

Also, the evaluation based on risk level of OHS in all production processes showed that the highest sum of risk levels was reached for the category *accident risks* (64%, 394 points), followed by *ergonomic* (14%, 196), *chemical* (9%, 129 points), and *physical risks* (7%, 99 points).

3.3 Correlation between environmental risks and OHS

The correlation between the integrated mapping of environmental risks and OHS indicates that the highest significant risk level values were observed for sorting and disassembly (Chart 7 and 9). This may be explained based on the fact that these activities involve more intense handling of waste by workers, meaning that they have to use manual tools and equipment more often. In addition, this activity demands special attention in the management of WEEE due to the segregation of potentially recyclable materials.

The main environmental impacts in sorting and disassembly caused by emergency aspects were the change in air quality (atmospheric emissions due to the breaking of monitors), changes in soil, water, and air (potential fires caused by electrical problems). Other environment impacts generated by routine aspects were also observed, like the reduced availability of natural resources (consumption of electrical energy) and changes in soil and water quality (generation of class I solid waste – hazardous).

The environmental control measures aimed to reduce the environmental impacts discussed above and in research published by Robinson (2009), Cobbing (2008), Widmer et al. (2005) and Kiddee et al. (2013) include: 1) the use of a protection hood to disassemble monitors; 2) the compliance with an official standard used in Brazil (NR 10, Brasil, 1978), which regulates electrical installation, specification sheets, one-line diagrams, specification records, staff training, and other aspects; 3) use of renewable energy sources such as solar cells; 4) and the development and implementation of a solid waste management plan specifying all required steps. These control measures have to address the generation of waste, storage requirements, collection, transportation, and, mainly, treatment and fate technologies for solid waste class I.

The main aspects in impacts that cause occupational health problems include: 1) fire hazard and lightning (burns and death); 2) *accident risks* such as electric shock (burns, death), accidents with sharps (skin wounds, gashes) and heavy objects (cuts, crushing of limbs), hauling of sharps at the eyes (eye lesion, blindness); and 3) *chemical risks* such as exposure to toxic gases from broken monitors (respiratory problems) and direct contact with contaminated materials (dermatitis, rash).

The occupational hazards sorting and disassembly of WEEE in the organization are cause for concern. There is no specific survey about work accidents involving WEEE in Brazil. However, the last survey for all economic activities showed that there were 722,474 work accidents in the country in 2014, which included typical accidents, traffic accidents, and diseases associated with work (Brasil, 2015). Records also reveal that there were 10,259 work accidents with solid waste (which happened during collection, treatment, final disposal, recovery of materials, and decontamination) in the same year, 134 of which caused a disabling condition and 36 led to death.

The high number and severity of accidents in WEEE management organizations require efficient tools to identify, analyze, and control occupational risks. For the category *accident risks*, which includes the potential to cause occupational accidents and/or diseases and was the most severe observed in this research, we observed the immediate need to adopt control measures to protect workers. In addition to managerial efforts like risk mapping, actions like the use of hoods as protection during equipment operation, staff training, and use of personal protective equipment (PPE) have to be adopted.

In *chemical risks*, which are caused by exposure to gases released when monitors are broken, for example, the use of specific equipment for each activity (to control the environmental aspect atmospheric emissions) may significantly reduce this class or risk. Concerning the direct contact of hands with WEEE, which was discussed by Carvalho & Silva (2002), a possible short-term solution would be the use of PPE, such as waterproof gloves resistant to sharps.

An integrated management control system that considers environmental risks and OHS hazards that are classified as critical is routinely adopted in the emergency cases. This control system should also include the selection of potential scenarios, sequence

of required procedures, reports, well trained staff, and simulation response exercises.

The results of the present study also point to the need to define controls associated with the transportation of products, coproducts, and waste. The importance of this control was also discussed by Moraes et al. (2010).

The training and qualification of transportation staff is another requirement in the scenarios identified in the emergency situations discussed. Training and qualification include (i) the control of official documents (authorization to transport hazardous products, environmental licenses, correct training of drivers, signage of vehicles, etc.); (ii) the maintenance of fleet of vehicles (schedule and record of preventive and corrective maintenance); and (iii) the inspection of loading and unloading procedures (checklists of environmental requirements and OHS needs such as the existence and expiration dates of fire extinguishers, condition of seatbelts, tires, signage, valves, PPE, etc.).

4 Final considerations

Risk management is an essential tool in the elimination or minimization of uncertainties in an organization, defining priorities of the main threats and opportunities, and may be used by managers in decision-making processes. In this scenario, organizations are aware of the importance of developing and implementing an integrated risk assessment program.

The present study developed and tested an integrated methodology of environmental risk management in a WEEE management company considering environmental risks and OHS hazards. The results afforded to determine the priority of risks, helping managers in decision-making processes.

The main conclusions of this study are:

- Sorting and disassembly were the production processes with the highest risk level values for risks classified as significant;
- The number of significant environmental aspects associated with transportation of products, coproducts, and waste causes concern;
- Environmental aspects associated with fires and spills or leaks were classified as serious;
- The category *accident risk* stood out in the survey of risk and health problems. When risk level values of all production processes are added, we observed that this group reached the highest score (69%, 934 points). These risks include fire hazards, lightning, electric shock, work with sharps, work with heavy objects, the hauling of sharps at the eyes;
- The main *chemical risks* were exposure to toxic gases from broken monitors (respiratory problems) and manual contact with contaminated material (dermatitis and rash).
- The main control methods for the identified risks are:
- Disassembly of monitors using equipment installed in a protective hood;
- Electrical installations in compliance with Regulation NR4 (Brasil, 1978);
- Use of renewable energy sources, like solar cells;
- Development and implementation of a management plan for dangerous solid hazards;
- Use of PPE in sorting and disassembly, especially waterproof gloves resistant to sharps;
- Appropriate staff training covering identification of hazards, use of PPE, and prevention of work accidents;
- Identification and correct approach to emergencies;
- Qualification of suppliers of transportation services for products, coproducts, and waste.

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