AMBIENTE & SOCIEDADE 25 anos años years

Electrical and electronic equipment waste as a secondary source of critical and strategic materials

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Abstract: Brazil has recently released a list of prioritized strategic materials addressing issues related to trade balance, supply, and technology development. In this context, it is possible to associate waste electrical and electronic equipment (WEEE) as an important secondary source for several types of materials. The composition of these wastes is extremely complex and includes many materials from the Brazilian list. The objective of this study is to characterize some types of WEEE to assess the presence and quantities of these materials, thus promoting their recycling. High concentrations of strategic materials such as Al, Cu, Ni, Li, Co, Si, Au, and rare earth elements have been identified in printed circuit boards, batteries, LEDs, and solar panels. It can be inferred that WEEE is an important source of raw materials, and the consolidation of a national recycling system is essential to promote a circular economy and national sovereignty.

Keywords: WEEE, Recycling, Circular economy, Urban mining, Solid waste

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São Paulo. Vol. 28, 2025

Original Article

DOI: http://dx.doi.org/10.1590/1809-4422asoc0203vu28L1OA

Introduction

In a report released by the United Nations University (UNU) in 2020, the global generation of waste electrical and electronic equipment (WEEE) was estimated at 53.6 million tons per year (7.3 kg per capita), with WEEE being the category of solid waste with the highest growth in generation in recent years (from 9.2 in 2014 to a forecast of 74.7 million tons per year in 2030) (FORTI *et al.*, 2020).

The context of WEEE generation also includes the high informality of end-of-life management, with only 17.4% destined and documented by formal means, owing to the technological difficulties in collection and recycling that the actors in this process still encounter (BOTELHO JUNIOR *et al.*, 2024; FORTI *et al.*, 2020). On the basis of this scenario, the report indicates that recycling is a fundamental strategy for minimizing environmental and social impacts from the generation of WEEE and is a key component of the 2030 Agenda for Sustainable Development in goals 3, 6, 8, 11, 12 and 14.

In addition to sustainability issues, the generation of WEEE and its recycling have taken on strategic contours for the supply area of nations and companies. WEEE can contain significant quantities of valuable materials, not just economically but also for the technological and market dominance of so-called information technology products (CENCI *et al.*, 2022b). The search for solutions to mitigate the strategic vulnerability of the supply of these materials, which, by definition, already have limited availability, is an important focus of current research, and the recycling of WEEE has emerged as a promising alternative for many of them.

Several countries and regions have their lists of critical and strategic materials defined, publicized, and periodically updated, most notably the lists of the United States of America, the European Union and China. Despite some differences in the methodologies adopted to define which materials are considered critical and strategic, these lists basically spell out the main materials to avoid supply vulnerability and represent important strategic gains in the world market.

In this sense, Brazil, through Resolution No. 2 of June 18, 2021, of the Ministry of Mines and Energy, released its own list of strategic materials (MME, 2021). The Brazilian list is similar in format to the Chinese list, presenting the categories of minerals that the country depends on for import, which are important for their application in high-tech products and processes and are essential for promoting a surplus in the Brazilian trade balance. Figure 1 shows the strategic materials considered by Brazil.

Figure 1 – Categories of Brazilian strategic materials.

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Although it is growing, the national recycling infrastructure is not currently capable of using WEEE to recover these strategic materials. There are many limiting factors, and studies have set out to map them. Education and information, collection structure, informality, regulation, scale, technology and profit are some of the points raised in the literature (DE OLIVEIRA NETO *et al*., 2022; DIAS *et al*., 2022a; SANTOS; OGUNSEITAN, 2022; XAVIER; OTTONI; LEPAWSKY, 2021). In practice, there are few WEEE recyclers in the country, and most apply only rudimentary methods for separating materials. In a recent study, DIAS *et al*. (2022a) reported only 140 possible recyclers in Brazil, of which only 82 confirmed that their activities involved WEEE recycling. Among these 82 recyclers, 81% only dismantle the equipment without any additional waste recovery techniques. The study also discusses the final destination of these components, in which the most complex and valuable components are exported to extract the materials of interest that are completed outside Brazil's borders. Thus, there is a clear national challenge to expand recycling and develop technology to recover valuable and strategic materials from WEEE so that the cycle of materials is closed within Brazilian borders, generating the development and security of the supply of important raw materials.

In 2020, a major step was taken in this direction with the signing of the sectoral agreement for the reverse logistics of WEEE. The agreement provides for the phased implementation of the system for household equipment, with mandatory responsibilities defined for the various players in the process, including the operationalization and financing of activities. In general, the sectoral agreement for reverse logistics can encourage the formalization of recyclers, increasing the scale for collection and recycling, investment in technology, standardization of processes and safety in activities (DIAS *et al*., 2022a). It is therefore hoped that promoting recycling activities will stimulate the creation of an industry aimed at extracting valuable and strategic materials.

The first step toward this development is proper knowledge of the waste to be recycled and its potential and challenges. Knowledge of the structure and composition of these materials makes it possible to find opportunities, define more efficient processes and routes and estimate gains. The Laboratory of Corrosion, Protection and Recycling of materials (LACOR) at the Federal University of Rio Grande do Sul (UFRGS) has been working on the characterization and recycling of WEEE since 1997, with several papers published on different types of equipment (BERNARDES; BOHLINGER; WUTH, 1997; VEIT *et al*., 2005). In the current context of vulnerabilities, geopolitical pressure and opportunities, it is pertinent to compile and present the potential of WEEE as a secondary source of strategic materials for the Brazilian market. The aim of this work is to explore the chemical characterization of some of the main types of WEEE studied at LACOR, assessing which materials can be recovered according to Figure 1. The Brazilian WEEE recycling industry is still in its infancy, and it is hoped that this study will highlight the importance of proper management and better use of this waste.

Methodology

This paper presents chemical characterizations carried out on the following equipment: smartphone printed circuit boards (PCBs), LED lamps, lithium-ion batteries and photovoltaic panels. Characterization strategies relevant to each type of equipment were adopted. All the equipment was collected from users or recycling companies.

Smartphone-based PCBs

Forty smartphones of various makes and models manufactured between 2012 and 2020 were collected. The PCBs were removed manually, and their magnets were removed and demagnetized by heating them in a muffle furnace at 700°C for 3 hours. All the PCB materials (including the magnets) were then ground together in a knife mill such that 100% passed 2 mm. The samples, in triplicate, were collected with quartering equipment and sent for acid digestion and analysis via inductively coupled plasma–optical emission spectrometry (ICP–OES) to quantify the metal concentration.

Acid digestion was carried out with *aqua regia* (HCl and HNO_3, 3:1) at a solid–liquid ratio of 1 g/20 mL at 70°C for 2 h with stirring at 200 rpm. The silver was digested with concentrated HNO_3 under the same conditions.

LED Lamps

A total of 90 LED lamps (15 lamps from 6 distinct brands, 3 of which were tube lamps and 3 were bulb lamps) were collected. All the lamps were opened manually and separated into their four main components: housing, module, LEDs and PCB. The components were milled to 100% through 2 mm, and the samples were quartered for individual characterization in triplicate (acid digestion and ICP-OES analysis).

Acid digestion was carried out with *aqua regia* (HCl and HNO_3, 3:1), a solid-liquid ratio of 1 g/20 mL, 70°C, for 2 h, stirring at 200 rpm, and pure HNO3 for silver characterization under the same conditions. To obtain the composition of all the LED lamps, the characterizations of the components were summed while considering the mass balance between them. Details of the methodology and results are available in CENCI *et al.* (2020).

Lithium-ion batteries

Lithium-ion batteries from 40 discarded smartphones manufactured between 2012 and 2020 (with the same devices as those described in section 2.1) were collected. The batteries were removed manually, discharged in saline solution (immersed in salted water for two days), processed together in a knife mill to 100% throughput at 2 mm and quartered to obtain samples in triplicate.

For smartphones, cobalt oxide batteries and nickel, manganese and cobalt oxide batteries are expected. The samples were analyzed via acid digestion and ICP-OES. Acid digestion was carried out with *aqua regia* (HCl and HNO3, 3:1) at a solid-liquid ratio of 1 g/20 mL at 70°C for 2 h with stirring at 200 rpm. There was no acid digestion with pure HNO3, as the presence of silver in the batteries is not expected.

Photovoltaic panels

A polycrystalline silicon photovoltaic (PV) module (manufactured in 2018) was collected and manually disassembled into three components: a junction box, a frame and a laminate. The frame and junction box were removed, their masses were measured, and the frame was analyzed by X-ray fluorescence (XRF).

After removing the frame and the junction box, 500 g of the PV laminate was processed in a knife mill until it was 100% through 1 mm and quartered to obtain samples in triplicate. The samples were analyzed via acid digestion and ICP-OES. Acid digestion was carried out with pure HNO3 due to the large presence of silver at a solid-liquid ratio of 1 g/20 mL at room temperature for 6 hours with stirring at 300 rpm.

Results

Smartphone-based PCBs

PCBs are considered one of the most economically valuable types of WEEE and have a wide-ranging composition in terms of the number of elements that can be found in them (BOOKHAGEN *et al.*, 2020; D'ADAMO *et al.*, 2019). Table 1 contains the results of the chemical characterization of smartphone PCBs. In terms of economics, the concentrations of Au, Ag and Cu stand out, with values higher than those normally found in typical ores (CENCI *et al.*, 2020). These elements also have the highest number of scientific publications on recycling (CENCI; EIDELWEIN; VEIT, 2023)

Table 1 – Concentration of elements found in smartphone-based PCBs.

Element	Concentration (%)	Element	Concentration (%)
Ag	0,06	Nb	0,03
Al	1,39	Nd	0,26
Au	0,22	Ni	4,59
Co	0,04	Pb	0,07
Cr	2,06	Pd	0,08
Cu	43,35	Pr	0,06
Fe	16,96	Pt	<LOD*
Ga	0,04	Sb	0,06
Li	0,08	Sn	2,54
Mg	0,07	W	0,09
Mn	0,17	Zn	2,86
Mo	0,03		

* LOD: limit of quantification.

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For example, the concentration of gold (Au) identified in smartphone PCBs was 0.22%. In contrast, the gold deposits found in the Iron Quadrangle have levels ranging from 0.5-12 g of gold per ton (g Au/t) or 0.00005-0.000012%. (TRINDADE; BARBOSA FILHO, 2002). It is estimated that obtaining the amount of gold needed to make a single-cell phone circuit board results in the generation of approximately 220 kg of mining waste, with the aggravating factor that cyanide is used during the extraction process, resulting in significant potential for pollution (KASPER, 2011).

With respect to copper, the levels found in mineralization vary from 0.2% to 1% (ROCIO *et al.*, 2012), whereas smartphone PCBs have a concentration of 43.35% copper. For silver, high-concentration ores typically contain between 0.006% and 0.01% (SVERDRUP; KOCA; RAGNARSDOTTIR, 2014), and smartphone PCBs have a concentration of 0.06%.

In the strategic question, considering the Brazilian list (Figure 1) for comparison, several materials were identified as being present (Mo, Cu, Co, Sn, Nd, Pr, Au, Pd, Li, Nb, Ni, Fe, Al, Mn and W). Among these elements, high concentrations of Cu, Fe, Sn, Ni, Au and Nd stand out. Other elements, such as Ga and Sb, are present in lists of strategic materials from other countries and regions and may also be relevant for recovery in different contexts.

The smartphone PCBs contained 0.26% Nd. Nd, an element belonging to the "rare earth" group, is used to manufacture neodymium-iron-boron magnets, which are an essential component of the transition to a low-carbon energy economy applied, for example, in direct-drive wind turbines, electric and hybrid vehicles, hard disk drives and cell phones (ROLLAT *et al.*, 2016). However, the production of this metal is highly concentrated in China (BINNEMANS *et al.*, 2013). Some countries have lost the ability to mine and process due to a decrease in infrastructure, creating a gap in the supply chain and fluctuating prices (DU; GRAEDEL, 2013).

A key point to explore is how to make proper use of this waste to recycle these strategic materials. Owing to the high concentration of Cu in PCBs, the traditional industrial approach is to include this waste in Cu metallurgy processes (GHOSH *et al.*, 2015; KAYA, 2016). Cu metallurgy (pyrometallurgy) makes beneficial use of metals that are diluted in the Cu collector metal alloy. Through the electrorefining process, in which the Cu produced is purified, a concentrate is generated of the metallic elements collected (Au, Sn, Ni, Mo, Co, and Pd) that can be concentrated and recovered (REUTER *et al.*, 2019). The elements Fe and rare earth elements (Nd and Pr), which are present at significant concentrations in PCBs, can be removed beforehand by magnetic separation, increasing the use of recycling routes. An efficient recycling chain associated with the national metallurgical industry is essential for making the most valuable and strategic materials contained in PCBs.

LED Lamps

LED lamps are a relatively new type of WEEE and have rarely been studied in terms of their recyclability. However, their high energy efficiency, coupled with cost reductions due to the popularization of this technology, have meant that this type of lighting system has dominated the market for several years, and consumption is still expected to grow significantly (UNEP, 2017; ZISSIS; BERTOLDI, 2018). The size of the global LED lighting market was valued at US$50.9 billion in 2020 and is expected to expand at a compound annual growth rate of 12.5% from 2021-2028 (GRAND VIEW RESEARCH, 2020). A follow-up report by the International Energy Agency (IEA) mentioned that to achieve net-zero carbon emissions by 2050, LED technology needs to make up the entirety of all lighting product sales by 2025 (IEA, 2023). As a natural consequence of the consolidation of LED lighting systems, a high generation of WEEE of this type is expected, and its recycling appears necessary and a market opportunity in terms of urban mining. LED lamps typically consist of four components: a PCB, a polymeric and metallic housing, LEDs, and an LED module (support where the LEDs are positioned) (CENCI *et al.*, 2020). Table 2 shows the average concentrations of the tubular and whole bulb lamps.

Table 2 – Concentration of elements found in LED lamps.

Element	Concentration (%)
Ag	0,01
Al	24,04
Cu	3,07
Fe	1,32
Ga	0,01
Ni	0,52
Pb	0,02
Au	0,01
Sn	1,95
Y	0,01

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The high concentration of Al, which is considered a strategic Brazilian material, specifically an essential material for the surplus, is due to the presence of metal plates in the housing and LED modules. These plates can be easily recovered mechanically, as they are homogeneous and do not require extractive metallurgical processes (CENCI *et al.*, 2020; MARTINS; TANABE; BERTUOL, 2020).

Even though it contains a PCB, the characterization of an LED lamp does not present the great diversity and concentration of elements as a smartphone PCB. The PCBs of LED lamps are considered less valuable, with lower concentrations reported for economically valuable and strategic elements (CENCI *et al.*, 2020). Cu, Fe, Ni, Sn, Au, and Y are the other Brazilian strategic elements (in addition to Al) found in LED lamps. Cu, Sn, and Fe are mostly present in PCBs, whereas Ni is present in bulb housings (CENCI *et al.*, 2022a). The Au element is present in the PCI components, LEDs, and modules, and the Y element is present exclusively in the LEDs, which are difficult to retrieve owing to their polymer encapsulation (CENCI *et al.*, 2021).

The recycling of LED lamps is still in its infancy in industry. In general, the recovery of Al, the strategic material with the highest concentration, is possible through simple processes carried out by small recyclers. However, it is important to consider that the LED module, where the largest amount of aluminum is found, serves as a support for the LEDs and often, owing to the difficulty of removing them manually or even owing to the lack of knowledge of recyclers, the LEDs end up making up the aluminum scrap itself and end up becoming part of the scum of the metallurgical aluminum recycling process. In this sense, there is a crucial point to be considered in the technological development of the architectural design of lamps and the processes for separating the LEDs deposited on the metal module. Once the Al is recovered, the LEDs can be processed like other WEEE in primary Cu metallurgy, potentially taking advantage of the concentrations of

Cu, Au, Ni and Sn and through specific routes (which still need to be developed) for the extraction of rare earth elements.

Lithium-ion batteries

There are several types of lithium-ion batteries. The ones commonly found in WEEE are cobalt oxide, nickel-manganese-cobalt oxide, manganese oxide, and iron phosphate (ABU *et al*., 2023). Table 3 shows the concentrations of metals detected in a mixture of 40 smartphone batteries, where the presence of several types of batteries is expected but with a predominance of cobalt, nickel, and manganese oxides. The results of the ICP-OES analysis reveal a high Co content in addition to the presence of Ni and Mn, which indicates that the majority of the smartphone batteries analyzed are of the cobalt, nickel, and manganese oxide types, popularly known as NCM.

Table 3 – The concentration of elements found in smartphone lithium-ion-batteries.

Element	Concentration (%)
Al	19,94
Co	24,05
Cr	0,03
Cu	10,98
Fe	0,54
Li	2,83
Mg	0,11
Mn	1,67
Ni	0,71
Pb	<LOD*
Sn	0,14
Zn	0,09

*LOD: limit of quantification.

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First, there is a high concentration of Al and Cu, which are strategic metals for balancing the trade surplus. Al and Cu are used in batteries as collectors of electric current and support for fixing the cathode and anode materials. Al is also found in the casings of smartphone batteries.

In addition to Al and Cu, there are strategic materials such as Co, Fe, Li, Mn, Ni, and Sn, with high concentrations of Co. Notably, in addition to the materials listed in Table 3, there is graphite, which is the main constituent of battery anodes (RAJ *et* *al.*, 2022), a material that can also be considered a strategic material according to the list shown in Figure 1. Graphite recovery is rarely addressed in recycling work (CENCI; EIDELWEIN; VEIT, 2023), indicating that a knowledge gap needs to be filled.

These results reveal a gap in opportunity for the technological development of a smartphone recycling chain that must consider the diversity of materials used in the recycling of this type of WEEE. Taking advantage of the various components of WEEE is essential for promoting a circular economy since there are large amounts of cobalt, aluminum, and copper, as well as lithium, manganese, and nickel (metals that appear on the list of Brazilian strategic materials).

The search for a recycling process for lithium-ion batteries has been a topic of great interest in scientific research in recent years (CENCI *et al.*, 2024). The majority of processes converge on a comminution and granulometric separation stage using sieves (CAMARGO *et al.*, 2024a, 2024b) , which concentrate the anode and cathode materials (called black mass) into the finest fractions (generally below 0.25 mm) and generate a concentrated fraction of Cu and Al (RAJ *et al.*, 2022). In the black mass, various extraction methods can be applied to recover Li, Co, Mn, Ni, and Fe, with a predominance of hydrometallurgical techniques, which are more attractive, given that in pyrometallurgical processes, Li is commonly retained in the slag from the smelting process (ALI; KHAN; PECHT, 2021; LATINI *et al.*, 2022).

Photovoltaic panels

Considering the crystalline silicon module studied, after disassembly, the frame represented approximately 22.34% of the mass, the junction box 2.49%, and the PV laminate (module without a frame and junction box) 75.17%. The frame was made of an anodized aluminum alloy, type 6063T5. Considering the market value of Al, the frame is a substantial economic source and is listed as strategic material on the Brazilian list. Removing the frame is a recycling step of low technological complexity and high financial return, so there can be minimal use of panels with low investment. Table 4 shows the concentrations of specific elements and materials in the PV laminates.

Table 4. Concentration of elements found in crystalline silicon photovoltaic laminates (modules without frames and junction boxes).

Element	Concentration (%)
Ag	0,10
Al	1,37
Cu	3,21
Fe	0,51
Pb	0,15
Sn	0,23
Si	6,23

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As shown in Table 4, the PV modules contain metals with high added value (Ag, Al, Cu, and crystalline Si). However, physical methods are needed to concentrate them beforehand and thus reduce the consumption of reagents or energy in a later recovery stage via chemical or thermal treatment (CAMARGO *et al.*, 2021, 2023; DIAS *et al.*, 2018, 2022b; DIAS; BENEVIT; VEIT, 2016). Among these elements, Al, Cu, and Si are on the Brazilian list of strategic materials. Although Ag is not listed as strategic, we know that, owing to its high economic value, it is an element of great interest for recycling from PV panels. CAMARGO *et al.* (2023) used mechanical and thermal processes to produce a silicon concentrate with 40 times more silver than a high-concentration ore.

Notably, approximately 80% of the laminates are made up of glass (not mentioned in Table 4), which can be sent for recycling as long as it is free of other contaminants. Academic studies and recycling industries mostly use grinding steps to decapsulate the PV cell and release the layers of materials (CONTRERAS LISPERGUER *et al.*, 2020; DIAS *et al.*, 2017; DIAS; BENEVIT; VEIT, 2016; RABAIA; SEMERARO; OLABI, 2022). As a result, the total separation of glass without mixing it with polymers, metals, or silicon has become a technological challenge. Additionally, the generation of fine glass particles reduces their recyclability for more noble purposes, such as solar glass (DEL PERO *et al.*, 2019).

The recycling of PV panels is necessary for the supply of raw materials as an urban mining strategy, but it is also fundamental for the management of this waste to enable the growing use of this renewable energy source. PV panels have an estimated useful life of approximately 25-30 years (ATASU; DURAN; WASSENHOVE, 2021; PAIANO, 2015; PETROLI *et al.*, 2024). However, many of these panels reach the end of their useful life even before this period because of damage during installation or storms, component failures, or economic incentives to replace older modules with more efficient modules (TAO *et al.*, 2020).

Brazil, a leader in solar energy in Latin America and the Caribbean, is expected to become one of the top five global markets in the next five years (IRENA, 2022; SOLARPOWER, 2022) The forecast for photovoltaic waste generation in Brazil is 2,500-8,500 tons by 2030, and 300,000-750,000 tons by 2050 (IRENA AND IEA-PVPS, 2016). Brazil therefore has the potential to become a regional recycling hub in line with its renewable energy generation capacity.

Although crystalline silicon modules dominate the photovoltaic market, second-generation cadmium telluride (CdTe) modules have shown greater efficiency, lower cost, and longer service life. Therefore, the demand for cadmium and tellurium could increase 7-times by 2040, resulting in a shortage of 1,300 tons of cadmium and 1,400 tons of tellurium (CAMARGO *et al.*, 2024; IEA, 2021; MARWEDE; RELLER, 2012; USGS, 2021). Studies indicate that the development of solar energy may be limited by the availability of rare metals such as tellurium (LIU *et al.*, 2021; SHAO *et a*l., 2020; TOKIMATSU *et al.*, 2017; WATARI *et a*l., 2019) and that the recovery of photovoltaic waste is critical to balancing the difference between the supply and demand of this metal (CURTIN; VAIL; BUCKLEY, 2020; FTHENAKIS *et al.*, 2020; LI *et al.*, 2022; MCNULTY; JOWITT, 2022; WANG *et al.*, 2020).

Conclusions

This work explored the characterization of several types of WEEE, such as printed circuit boards and smartphone batteries, LED lamps, and PV panels. This waste is widely generated owing to technological development and tends to accumulate in urban centers.

The results, on the basis of the experience of LACOR's research group, show that WEEE is an important secondary raw material for obtaining strategic materials with high added value, demonstrating the presence of various metals (Al, Cu, Ni, Li, Co, Si, Au and rare earths) considered critical and strategic, not only by Brazil but also in high quantities in WEEE. These secondary raw materials can encourage urban mining actions and promote a circular economy in the country.

In the Brazilian context, urban mining plays a key role in reducing pressure on natural resources traditionally extracted through primary mining, conserving biodiversity, mitigating climate change, promoting, and generating jobs, reducing waste going to landfills, expanding the circular economy and consequently for Brazil's sustainable socioeconomic development.

Acknowledgments

The authors would like to thank CNPq, CAPES, FAPERGS, and FINEP for their financial support in conducting this work.

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Submitted on: 16/06/2024
Accepted on: 16/08/2024
2025;28:e00203

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Resíduos de equipamentos eletroeletrônicos como fonte secundária de materiais críticos e estratégicos

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Resumo: O Brasil lançou recentemente uma lista de materiais estratégicos prioritários, que aborda questões estratégicas de balança comercial, suprimento e desenvolvimento de tecnologia. Neste contexto, é possível associar os Resíduos de Equipamentos Elétricos e Eletrônicos (REEE) como uma importante fonte secundária para diversos tipos de materiais. A composição destes resíduos é extremamente complexa, incluindo muitos materiais da lista brasileira. O objetivo deste trabalho é caracterizar alguns tipos de REEE a fim de verificar a presença e quantidades desses materiais, e fomentar, desse modo a sua reciclagem. Foram identificados, nas placas de circuito impresso, baterias, LED e painéis solares altas concentrações de materiais estratégicos como Al, Cu, Ni, Li, Co, Si, Au e Terras raras. Conclui-se que os REEE são fontes importantes de matéria- prima e que a consolidação de um sistema nacional de reciclagem é essencial para fomentar a economia circular e a soberania nacional.

***Palavras-chave*:** REEE, Reciclagem, Economia circular, Mineração urbana, Resíduos Sólidos.

São Paulo. Vol. 28, 2025

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Residuos de equipos eléctricos y electrónicos como fuente secundaria de materiales críticos y estratégicos

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Resumen: Brasil ha lanzado recientemente una lista de materiales estratégicos prioritarios que aborda cuestiones estratégicas de la balanza comercial, suministro y desarrollo tecnológico. En este contexto, es posible asociar los Residuos de Equipos Eléctricos y Electrónicos (REEE) como una fuente secundaria importante para diversos tipos de materiales. La composición de estos residuos es extremadamente compleja, incluyendo muchos materiales de la lista brasileña. El objetivo de este trabajo es caracterizar algunos tipos de REEE para verificar la presencia y cantidades de estos materiales, fomentando así su reciclaje. Se identificaron en placas de circuito impreso, baterías, LED y paneles solares altas concentraciones de materiales estratégicos como Al, Cu, Ni, Li, Co, Si, Au y Tierras Raras. Se concluye que los REEE son fuentes importantes de materia prima y que la consolidación de un sistema nacional de reciclaje es esencial para fomentar la economía circular y la soberanía nacional.

***Palabras-clave*:** REEE, Reciclaje, Economía circular, Minería urbana, Residuos Sólidos.

São Paulo. Vol. 28, 2025
Artículo Original