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Electronic waste: a logistical, environmental or educational problem?

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ABSTRACT

Electronic waste management (EWM) has become an urgent problem due to expanding consumption and device obsolescence. The present study sought to describe the interrelationship between EWM, reverse logistics and environmental education, and expand opportunities for sustainable EWM. To this end, a bibliographical review was made of scientific articles, and legal and normative documents. We found that the rapid growth and inadequate disposal of EW cause major socio-environmental problems. Furthermore, the reverse logistics system in Brazil faces challenges in EW collection that stem from a lack of knowledge and awareness in the general population. Environmental education in schools is an important tool for raising individual awareness and responsibility and finding solutions to socio-environmental problems. The most significant finding of this study is the importance of integrating school-based environmental education with e-waste management to effectively promote citizen engagement and participation in reverse logistics. Regarding social and environmental contributions, this study highlights the importance of environmental education in developing responsible citizens whose actions can reduce the negative impacts of inappropriate electronic waste disposal on the environment.

PALAVRAS-CHAVE: E-waste. Reverse Logistics. Environmental Education.

1 INTRODUCTION

Rapid technological advancement has resulted in society's growing dependence on electronic devices, triggering a veritable avalanche of electronic waste (EW). Globally, EW is the fastest growing type of waste, increasing roughly 4% annually and 21% in just five years (FORTI *et al.*, 2020; GREEN ELETRON, 2021). The phenomenon transcends mere waste management and has become an ethical and ecological dilemma of extreme importance.

Planned obsolescence and consumerism have amplified the problem. Technological innovation has also contributed by creating new types of devices and encouraging replacement of equipment with similar functions. Devices that are still functioning are often replaced by new devices that provide only incremental improvements, which leads to the accumulation of electronic waste.

Inappropriate disposal of this waste has devastating consequences for environmental and public health, including contamination of soil and groundwater with toxic substances such as mercury and lead (BRASIL, 2000; WHO, 2021; FERREIRA; ANJOS, 2001).

Reverse logistics provides a more sustainable and circular approach to managing these materials. The process is one of the tools established by the National Solid Waste Policy of Brazil that comprises a set of actions and procedures for collecting waste, returning it to companies for reuse or appropriate disposal, and ultimately contributing to economic and social development (BRASIL, 2010).

This emphasis on collecting and returning waste to companies for reuse or recycling and proper disposal, serves as an operational model for mitigating the adverse impacts of EW. However, the effectiveness of reverse logistics only works when complemented by a culture of environmental responsibility and awareness (SANT'ANNA; MACHADO; BRITO, 2015). Therefore, EWM must be seen not only as the responsibility of manufacturers, but also of governments and citizens.

A sustainability-oriented mindset can be fostered at the earliest stages of education by incorporating environmental teaching in schools. This teaching, however, should not be

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restricted to mere facts about the state of the environment, but should "promote the idea of citizenship and the expectation of joint collective action and mobilization" (GUIMARÃES, 2004, p. 33, *our translation*).

Thus, environmental education can equip young people with the knowledge and skills needed to make sustainable decisions and prepare them to become engaged global citizens that can participate in informed debates. Furthermore, it can prepare them to propose solutions and implement thoughtful actions that benefit not only society, but the entire ecosystem of which they are part.

Given this background, the objective of the current study is to describe the interrelationship between electronic waste, reverse logistics and school-based environmental education. This is achieved through three topics: i) the complexities related to electronic waste, ii) relevant legislation and iii) the role of environmental education and schools in developing citizens.

Given increasing consumption and the growth of EW, the current study is significant since it addresses a contemporary and essential theme for integrated management and waste management. This study can also impact the academic sphere by inspiring ideas and guidelines for educational institutions and generating positive benefits for society and industry.

2 METHODOLOGY

The methodology used was a narrative bibliographic review that was qualitative and descriptive. This approach was used to critically and comprehensively analyze the literature related to the topics of electronic waste, reverse logistics and environmental education.

Relevant articles were searched for in the Scielo, CAPES Periodicals and Google Scholar databases using the descriptors 'electronic waste', 'reverse logistics', 'waste management', 'shared responsibility' and 'environmental education'.

Books and reports from institutions specializing in waste management were also consulted. Legal and normative Instruments, such as laws, decrees, and resolutions, were also analyzed to understand the regulations and guidelines that shape the situation in Brazil.

Studies that were not directly related to the topics of interest were excluded, ensuring the inclusion of only those that contributed significantly to the overall understanding of the topic. Works published in Portuguese and English were considered.

The selected studies were then thoroughly and critically analyzed. The most relevant concepts, findings and conclusions were identified and synthesized to provide an understanding of the interrelationship between EWM, reverse logistics and environmental education. This methodology allowed for a well-founded analysis and provided context and a deeper dive into the concepts discussed in this research.

3 THEORETICAL DISCUSSION

3.1 The electronic waste problem

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Electronic equipment is defined as "products whose operation requires the use of electric current or electromagnetic fields" (ABREE, 2022, p. 10, *our translation*). When these devices become waste, they are called electronic waste, waste from electronic equipment, or simply e-waste (GREEN ELETRON, 2021).

In Brazil, this equipment is categorized into four distinct groups: white, brown, blue and green (ABREE, 2022). The white category includes refrigerators, air conditioners, clothes washing machines and dishwashers while the brown category includes monitors and televisions (tube, plasma, LCD and LED), DVD players, audio equipment and camcorders. Items such as mixers, blenders, electric irons, drills, hair dryers and vacuum cleaners are included in the blue category. Finally, the green category includes computers, computer accessories, tablets, and cell phones.

The legitimate need for devices that make modern life easier cannot be ignored. However, rampant consumerism fueled by marketing schemes and a culture of novelty amplify the negative impacts of these needs. Technological advances have enabled the constant launch of new products, which accelerates obsolescence and quickly makes objects disposable (CARVALHO, 2016). This, in turn, has contributed to the disorderly increase in large-scale waste production, which transcends local and regional borders and brought about a challenge of global proportions.

From the extraction of mineral resources to manufacturing and then disposal, each stage of an electronic device's life cycle comes with its own ecological and social footprint, since every time a product is created, it inevitably generates waste during its manufacture and disposal (NUNES; BASTOS, 2018). Furthermore, a production system that prioritizes accelerated obsolescence leads to alarming rates of natural resource extraction, environmental depletion, and greater risk for geopolitical conflict.

Irresponsible disposal and inadequate management of EW affect the environment and have serious implications for human health caused by toxic elements in this waste (FREITAS; OLIVEIRA, 2021). According to Ferreira and Anjos (2001), waste containing heavy metals, such as lead, cadmium, and mercury, can enter the biological chain, accumulate over time and potentially trigger numerous health problems such as lead poisoning, nervous system disorders, infections, cardiovascular problems and cancer (WHO, 2021).

Electrical and electronic waste contain heavy metals that can contaminate soil and groundwater. Thus, the World Health Organization has highlighted the growth of poorly managed EW and the risks the resulting contamination poses to more vulnerable populations (WHO, 2021).

Furthermore, millions of people around the world, including children, are involved in dangerous activities related to waste processing that may involve exposure to the toxic substances in electronic waste (WHO, 2021). This exposure puts people, especially children, at risk for health problems that range from heavy metal poisoning to developmental difficulties.

In 2019, roughly 53.6 million tons of EW were generated globally, an increase of 21% over the last five years, with projections of 74.7 million tons by 2030. However, only 17.4% of this waste was collected and recycled appropriately (FORTI *et al.*, 2020; WHO, 2021).

This means that most of this waste — 82.6% — was not tracked and was likely disposed of, sold, or recycled improperly. The result of this inefficient or inappropriate waste

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management is an annual global raw material waste of approximately $57 billion USD (ABREE, 2022; FORTI *et al.*, 2020).

Thus, the ecological repercussions of the inappropriate recovery or disposal of EW affect social and cultural strata. According to data from E-Waste, a global report from the United Nations, the inadequate recycling of refrigerators and air conditioners resulted in emissions equivalent to approximately 98 million tons of carbon dioxide (CO_2) in 2019 (FORTI *et al.*, 2020).

However, proper waste handling can have considerable benefits, such as saving up to 15 million tons of CO_2 equivalents in 2019 (FORTI *et al.*, 2020). Thus, Nunes and Bastos (2018) highlight the importance of reusing and recycling of waste throughout the production process, as this reduces the use of natural resources and generates new jobs.

According to a report released by Green Eletron (2022), Brazil is the fifth largest producer of electronic waste in the world. This ranking draws attention to the urgent need for effective interventions. The same report indicates that only 3% of this waste is effectively reused or recycled in Brazil. This low rate of reuse does not contribute to socio-environmental sustainability, as it does not generate jobs and income and wastes significant opportunities to engage in more circular and responsible practices.

Competent EWM collection and recycling programs, led by companies, NGOs and universities, do exist in Brazil (SANT'ANNA; MACHADO; BRITO, 2015). However, these initiatives struggle to succeed because of isolation and a lack of continuous collaboration from other actors in the reverse chain. This suggests that a more integrated and collaborative approach, involving all actors, is necessary to achieve successful and sustainable EWM in Brazil.

3.2 Regulations and shared responsibility in Brazil

Public policies play a fundamental role in tackling socio-environmental challenges such as waste management. Thus, according to Silva and Capanema (2019), governments have been adopting policies that reduce waste production, encourage circular economies through reuse, recycling and, when necessary, transforming waste into energy. The same authors point out that developing countries, such as Brazil, face more significant obstacles in waste management than do developed countries.

Regulatory and political initiatives related to EWM in Brazil have evolved over time and made various contributions (Table 1).

Table 1- Significant Legal and Normative Instruments for Electronic Waste in Brazil

Normative and Legal Instruments	Descriptions
Resolution CONAMA No. 257/1999	One of the first regulatory frameworks addressing electronic waste in Brazil. The resolution highlights the need for adequate treatment and disposal of waste that contain lead, cadmium, mercury, and related compounds. (BRASIL, 1999)
Resolution CONAMA No. 401/2008 Resolution CONAMA No. 424/2010	These resolutions update and complement Resolution CONAMA No. 257/1999, with particular focus on reverse logistics (i.e. the responsibilities of manufacturers and distributors in managing product life cycles and disposal). (BRASIL, 2008, 2010a)

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National Solid Waste Policy (2010)	Introduced the concept of shared responsibility, such that manufacturers, resellers, and consumers are equally responsible for managing waste. PNRS also launched the National Solid Waste Plan as one of its main instruments. (BRASIL, 2010b)
Agenda 2030 for Sustainable Development (2015)	Brazilian global commitments that include Sustainable Development Goal (SDG) 12, which addresses sustainable production and consumption, and recommends specific targets for responsible waste management. (ONU, 2015)
Federal Decree No. 10,240/2020	Formalized the Sector Agreement for the Reverse Logistics of Electronic Products, complementary to PNRS, establishes goals for manufacturers, importers, distributors, and dealers in setting up voluntary delivery sites, geographic coverage, and the collection and adequate disposal of electrical and electronic devices that have reached the end of their useful life. (BRASIL, 2020)
Federal Decree No. 10,936/2022	This recent decree aims to increase electronic waste recycling in Brazil by establishing a national reverse logistics program, which aims to optimize the implementation and operation of physical and logistical infrastructure, providing economies of scale and enabling synergies between systems. (BRASIL, 2022)

Source: Prepared by the authors, 2023.

In a society increasingly driven by electronic devices, waste management has become a multidimensional challenge that goes beyond the simple disposal of discarded objects. Thus, each regulatory and political framework can contribute to EWM, whether by promoting reverse logistics, emphasizing shared responsibility, or establishing concrete targets for collection and recycling.

Reverse logistics is an important aspect of Brazil's National Solid Waste Policy, established by Law No. 12,305/2010. It refers to a set of actions, procedures and means that enable the collection and return of solid waste to the business sector for reuse, recycling, or environmentally appropriate disposal (BRASIL, 2010). National Solid Waste Policy establishes reverse logistics as a key strategy for dealing with the environmental and social challenges related to solid waste, especially those that present a significant risk to public health or environmental quality.

Carvalho (2016) states that reverse logistics impacts EWM and offers environmental benefits that include energy savings, preservation of natural resources and reduction of waste in landfills, while minimizing harmful chemical processes. The author also highlights social benefits, especially for street collectors of recyclable materials, and financial benefits for companies achieved through lower cost raw materials.

However, the benefits of a reverse logistics system can only be achieved through the participation of all parties, including public authorities, the business sector and society. The process depends on consumers returning waste appropriately. However "national and international experiences have shown that poor coordination between actors in the reverse logistics chain remains a problem in most countries" (SANT'ANNA; MACHADO; BRITO, 2015, p. 101, *our translation*).

To improve coordination between these actors and improve the efficiency of the reverse logistics system in Brazil, the National Solid Waste Policy introduced the concept of shared

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responsibility. This concept helps reduce adverse environmental impacts and incentivizes a circular economy by ensuring that all participants assume their share of responsibility in the sustainable management of waste and discarded products (BRASIL, 2010).

The sectoral agreement for reverse logistics of products, formalized by Decree No. 10,240/2020, is an important example of government measures to deal with electronic waste in a responsible and sustainable way by creating concrete targets for collection and recycling. It establishes that, from 2021 to 2025, companies must set up more than 5 thousand voluntary delivery sites in the 400 largest cities in the country. Furthermore, it foresees a gradual increase in collection over these five years, culminating in 2025 with the equivalent of 17% of the weight of the products that entered the market in 2018. (GREEN ELETRON, 2021; BRASIL, 2020).

According to ABREE (2022), the goal for 2021 was that companies were responsible for collecting 1% of the products (by weight) that they had placed in the market in 2018 and must maintain this percentage throughout different product lines. Thus, in 2018, the collection target was 10,924 tons of waste from electrical and electronic equipment and household appliances. However, only 1,245 tons of waste were recovered, or 11.4% of the target (ABRELPE, 2022).

As noted by Sant'Anna, Machado and Brito (2015), achieving goals is far from simple. The authors emphasize that a reverse electronics chain must be developed gradually given the lack of experience and collaboration between the Brazilian State, the market and society.

ABREE (2022) admits that, despite its efforts to collect electronic materials, the goal established by Decree No. 10,240/2020 has not been achieved. The organization highlights that these goals will only be achieved by raising consumer awareness of correct disposal and implementing incentives that would improve the success and efficiency of the system.

Similarly, Rodrigues and Menti (2017) warned that despite advances in solid waste management policies in Brazil, there is still a significant challenge regarding public awareness. According to the authors, many people are not fully aware of appropriate disposal practices, which results in the abandonment of waste in inappropriate places. Thus, despite government measures, a lack of awareness continues to be an obstacle to effective solid waste management in Brazil.

3.3 Environmental education and the development of citizen awareness

Responsible management of electronic waste depends on citizen awareness and involvement, which can help reduce waste production and improve waste management efficiency. However, a survey carried out by Green Eletron (2022) revealed that many Brazilian citizens are unaware of the environmental and health risks associated with inappropriate EWM. For example, 75% of the respondents were not aware that any electronic device can be recycled if disposed of properly.

This lack of knowledge about what constitutes electronic waste and how to correctly dispose of it contributes to inadequate disposal practices, relegating citizens, in this case, to the status of polluters. Thus, Gobira, Castilho and Vasconcelos (2015) found that these policies are difficult to implement given the lack of knowledge, understanding and adherence to guidelines of all parties, including civil society. This gap between policies and their effective execution

highlights the need for a more comprehensive approach that goes beyond regulation and involves the population in problem solving.

Jacobi (1998) identified that the population's lack of responsibility in environmental issues results from a lack of information, environmental awareness, and community involvement. In turn, Reigota (1998) emphasized the importance of building awareness of global environmental problems, issues, and individual responsibilities.

Environmental education can play an important role in achieving this goal. However, this education should not be limited to just the transfer of knowledge but should also focus on developing responsible attitudes towards sustainability. As Bandeira, Ximenes and El-Deir (2016) and Cavalcante (2016) state, environmental education equips individuals with the information, skills, and dispositions necessary to bring about behavioral changes.

According to Brazilian national curricula guidelines, environmental education can trigger significant social impacts by promoting citizenship attitudes and values (BRASIL, 1997). To this end, Reigota (2009) asserts that environmental education must transcend mere teaching about the environment to providing political education that empowers citizens to demand and contribute to a fair society, both nationally and globally, that promotes self-management and ethical relationships with the community and the environment.

Therefore, environmental education transcends the naturalistic paradigm, which is perceived as the utopian care of ecosystems and wildlife, and something detached from everyday life. Instead, it should incorporate environmental issues into everyday life, from individual choices to political issues, inviting reflection on the structure of life, its origins, impacts and the role of citizens. In this way, environmental education is transformed into a comprehensive form of education (DOURADO; BELIZÁRIO; PAULINO, 2015).

Carvalho (2004) notes that critical environmental education helps develop individuals as integral parts of society and history, emphasizing common responsibility for the environment and society, without rigid divisions. This approach aims to reveal reality in its entirety, covering environmental, social, and political aspects, and integrating educational process into daily reality and thereby transforming society (GUIMARÃES, 2004). Therefore, environmental education plays a fundamental role in the formation of conscious citizens, enabling them to understand the complexities of the contemporary world and to actively contribute to the sustainability of the planet.

3.3.1 The role of the school

National Solid Waste Policy not only establishes guidelines for integrated management and solid waste management, it also recognizes the importance of environmental education. The law is integrated into Brazilian Environmental Policy and operates in line with the National Environmental Education Policy (BRASIL, 2010). These policies recognize the prominent role educational institutions play in citizenship and community building.

Thus, Brazilian Environmental Policy argues that environmental education must be integrated into all levels of education, and thereby empower citizens to actively participate in protecting the environment (BRASIL, 1981). National Environmental Education Policy also

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enshrines environmental education as a human right that must be incorporated into all levels and types of education (BRASIL, 1999).

"If society must move towards more sustainable practices, the school, as a social space designed to educate, must play a role in this reorientation" (DOURADO; BELIZÁRIO; PAULINO, 2015, p. 40, *our translation*). Similarly, Besen (2012) stresses the significant role of schools in promoting sustainable development by encouraging active citizenship and addressing issues such as sustainable consumption and adequate waste management, including reducing, reusing, and recycling.

All levels of school, from kindergarten to postgraduate, are suitable for environmental education (REIGOTA, 2009). Thus, environmental education should not be restricted to specific age groups, but conceived as a continuous life-long process that must adapt to different age groups regarding content and methodology.

In political terms, Moran (2007) emphasizes the importance of transforming schools into spaces for cooperation, inclusion, and awareness. This can be achieved by engaging the local community, connecting classroom lessons with real-life situations, and providing opportunities for families and the community to learn. This approach, as noted by Besen, benefits both the school and the community around it, "since small efforts to promote sustainability begin at home, at school and in the neighborhood" (2012, p. 43, *our translation*).

Even when environmental education focuses on students' daily lives, it should not ignore seemingly distant subjects (REIGOTA, 2009). Given the goal of developing identity and participation not only as Brazilian citizens, but as global citizens who are aware of their role in the planetary context.

Thus, schools can play a fundamental role in promoting environmental education and helping students become informed and engaged citizens. By creating an environment that encourages critical reflection, responsibility and ethics, schools help develop individuals prepared for emancipation and positive change in society (DOURADO; BELIZÁRIO; PAULINO, 2015). In this way, societal transformation begins with the transformation of education.

3.3.2 EWM, legislation and environmental education

EWM is a complex challenge that requires a holistic approach. Thus, regulations and environmental education play interconnected and complementary roles in efforts to make e-waste management more effective, responsible, and sustainable. Improving the synergies between these elements is essential to tackling the socio-environmental problems associated with EWM.

Studies have shown the importance of schools in addressing the problem. Freitas and Oliveira (2021) highlighted the need for campaigns that raise EWM awareness and strengthen knowledge about appropriate applications of legislation. The educational intervention described by Morozesk and Coelho (2016) demonstrated that environmental education can help students understand the importance of environmentally correct EWM and empower them to adopt sustainable practices and influence their families.

School activities related to electronic waste can raise student awareness and promote citizenship, collaborative attitudes, and the principles of reducing, reusing and recycling

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(MARQUES; DREHMER-MARQUES; PERSICH, 2018). Furthermore, using reverse logistics as an educational strategy helps empower critical citizens who can positively influence society by carrying the impact of these activities from the school to the greater community (SANTOS *et al.*, 2021).

These school-based studies show that environmental education is an essential tool in developing awareness of EWM and promoting reverse logistics. They also contribute to a deeper understanding of EWM issues and encourage responsible acquisition, disposal, and recycling practices.

4 CONCLUSION

Given the global expansion of the electronics market, rapid device obsolescence, inadequate disposal, and consequent need for responsible EWM, this study sought to describe the interrelationship between electronic waste, reverse logistics and environmental education.

Rapid production and improper EWM deplete natural resources, degrade the environment, and threaten public health, especially in vulnerable communities. Moreover, the lack of recovery and reuse of this waste is a missed opportunity for creating jobs and generating income. Thus, Brazil has implemented regulatory and political measures to promote responsible waste management with emphasis on shared responsibility and the reverse logistics system. However, reports and research have highlighted the ineffectiveness of EW collection, which is often attributed to a lack of public awareness.

Clearly, citizens play a key role in all phases of the product life cycle - from the decision to purchase and choosing more sustainable options, to efficient use that extends product life, and finally responsible disposal. In short, citizens can choose to act in more responsible and participatory ways at all stages of the product life cycle. Furthermore, informed citizens can influence other actors throughout the chain, such as companies and governments, to adopt and comply with effective waste management practices.

Thus, the effectiveness of policies largely depends on the active involvement of citizens, although many are still unaware of the environmental and health risks associated with EW, which results in inadequate disposal practices. The current study highlights the importance of informing, raising awareness and changing the behaviors of citizens who can then contribute more effectively to reverse logistics. Greater awareness is needed to ensure appropriate use, of collection sites for example, as recommended by Brazilian legal and regulatory instruments.

Environmental education can fill this knowledge gap, empowering people with essential information, skills, and attitudes that promote behavioral transformation and the adoption of more responsible waste management practices. Specifically, environmental education in schools provides a foundation for achieving sustainable development and should be reinforced at all levels, from elementary to higher education. This study highlights its importance in developing more informed and engaged citizens regarding socio-environmental challenges, especially those caused by inadequate EWM.

Nevertheless, environmental education is limited by its focus on educational institutions and neglect of other learning environments, such as domestic, community and corporate. Furthermore, despite highlighting the merit of environmental education and the role of schools

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in training citizens, the current study did not explore the details of how to implement educational programs focused on electronic waste.

Therefore, future research could investigate how other non-formal educational settings could help raise awareness in citizens regarding local and global socio-environmental problems. Subsequent studies could also focus on evaluating the effectiveness of specific environmental education programs in schools and on strategies to optimize their impact on student awareness and engagement in electronic waste management.

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