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IMPLANTATION OF A PRINTED CIRCUIT BOARD RECYCLING INDUSTRY IN BRAZIL: ENVIRONMENTAL ASPECTS

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ABSTRACT: Besides the expressive e-waste generation, Brazil has not specialized industry to perform the printed circuit boards (PCB) recycling. Usually, after dismantling process of end-of-life equipment's such as laptops, desktops, smartphones and tablets, the PCB are removed and mechanically processed. Then, the crushed PCB are recycled in foreign industries. This paper presents a discussion regard the environmental elements considering the installation of PCB recycling industry in Brazil and potential locations based on environmental licensing criteria observed in the legislation and also studies regarding environmental feasibility of recycling industries. An adapted Leopold Matrix (Leopold, 1971) was applied. The environmental evaluation was carried out by dividing the impacts into little or very significant, and then the impacts that would be minimized with the implementation of the PCB recycling industry inside Waste Treatment Centers (WTC) as potential locations for comparison purposes. The results of environmental evaluation indicated three most relevant environmental impacts related to PCB recycling industry installation: changes in soil quality, changes in the quality of water resources and the occurrence of accidents. Through the estimation of generation and collection of e-waste, the gross economic potential of the reverse logistics chain of PCB collected in Brazil was calculated, reaching up to almost 4 trillion reais in the year 2025. The Waste Treatment Centers were considered as potential locations to PCB recycling industries due to minimization of some impacts, such as impacts of loss of vegetation cover, interferences on cultural and natural heritage, interferences in contaminated areas and visual impact, since the WTC is already in a place that previously meets all these requirements. Although a hypothetical industry was considered in the environmental evaluation, the main goal of this paper was promoted an initial discussion regarding the importance of national recycling industries being created in order to allow the full e-waste reverse logistic chain in Brazil.

Keywords: E-waste. Printed circuit boards. Recycling. Reverse logistic. Environmental evaluation.

1. INTRODUCTION

Waste electrical and electronic equipment (WEEE) is the category of waste that has the highest growth worldwide (LIU et al., 2020) and, in 2021, it is estimated that the planet has a generation of about 52.2 million metric tons (NEEDHIDASAN, AGARWAL, 2020).

About 85% of Brazilians keep e-waste in their homes (CETEM, 2018) and the reason for this high retention rate may be related to the lack of knowledge of where or how to dispose it, difficulty in transporting the e-waste to the point of disposal and lack of awareness of the population.

Law nº. 12305 / 2010, which institutes the National Solid Waste Policy (PNRS), established the order of priorities for actions that should be used for the proper management and management of waste, namely: non-generation, reduction, reuse, recycling, treatment of solid waste and final environmentally correct disposal of waste. Among the options for final disposal, recycling of electronic waste stands out for minimizing environmental impacts by preventing it from being deposited in landfills, in addition to reducing the use of natural resources in manufacturing processes and, when there is no informality in recycling, any damage to to the recyclers' health can also be minimized (CAETANO et al., 2019).

Considering all of the varieties of e-waste, there is commonly the presence of Printed Circuit Boards (PCB). They're components of electronic waste that have a greater added value, since they have more than 60 different metals, including copper, gold, silver, aluminium and iron. It makes it a notable economic motivator for recycling. On the other hand, heavy metals encourage recycling by the environmental aspect (GÁMEZ, 2019; KUMAR, RAWAT, 2017; EPA, 2015).

However, despite environmental, legal and economic issues favouring recycling of e-waste, Brazil still needs to structure the electronic waste recycling chain by installing recycling companies to promote the recovery of the materials that make up the e-waste, as PCB recycling treatments are expensive and, in Brazil, there are no companies that carry out this type of treatment.

As shown above, the analysis of the most important environmental elements for the installation of a PCB recycling company was identified as a research gap. It is known that the viability of an enterprise is analyzed under the technical, economic and environmental dimension, however, the present study focused on the environmental segment.

2. METHODOLOGY

2.1 Stage 1 – Identification of potential locations for implantation of the Printed Circuit Board recycling company

In Brazil, one of the possible and conventional methods of disposing of the e-waste is the landfill (MANÉO et al., 2019), that is, the e-wastes that would be treated by the recycling plant arrives at places that have/are a landfill, such as an example, a Waste Treatment Center (WTC).

According to NBR 10.157/1987 (ABNT, 1987), "to ensure the proper design, installation and operation of a hazardous waste landfill, requirements are established regarding the location, segregation and analysis of waste, monitoring, inspection, the closing of the facility and staff training." (ABNT, 1987, p.3). In this standard, some parameters necessary for the ideal location of a hazardous waste landfill were identified, such as protection of underground and surface water resources, site topography, liquid waste disposal, gaseous emissions, distance from population centres, emergency plan, and others (ABNT, 1987).

For a WTC to be in full operation of its activities, it is understood that it meets all the requirements provided for in the current legislation. Therefore, it is possible to admit that the company under study could be allocated within the available area of a WTC, directing the identification of the potential location. Such location doesn't exclude the fact that the company mentioned must adhere to all the requirements for its implementation.

Thus, for the identification of potential locations for the installation of a PCB recycling company, this work considered existing Waste Treatment Centers (WTC) that have available areas, since these locations comply with the technical and legal requirements that facilitate some aspects for the elaboration of the project, implantation and operation of a recycling company.

Since the implantation of a recycling company is within a WTC, the advantage is that the raw material arrives at the site. In addition, it is noted that there would be a reduction in the costs of transporting the waste generated by the recycling plant, which will be discarded within the WTC itself, and also a reduction in the emitted gases and road traffic (PAPADOPOULOS et al., 2020).

Another advantage of this location is that a WTC already has at least a minimum distance indicated by organs regulatory agencies between the company and the population affected by the impacts caused, bringing health and safety to the surrounding communities. It is understood, therefore, that the implementation of the recycling company within the area of a WTC causes the reduction of environmental impacts and financial expenses (ABNT, 1987).

Thus, for a city/locality that doesn't have a WTC, it will be more costly to set up an e-waste recycling company, as it will need to comply with all legal requirements concerning the project, except for the other advantages mentioned above. As said above, the indication for locations that don't have a WTC is to conduct a survey of the presence of WTC in the nearest communities and, thus, to analyze the cost-benefit of the distance and compliments to be carried out.

In this work, we consider the most significant environmental elements for the implementation of an e-waste recycling company but there is still an economic and technical part, which is not part of the scope. Thus, there may be examples of locations with the absence of a WTC but in need of investment for it or that have recycling companies for other materials in a short distance, with an infrastructure and technical manpower in a certain part. Consequently, the analysis of the ideal place for the implantation of an e-waste recycling company needs to consider not only the environmental viability but also the technical, economic and social scope, among others.

2.2 Stage 2 – Survey of the relevant environmental impacts for the implantation of the Printed Circuit Board recycling company

At this stage, the impacts related to the recycling process and the installation of the recycling company relevant to the environmental impact assessment were raised from a bibliographic review. The set of impacts considered was the result of joining the Manual for Elaboration of Environmental Studies of the Environmental Company of the State of São Paulo (CETESB) with the impacts contained in Sánchez's book, Environmental Impact Assessment - Concept and Methods (CETESB, 2014; SÁNCHEZ, 2013).

Unlike many projects, an e-waste recycling company does not have pre-defined impact references for evaluation, due to the scarcity of this industry. Thus, projects from different areas (mining, waste landfill, dam and highway project) were joined, drawing up a list of likely impacts to the proposed study, and are shown in Table 1.

Therefore, the set of environmental impacts that were analyzed is concluded.

Table 1. List of potential impacts selected for the planning, implementation and operation steps.

Impacts on the Planning Stage	Impacts on the Implementation Stage	Impacts on the Implementation / Operation Stage	Impacts on the Operation Stage
Generation of expectations in the population	Water resource interference	Unleashing and intensifying processes of superficial dynamics	Changes in the quality of water resources
	Generation of demolition waste	Interference in contaminated areas	Changes in soil quality
	Loss of vegetation cover	Impacts on fauna	Changes in noise levels
	Interference in protected areas	Interference in infrastructure and public services	Changes in air quality
	Interference with cultural and natural heritage	Impacts on road infrastructure and traffic	Public health risks
		Increase in income	Occurrence of accidents
			Odour

	Visual impact

Source: Adaptated from CETESB, 2014 and SÁNCHEZ, 2013.

2.3 Stage 3 – Definition of a recycling route for Printed Circuit Boards

A less expensive and alternative bio-hydrometallurgical route was considered in the present work, being the combination of mechanical processes for the preliminary treatment of PCB, bioleaching for copper recovery, chemical leaching for recovery of precious metals and electrochemical precipitation for recovery of metals. An alternative recycling route involving bioleaching was considered, in comparison to the traditionally applied methods (pyrometallurgical), due to the lower investment cost, simplicity of the installations, less environmental impact and less energy consumption (ANNAMALAI, GURUMURTHY, 2019).

The main disadvantages of bioleaching are process time and factor compatibility. The copper recovery process through bioleaching, which can take up to 15 days, can be caused by the absence of a favourable microbial growth environment and optimized parameters or factors that govern the process. Bioleaching factors include biotic factors, such as the type of microbial culture and its concentration and abiotic factors such as pH, temperature, aeration and concentration of nutrients. In addition, specialized execution is necessary to control these parameters, the right choice of the type of microorganism and laboratory manipulation of the process (ARYA, KUMAR, 2020; MOREIRA, 2019; HAIT, PRIYA, 2017).

2.4 Stage 4 – Analysis of the most significant elements for Environmental feasibility of implementing a Printed Circuit Board recycling company

For the evaluation of impacts, the method of interaction matrices was adapted, which aims to relate the action/activity with the factor, being efficient in the identification of direct impacts. The method has the advantages of low cost and ease, addressing quantitative and qualitative data and can be adapted for various proposals. On the other hand, it has as a disadvantage the lack of factors: verification of indirect effects and probability of occurrence of impacts (GEBLER, LONGHI, 2018).

Elaborated in 1971, the Leopold Matrix is founded on a list of 100 actions/activities with potential for environmental impact and 88 environmental factors, being one of the most applied matrices worldwide (LEOPOLD et al., 1971; FINUCCI, 2010). A matrix does not necessarily need to assign numerical values for each impact, in reality, the matrix is composed of two lists that are ordered in the form of lines and columns. Based on this, it is possible to analyze whether the impact in focus is negative or positive. As this method can be applied to different projects, the result of the significance of each impact is relative (HIGUCHI, 2019).

Based on the original matrix of Leopold (1971), on the knowledge of some matrices adapted by Sánchez and impacts addressed by CETESB (2014), and an adapted matrix was elaborated that portrayed, in the most equivalent way possible, the relationship between the actions of an e-waste business and the impacts caused by it, whether it’s positive or negative.

Thus, the elaboration of the adapted matrix took place in four macro stages. Initially, potential impacts and activities and services that could be related to the actions of the recycling company were pointed out, concerning the stages of planning, implementation and operation.

In the second stage, each impact was crossed with at least one activity/service, and this associated cell (impact-activity relationship) received a classification of very or little significant, represented in the table through the symbols “O” and “X”, respectively. Then, a value was assigned to the titles of very significant and of little significant, with values 3 and 2, respectively. With a designated number, it is possible to perform the sum of each line of impacts, in which the total value was assigned to significance. Therefore, the most relevant impacts will be those that obtained the highest total values, that is, the greatest significance.

The last step was based on the consideration that the recycling company should be located in an area attached to a WTC, given that the magnitude of some impacts can be assessed as less significant if the project is located within this advantageous location. Therefore, a new analysis was made based on this consideration. Thus, in addition to the cell marked with a symbol, the minimization of impacts due to the company's location was highlighted in the spreadsheet with the cell filled in grey in its background. For a total of significance with the minimized impacts, the value of -1 is assigned to these cells.

Consequently, there are two significant results for each impact, one considering the implementation of the recycling company within the WTC and the other taking into account the implementation in a common area. Therefore, the assessment of environmental impacts and their scope with the implementation of the recycling company considered the legal, institutional and technical-scientific procedures, which aimed to characterize and identify the potential impacts on the future installation of the recycling company in an area attached to the WTC to predict the importance of these impacts.

The last column, “Significance”, refers to the results obtained regarding the analysis of the entire matrix. In the “Symbols” column, each symbol was added per impact line, with the sum of the lines in the “Symbols” column assigned to the “Total / No WTC” column. The column “With WTC” is the consideration of the recycling company to be within a WTC, its total is less than or equal to the Total / Without CTR because it is added -1 in the impact-activity relations minimized by this factor.

After the sums and the analysis of the results, a classification of the significance of the impacts of a company located in a location outside a WTC was performed using the scale described in Table 2, in which it is possible to group the impacts into three types of relevance.

Table 2. Classification of the significance of impacts.

Relevance	Scale
Low	<9
Medium	9-15
High	>15

3. RESULTS AND DISCUSSION

Based on the selection of the environmental impacts and activities of a PCB recycling company, the Leopold matrix was adapted for this research and the analysis presented in Figure 1 was carried out.

Stage	Impact	Disclosure of the project	Implementation of the construction site	Displacement of machines	Excavation for land preparation	Job creation	Vegetation removal	Plant curtain implantation	Construction of the company's infrastructure	Transport of e-waste/inputs	Disposal of e-waste	Disassembly of e-waste	Mechanical process	Bioleaching process	Electrochemical precipitation	Disposal of tailings	Effluent generation	Maintenance of tanks	Symbols ●	Symbols ✖	TOTAL W/ WTC	TOTAL W/O WTC
Planning	Generation of expectations in the population	●				●													6	0	6	6
Implantation	Water resource interference				✖		●	✖	✖										3	6	9	5
	Generation of demolition waste		●						●										6	0	6	6
	Loss of vegetation cover				✖		●		✖										3	4	7	4
	Interference in protected areas				✖		●	✖	✖										3	6	9	6
	Interference with cultural and natural heritage					●	●	✖											6	2	8	7
Implantation/ Operation	Unleashing and intensifying processes of superficial dynamics		✖	✖	●			●	✖	●									9	6	15	13
	Interference in contaminated areas		✖					✖	✖										0	6	6	3
	Impacts on fauna				✖		●	●	✖	✖						●			9	6	15	11
	Interference in infrastructure and public services		✖	✖						●									3	4	7	6
	Impacts on road infrastructure and traffic		✖	●						●									6	2	8	9
	Increase in income					●													3	0	3	3
Operation	Changes in the quality of water resources										✖			●	●	●	●	✖	12	4	16	14
	Changes in soil quality										✖			●	●	●	●	✖	12	4	16	14
	Changes in noise levels									●		✖	●						6	2	8	7
	Changes in air quality									●			✖	●		●			9	2	11	9
	Electric power consumption													✖	●		●	✖	6	4	10	10
	Occurrence of accidents									●		✖	✖	●	●	●	●	✖	15	6	21	18
	Odour															●	●	●	9	0	9	6
	Visual Impact									✖						✖			0	4	4	2

KEY:

Assigned value	Representation		Relevance	Scale
3	●	Very significant	Low	<9
2	✖	Significant low	Medium	9-15
-1	(grey)	Minimizing the impact of implementing the company within the WTC	High	>15

Figure 1. Leopold matrix adapted to assess the environmental impacts of a PCB recycling company.

Thus, 20 impacts and 17 services/activities were listed for analysis, generating 340 interactions in the adapted matrix. Of the total impacts, 10 were of low relevance, 7 of medium relevance and 3 of high relevance.

The impacts of low relevance were: generation of expectations in the population, generation of demolition residues, loss of vegetation cover, interferences on the cultural and natural heritage, interferences in contaminated areas, interferences in infrastructure and public services, impacts in the road infrastructure and in traffic, increased income, changes in noise levels and visual impact.

Many of these impacts had their impact-activity interactions minimized by the implementation of the recycling company within a WTC, for example in the impacts of the loss of vegetation cover, interferences on cultural and natural heritage, interferences in contaminated areas and visual impact in which it is admitted that WTC is already implemented in a location that previously meets all of these requirements.

The impacts of generating expectations on the population and increased income are considered positive since, in the disclosure phase of the implementation of the company, there is the possibility of new jobs, the services provided by the recycler and the possible sales related to the operation of the recycling company. When the company is already operating, many stakeholders are involved in the whole process, increasing the income of the community. For example, when contracting the construction of the company's infrastructure, purchasing third parties of the inputs involved in the recycling process, in the contract for new employees, among others.

The impacts of medium relevance are triggering and intensification of processes of surface dynamics, interferences in water resources, interferences in protected areas, impacts on fauna, changes in air quality, consumption of electricity and odour. Of these, interferences in water resources and odour are impacts that have had all their impact-activity relationships minimized by the implementation of the company within a WTC. This is due to the environmental licensing previously carried out by the WTC itself, which include the water resources located there, and the distance between the WTC and the population, minimizing the effect of the odour impact on the community.

Even with the formal recycling of e-waste, the change in air quality is a factor that is not minimized like the change in water resources, for example. In the mechanical process of e-waste recycling, particulate material that can be airborne containing flame retardants and heavy metals is generated (GRAVEL et al., 2019). Gravel et al. (2019) proposes as a remediation measure better ventilation and suction near work tables and dust-generating machines to reduce the levels of particulate material. Anyway, the pyrometallurgical process generates more emissions of gases and dust, in addition to the greater consumption of electric energy, when compared to the bio hydrometallurgical process. (FOMCHENKO, MURAVYOV, 2018).

Finally, the highly relevant impacts are changes in the quality of water resources, changes in soil quality and the occurrence of accidents.

As the entire ecosystem is connected, the occurrence of an accident within the recycling process of the e-waste, a highly hazardous waste, can cause changes in soil and water quality. Environmental biogeochemical flows are driven by processes such as deposition in the atmosphere (dry/wet), leaching, adsorption, complexation (through which heavy metals and by-products can be formed), absorption by the plant, degradation (chemical/biological) and volatilization. (LI et al., 2020). In addition, the environmental fate of the pollutants depends on the physical-chemical, geomorphological and pedological properties of the environment (LI et al., 2020). Informal recycling is a factor that potentiates all of the aforementioned effects, as it uses primitive e-waste recycling techniques without any security, either for those who perform such practice, or for the environment that will be affected by the pollutants generated (KIM et al., 2020).

As shown in the spreadsheet, the occurrence of accidents was the most significant impact of this research, being justified by the fact that the e-waste is a hazardous waste. Thus, a minimum accident can confer high severity.

To reduce the risk/occurrence of environmental accidents in the e-waste recycling process, preventive measures are necessary to identify and manage occupational risks. Among the administrative measures, there are risk structuring, choice of potential scenarios, execution of simulations related to the identified scenarios and exposure of emergencies. (CAETANO et al., 2019). However, practical actions are also necessary as prescribed in Group 5 of Regulatory Norm (NR) 9, which deals with accident risks, where the reverse is mitigating measures: adequate physical arrangement, properly protected machinery and equipment, adequate tools and in perfect condition, adequate lighting of the workplace, regularized electricity, mitigation measures for fires and explosions such as adequacy of fire extinguisher, adequate storage of inputs and e-waste, among other situations that can contribute to reducing the occurrence of accidents.

In addition, precaution in e-waste recycling activities and services to mitigate environmental risks is directly related to the worker. According to the latest Statistical Yearbook of Accidents at Work (AEAT, 2017), in 2017, there were 549.405 typical work accidents, commuting and/or occupational diseases in Brazil, considering all economic activities, according to the National Classification of Economic Activities (CNAE).

According to the Regulatory Norm for Safety and Health at Work, NR 9, which determines the Environmental Risk Prevention Plan (PPRA), there are five groups of risks: Group 1 - Physical Risks, such as noise and vibrations from mechanical recycling process machines; Group 2 - Chemical Risks, such as exposure to gases and toxic substances contained in e-waste; Group 3 - Biological Risks, such as viruses and bacteria used in the bio-metallurgical process; Group 4 - Ergonomic risks, such as improper posture and manual weight lifting and transport in the manual e-waste disassembly process (NR 9). There is also NR 6, which establishes guidelines and guidelines for the use of personal protective equipment (PPE), such as noise mufflers or ear protectors, gloves and hoses, glasses and visors, among others, which are mandatory and avoid serious consequences in case the employee suffers some type of accident at his workplace (NR 6).

In addition, we have the e-waste and tailings transportation part of the recycling process, which needs to comply with the ANTT Resolution nº 5.848/19 above, which includes authorization and licenses for the transport of dangerous products, environmental license, habilitation and training of the driver, vehicle signage, among others (BRASIL, 2019). A challenge is that during the bioleaching process, metal ions that are considered toxic are used as catalysts. Therefore, transportation, storage and safe disposal are considered a concern regarding the negative impacts that can be caused to the environment (PATHAK et al., 2017).

Changes in soil quality have also been classified as a highly significant environmental impact. The soil can store the pollutants that are deposited in it, being strongly influenced by different anthropic activities and pollutants generated, such as, for example, the burning of residues. Plant roots can easily absorb toxic substances, especially heavy metals, which abound in e-waste (LI, ACHAL, 2020). When there is no adequate protection, the disposal of residues in the soil generates direct contamination, also affecting people exposed to these pollutants, whether through ingestion of soil nutrients, inhalation of particles or by released compounds and ingestion of animals that feed on the polluted soil. Contaminated soils can act as a continuous source of pollutants into the atmosphere. In addition, the guidelines available for the level of permitted organic and inorganic pollutants will depend on the intended use of the soil (MOECKEL et al., 2020).

As an example of the damage that can be caused to the soil, the following case studies are cited. The first case study is about the soil of a slum in Bangalore, India, where electronic waste is recycled. The analysis carried out in the soil of the place obtained results of up to 2.850 mg/kg of lead; 39 mg/kg of cadmium; 4.6 mg/kg of indium; 180 mg/kg of antimony; 957 mg/kg of tin and 49 mg/kg mercury (NGOC et al., 2009). An equivalent study was carried out in China by Wu et al. (2019), estimating the concentration of metals in the soil near an abandoned electronic waste recycling site. The concentration of heavy metals at the waste burning site were much higher than those in the rice field and stream samples, which were heavily contaminated with Cd, Zn, Pb, Ni and Ba (WU et al., 2019).

Bearing in mind that the heavy metals found in the electronic waste are not biodegradable, their large scale of production and consumption tend to intensify the risks of exposure to the environment and soil contamination, as results of previous studies that reveal the permanence of heavy metals in the recycling regions of electronic waste three decades after the ban on this informal job.

Finally, we have the impact of Changes in the quality of water resources, considered with high relevance, which is linked to the quality of the soil. Through the processes of leaching and diffusion of effluents, contaminants from e-waste can infiltrate aquatic systems (both groundwater and surface water). This happens in the places of disposal and/or processing of e-waste inappropriately, with aquatic biota also being contaminated (DU et al., 2020).

In the aquatic environment, heavy metals tend to adsorb to sediments but can be released from sediments and remobilized in water streams when the sediment is disturbed or the water chemistry is altered (WU et al., 2015). The remobilization of heavy metals is undesirable since they can be transported by water currents, possibly causing contamination in local sources. In addition to the flow rate of the water stream, the dispersion of heavy metals also depends on their mobility, such as the proportion of acid-soluble fraction (WU et al., 2016).

Exposure to heavy metals through water is also a health threat to populations in less developed countries that have insufficient water treatment facilities – if they exist. The risks of exposure to these metals for residents can be insignificant because of the low concentration in drinking water, but ingestion of groundwater represents a potentially significant risk (ZHENG et al., 2013).

According to Du et al. (2020), the diversity of heavy metals contained in the sediments of the analyzed water resource indicates that e-waste was the cause of the contamination. As an example, the elements Cu, Pb and Zn used for the production of PCB were found on a large scale, where copper wires are the main source of Cu, Ag, Sb and Sn, commonly used in PCB welds (DU et al., 2020).

Zheng et al. (2013) concluded that the risk (carcinogenic and non-cancerous) of oral exposure is much greater than the risk of inhalation and dermal contact derived from processes made with e-waste. The concentrations of metals in the groundwater in the present study were several orders of magnitude greater than common areas in southern China, indicating a substantial influence of e-waste recycling in groundwater in this area (ZHENG et al., 2013). The aquatic fauna also suffers from the contamination of water resources, Sun et al. (2018) reported significant results related to water contamination, such as carp from a river under study have the potential to bioaccumulate polybrominated diphenyl ethers (PBDE), reaching a concentration of 766 ng/g in their fresh weight. A test on aquatic snakes, the main aquatic predator of the studied ecosystem, reveals that they present in their composition about 16.512 ng/g of PCB, based on wet weight.

As an example of a mitigation measure for the contamination of water resources, there are aquatic plants that can be used as the natural resource to mobilize the heavy metals released from the contaminated sediment due to their absorption capacity. (BAI et al., 2018). An ideal candidate for phytoremediation must have rapid growth, be tolerant to heavy metals and able to efficiently absorb a variety of heavy metals so that it can act as a natural barrier to prevent the dispersion of these metals (OBINNA, EBERE, 2019). As with water resources, bioremediation has been considered an economical and ecologically appropriate solution for the remediation of soils contaminated with heavy metals. A study in China explored the potential of using a combination with the N12 bacteria inoculated in plant growth and soil microbial activities, resulting in the removal of heavy metals found in the soil. The efficiency of this soil phytoremediation process will depend mainly on the selection and appropriate combination of plants and microbes (LI et al., 2020).

The three highly significant impacts mentioned above can be minimized when the recycling company is located within a WTC in waste disposal and effluent generation activities, where the local logistics of the landfill reduces the costs and risks of these processes.

In short, the mitigating measures for the changes caused in the soil and the water are the prevention of accidents and the completion of the formal PCB recycling process, carefully observing all the technical requirements of the process control and complying with all the current legislation for the operation of the recycling company.

Therefore, it is worth mentioning that the environmental contamination surrounding the recycling of e-waste is the result of illegal activities related to the disposal of this waste and/or the occurrence of accidents in the process, which can lead to direct and indirect exposure to soil, air and consequently affecting the quality of health of the population, fauna and flora (LI, ACHAL, 2020).

It is important to highlight that this research carried out the analysis of the most significant elements for environmental feasibility. Therefore, for future work, the feasibility analysis of other relevant aspects, such as economic, technical, social and cultural for the implementation of a PCB recycling company is recommended.

Finally, the main contribution of the work is to offer an analysis of the main environmental elements that influence the environmental viability of WTC recycling companies, to take advantage of the metal extraction potential of this secondary source at the expense of grounding, which generates costs and waste mineral resources. It should be noted that both the adapted matrix and the analysis presented serve as a basis for studies on the implementation of recycling companies in any city/locality, with or without WTC.

4. CONCLUSIONS

In the analysis of the most significant environmental elements for the implantation of a printed circuit board recycling company, it was verified through the Leopold matrix (adapted for this research) three environmental impacts considered significant, which are: changes in soil quality, changes in quality of water resources and occurrence of accidents.

In the survey of the environmental impacts related to the recycling process to be adopted in the PCB recycling company, it was found, as no companies are operating in Brazil yet, that there is a need to complement the CETESB Manual for the Preparation of Environmental Studies with the literature, in that in both there is information related to projects such as mining, waste landfill, dam and road project, as well as adapting the Leopold Matrix to adapt to the characteristics of the PCB recycling company.

In the analysis of the most relevant environmental elements of the recycling company with reference to the requirements for environmental licensing, a bio-hydrometallurgical process and the respective potential impacts in the planning, implementation and operation stages were considered, and of the 20 impacts identified, only 3 were highly relevant impacts, which can be mitigated by carrying out the formal

PCB recycling process, carefully meeting all the technical requirements for controlling the process to avoid accidents.

Among the potential locations for the implantation of a printed circuit board recycling company, it's concluded that an advantageous location under the environmental aspect is an available area of a Waste Treatment Center, thus collaborating with the management of the effluents and waste generated. It was analyzed that the environmental impacts caused by the recycling company are minimized by being installed inside a WTC. Also, it was noticed that, for regions where they do not have an existing WTC, it is advantageous to look for nearby communities to implement the recycling company since the cost-benefit is greater than the implantation in a common location.

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