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Review

A Review of E-Waste Management and a Proposal for Effectively Implementing a Circular Model in Ecuador

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ABSTRACT

Although electrical and electronic equipment are the most used in everyday life, linear economy, which is based on producing, using, and discarding, is causing a high impact on human health due to the harmful effect of some of the materials that are disposed of inadequately. Consequently, the circular economy in the Electrical and Electronic Equipment Waste (WEEE) sector has taken a great boost, whose purpose is to reduce, reuse, and recycle. The aim of the article is to provide an overview of e-waste management and the circular economy in the Ecuadorian context. Methodologically, it is approached from a qualitative and exploratory method, constituting a starting point for the analysis of the selected sector. The results have implications applicable to the data collected for the case study, which are limited, and the management of electrical and electronic equipment waste, that requires changes in the value chain and collaboration between actors to ensure systemic functioning. In conclusion, the biggest challenge with respect to WEEE focuses on generating environmental and social health awareness, as well as the generation of circular economic activities.

KEYWORDS: e-waste; management; circular economy

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INTRODUCTION

The rapid consumption of electrical and electronic equipment (EEE) worldwide has led to an increase in electronic waste (e-waste) generation, posing a significant threat to human health and the environment. Proper management of e-waste has become a critical concern, with the need for sustainable solutions to tackle this global problem [1]. The United Nations estimates that between 20 and 50 million metric tons of this type of waste have been generated, and that only 20% or 25% has been formally recycled [2,3].

One approach gaining traction is the circular economy, which aims to keep materials and resources in use for as long as possible [4]. The

circular economy model encourages the reuse of products and recycling of materials, reducing waste and limiting the use of finite resources. This approach represents a significant paradigm shift from the traditional linear model of 'take, make, and dispose of' to a more sustainable and environmentally friendly approach [5,6]. Although becoming very popular during the last decade, there is not yet a common agreement on a definition for the CE. A number of definitions have been proposed during last years [7,8] though an academic consensus is still lacking.

In general, the CE encompasses a variety of proposals that seek to reduce the need to extract new mineral and energy resources, prolonging the useful life of products and transforming waste into new resources to reincorporate them indefinitely into the production chain [9]. CE is characterized as a systemic approach with a holistic view of the economic process, considering aspects such as products, components, recycling, reuse, renovation, repair, cascading and regeneration; as well as the use of renewable energy sources (solar, wind, biomass), obtaining energy from waste and sustainable consumption [8]. [10] emphasizes the deep economic shift from linear to CE: "turning the linear industrial economy into a loop or circular economy is, by definition, reducing the economic importance of resource extraction and waste management, and also reducing the environmental impairment caused by these industrial sectors". [10] (p. 4). Hence, CE requires decoupling economic growth from resource extraction and waste generation, emphasizing functional performance against ownership and product consumption. Accordingly, Stahel suggests that the change from a linear throughput to a stock management opens opportunities in three different loops: (i) reuse and remarketing of goods; (ii) product-life extension activities of goods; and (iii) recycling of molecules (secondary resources). Besides the definition, it is relevant to highlight the existence of a hierarchy within the different measures that can be applied within the implementation of the CE approach. In this sense, the butterfly diagram of the EMF [11] very well represents the different options for biological and technical resources, that can be observed within value chains, in order to effectively execute the principles of regenerating the nature, prolonging useful life of products and designing out waste. Also, [10] wisely stresses the importance of refusing, which is not necessary, reusing which is not damaged, repairing which is damaged, remanufacturing which is not working properly and finally, recycling which cannot be remanufactured.

Another interesting dimension of the CE paradigm is how it widely occurs, which is conceptualized as CE disruption. [12] have defined it as "A transformation in a socio-technical system which causes the systemic, widespread, and fast change from the harmful 'take-make-use-dispose' model to a socially and environmentally desirable and sustainable model that reduces resource consumption and address structural waste through

the deployment of circular strategies". Obviously, the actual implementation of CE principles can vary widely, depending on the maturity of the linear model, the economic structure of countries and/or regions, and on the specific configurations of the different value chains. In this regard, [13] propose a framework that addresses top-down and bottom-up interests to converge in favor of implementing a circular and regenerative economy. Therefore, they suggest aligning the different interests of policy makers, governmental bodies and manufacturing industries to succeed in the implementation of CE.

In this article we will focus on the configuration of the electrical and electronic waste value chain in a city in Ecuador. The possibilities for implementing circularity measures in this context therefore lie in the area of product recovery at the end of their useful life, in the form of repaired and refurbished products as well as remanufactured products, or in the form of materials suitable for new uses through recycling. The circular strategies will lie therefore in the end of the value chain of electrical and electronic products, i.e., where circularity takes advantage of the waste stream generated by the linear model. Other more ambitious CE approaches would focus on the early design and conception phases of these products in order to generate a wider range of activities and improve the circularity of the whole chain, while minimising e-waste generation.

The objective of this article is to provide an overview of the management of e-waste and circular economy in the Ecuadorian context, particularly in one of the most commercial cities in the center of the country. Cities have an important role to play in the implementation of circular economy models [14]. As the main places of consumption, cities are a critical link in the product value chain to implement actions aimed at reuse, repair or recycling. The selection of the case study in the city of Ambato (Ecuador) is justified by the importance of the e-waste stream, the existence of certain industry dealing with it and especially due to the interest of local and national governments on reducing e-waste.

From a methodological point of view, the paper addresses the objective by implementing a qualitative and exploratory approach, based on interviews and secondary data collection and analysis.

The paper is organised as follows. In the first section, the conceptual basis is set; so, contributions related to the literature of what constitutes e-waste and its management, circular economy and the regulations created in Ecuador are presented. Then, in the second section we proceed to outline the materials and methods applied in the research, from the selection of the case-study city, and the procedure of information collection and data analysis. In the third section of the article the results are presented and discussed. Starting with the review of waste management (value chain) and continuing with the analysis of data through the social, environmental, and political context that arises from the case. We conclude the analysis with the most interesting findings and

some recommendations for implementation aimed at policy makers and businesses.

Overall, this paper seeks to highlight the importance of transitioning to a circular economy model in managing e-waste, emphasizing the need for global cooperation and collaboration to achieve sustainable and long-term solutions. The circular economy represents a promising approach to address the growing concern of e-waste, providing a blueprint for a more sustainable and environmentally responsible future.

E-Waste: Overview

In recent decades, there have been important results in terms of the increase in the acquisition and use of electrical and electronic equipment (EEE) [2] in response to the appearance of new communication and information technologies, and above all, due to the easy accessibility of these devices by users. In this regard, among the largest part of waste generated by households are appliances such as refrigerators, washing machines, ovens, televisions, and other similar artifacts. Likewise, due to the use of the internet, cell phones, computers, tablets, etc. stand out [1], every year the percentage of waste discarded increases exponentially given its relatively short life cycle depending on the new creation of devices [15] generating what is currently known as e-waste.

The term e-waste has become a topic of interest to several authors, so [16] refer to it as electrical and electronic devices that have reached the end of their useful life, which can be considered as dangerous and harmful to both human health and the environment.

Electrical and electronic waste represents the fastest growing waste stream in the world [17], generating significant amounts of materials from both internally to the planet (electrical appliances) and externally (space debris), as well as environmental, health, and ethical issues [18].

[19] shows that e-waste is related to waste that corresponds to electrical and electronic equipment and, in turn, is formed by a mixture of certain components and materials that contain substances that can be toxic.

On the other hand, the definition granted by the European Union (Directive 2012/19/EU) describes this type of waste as electrical and electronic equipment and its components, which have already been discarded or are close to the end of their useful life, and for which there is no intention to be recycled or reused [20,21].

In addition to the environmental and health risks associated with e-waste, there are also economic and social implications. As noted by [22] “E-waste management can provide jobs, promote resource efficiency, and reduce the environmental impacts associated with mining and processing of virgin materials” (p. 1).

Overall, the concept of e-waste is critical to the sustainable development of our society, as improper management can lead to negative impacts on the environment, human health, and economy.

The United Nations Environment Programme (UNEP) also mentioned that, in 2020, electronic waste from cellular devices increased by eighteen times, while that of computers by five, and that of televisions by two in relation to previous years [23]. In the same line, the author shows that, for the same reference year, approximately 51.8 million tons of WEEE were reported worldwide, highlighting Japan, China, the USA, India, Russia, and Germany as the countries that produce the largest amount of waste in relation to the others existing.

In this regard, [24] mention that the production of this type of waste increases over time due to a series of factors such as geographical area, population, preferences and lifestyle, socioeconomic status, among others. Thus, the continent that tops the list is Asia (24.9 Mt.), followed by America (13.1 Mt.), Africa (12.9 Mt.), Europe (12 Mt.) and Oceania (0.7 Mt.).

In line with the above, [25] comment that the increase in this type of waste can be caused by inconsistencies in the applications of the laws established in each country, ranging from inspections to inadequate evaluations of the treatment, processing, import and export of this type of waste. In terms of WEEE management, developing countries still do not have adequate infrastructure, which means that the processing of waste of this type is done illegally, causing losses of valuable materials [26].

In the case of Latin America and the Caribbean, WEEE produced per person annually and by country varies considerably. In this regard, Uruguay is considered the country that generates the largest amount of electronic waste, with an average of 11 kg per person per year. On the other hand, Nicaragua is the one with the lowest production of this type of waste with an average of 2 kg [1].

In the same line of analysis at regional level, the problem of e-waste production per person is significant and continues to grow. For example, in Figure 1 the average reached for 2017 was 7 kg per person per year, which exceeded the world average of 6 kg per person. The results could respond to the bad reuse practices applied; in most cases, these products do not reach a recycling plant where they receive an adequate treatment; that is, in the best case they are given away or sold, partially increasing their useful life. However, in the negative case, these devices are thrown in the trash, burned, or buried.

Ecuador, specifically, is ranked fifth among the countries in the ranking, placing its WEEE production per capita below the Latin American average.

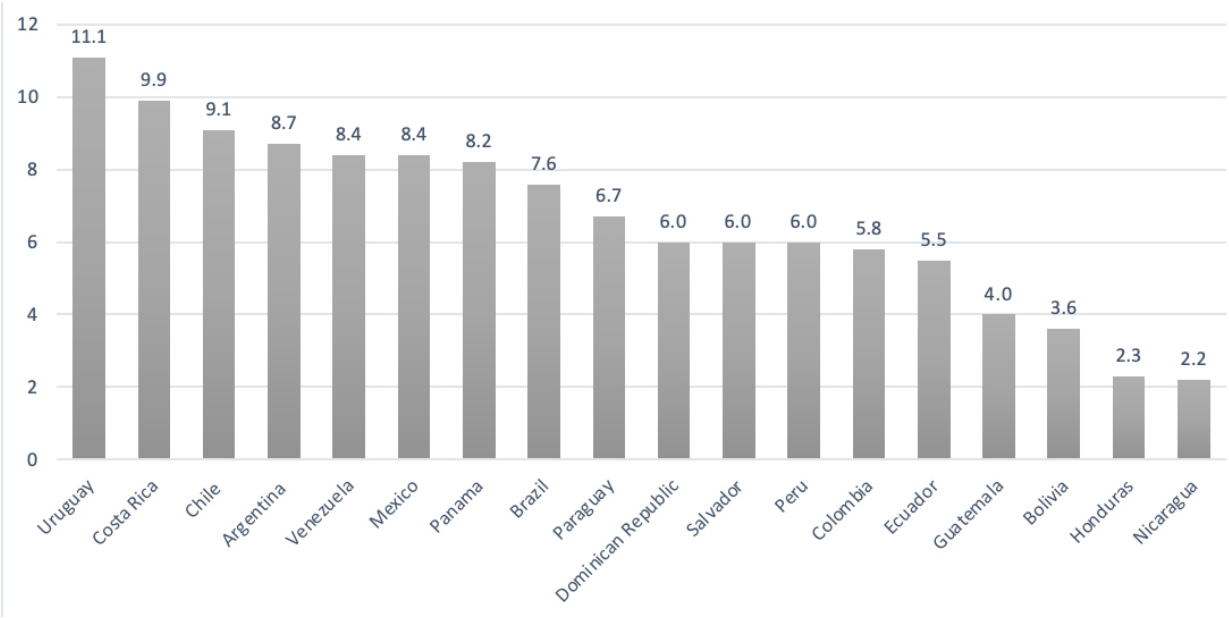

Figure 1. Estimate of e-waste per person in Latin America (per kg). Source: [4].

The growing concern for the care of the environment and sustainability has led countries to establish different policies and regulations that regulate the treatment of different types of waste. For WEEE, there have been several policies in place globally. However, the application of these is insufficient, at least, in the case of Latin America, where there was a 10% annual increase in waste production between 2017–2020 [1].

Even though Ecuador is a country that is located below the Latin American average, the generation of WEEE is considerable (Figure 2), with a growth of 14% between each year analyzed. However, despite the existence of agreements with the importing companies of this type of products, there is not enough reuse in the local production chains, only a small percentage of these devices are used for the dismantling of these in iron, copper, among others [25].

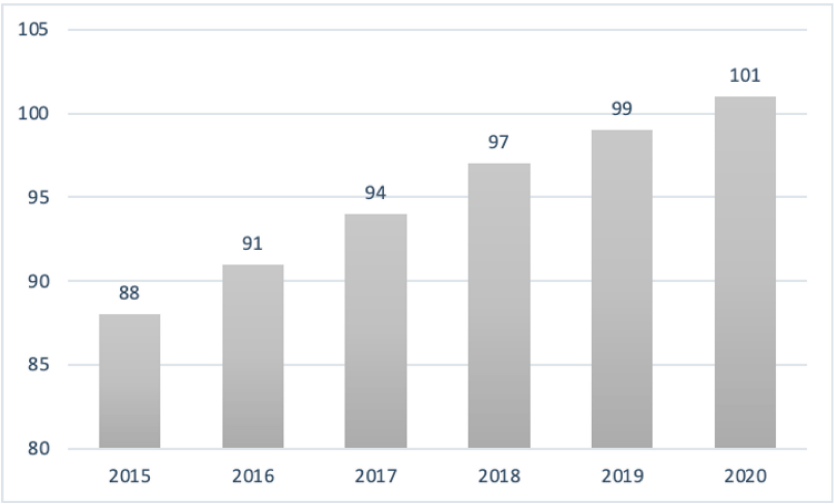

Figure 2. Volume of e-waste generation in Ecuador from 2015 to 2020 (in thousands of metric tons). Source: [26].

In 2019, the set of large and medium-sized enterprises generated 0.50% of special waste, particularly electrical and electronic equipment. Of the companies in question, 875 know the amount generated. However, the total of the companies in the sector under analysis report that they generated 508 tons of waste.

In Table 1 below, two facts to consider are highlighted; on the one hand, the number of companies between the years considered decreases by −0.18%, while the generation of WEEE increases considerably (136%).

Table 1. Companies that generated special waste, by type of waste. 2016–2019.

Special waste	2016			2019		
	Enterprises	Tons		Enterprises	Tons	
	Recount	Absolute	Relative	Recount	Absolute	Relative
Disused electrical and electronic equipment	1064	215	0.33%	875	508	0.50%

Source: [27].

The problem of e-waste production by companies is worrisome due to the amount of waste generated, the presence of toxic materials and the lack of adequate measures for its management and disposal. Increased awareness and regulations are required to effectively address this issue.

Ecuador has developed a series of public policies and programs with the purpose of creating a culture of recycling WEEE. In 2020 Ecuador generated approximately 101,000 metric tons, representing an increase of 14.7% compared to what was produced in 2015, which made it rank eighth [25].

Circular Economy in Ecuador: Regulations

Ecuador has been one of the Latin American countries that has actively participated in legislative and regulatory initiatives for the promotion and implementation of the Circular Economy (CE) to comply with the Sustainable Development Goals in 2030. Thus, CE has become an alternative to the linear model that has been lived in recent years. It proposes the design of efficient products in the use of energy and raw material, proposes the reduction of waste, and takes advantage of it, with the purpose of reducing environmental impacts [27].

In this sense, it should be borne in mind that the CE proposes a new paradigm by considering new modes of production from the origin, design, to the creation of environmentally sustainable business models, without neglecting the economic growth of society. In this regard, it should be mentioned that the CE is not specifically about simple initiatives applied

in each country, but about strategies duly planned and established in plans that maintain a long-term vision with their respective initiatives, to achieve the global objectives proposed by circularity [28].

In recent years, Ecuador has taken part in initiatives related to CE as a sustainable development strategy, promoting actions and proposals from both the public and private sectors, as well as educational institutions. In this context, significant instruments have been developed for the implementation of CE, for which proposals have emerged such as:

The National Pact for the Circular Economy was launched in 2019, after it was signed by the Government and various productive, social, and academic sectors. It proposes several aspects under which it is intended to take advantage of and industrialize waste, promote eco-design, articulate academic research and the development of technologies, promote cleaner production, value sustainable and resilient infrastructure, raise awareness among the population regarding environmental education, promote sustainable businesses, finally develop indicators to know the degree of implementation of CE [29].

White Book on Circular Economy in which the National Circular Economy Strategy is defined through a conceptual framework and guidelines to propose a public policy that serves as an incentive for circular economy projects and allows the strengthening of various social, artisanal, and small industry sectors in a way that promotes the sustainability of resources in closed cycles of the production, commercial, and consumer process [30]. This also reflected the opportunities and barriers faced by the Ecuadorian reality. Similarly, it includes lines of action based on four pillars (1) sustainable production, (2) responsible consumption, (3) comprehensive waste management, (4) policy mechanisms and financing for circular projects [30].

Particularly, we will focus on pillar 4 that refers to the Comprehensive Management of Solid Waste (CMSW) in which mention is made of the linear system of extraction, production, use, and disposal, since an adequate use or management is not contemplated for its management from start to finish of the product. Consequently, excess waste is generated with a negative impact on the environment, society, and the economy [30].

It is important to mention that within this pillar reference is made to aspects of interest for this research, such as: (1) harmonization and implementation of legislation that favors circular strategies, (2) Promoting zero waste models, (3) Innovation and involvement of multiple actors, (4) Implementing Extended Responsibility of the Producer and Importer (RPI)—complementary in Sustainable Production, (5) Promoting industrial symbiosis—greater detail in Sustainable Production, (6) Encouraging separation at source and differentiated collection of waste, (7) Improving the capacity for characterization and monitoring of solid waste generation quantitatively and qualitatively in each canton from the household sector, and in accordance with its productive activities, (8) Involving grassroots recyclers and environmental managers in the management model, (9)

Diversifying financing mechanisms to ensure the sustainability of CMSW [30].

A Technical Standard based on Circular Economy was created with the aim of promoting and guaranteeing consumption and sustainable production, as well as certifying CE projects in companies that are applying it, promoting waste management and consumption habits of sustainable products. Likewise, a specific standard is required for circular products and that the certification of this standard is coordinated by the Ecuadorian Accreditation Service (EAS) and the Ecuadorian Standardization Service (INEN), to guarantee comprehensiveness of the certification scheme and establish the right to the guarantee of repair in the legally established times according to the types of products [31].

Organic Law of Inclusive Circular Economy was approved in 2021 whose objective is to establish principles and mechanisms for the CE, as well as to indicate the attributions and responsibilities of the public and private sector, in addition to the fact that it aims to prevent and reduce the generation of waste. Finally, the use, reuse and recycling are promoted [32].

The above contributions constitute an important effort to promote sustainable production in the country, even though Ecuador has simply seen recycling practices and minimal changes in current business models and its value chain, which could end in an unfulfilled promise and only good intentions within sustainable development [33].

In the context of the circular economy, the value chain is reimagined as a circular value chain, in which waste is minimized, resources are reused or recycled, and value is created at every stage. This requires a systemic approach that considers the entire life cycle of a product, from the design and production stages to the end-of-life stage and promotes the circular use of resources. In this sense, in the following section we review the literature on the organisational phases of the value chain to ensure the correct management of resources throughout their life cycle, focusing specifically on the WEEE sector.

Resource Management (Value Chain)

Considering that CE is a set of approaches that allows to create, deliver products, components and materials of utility for customers and society, through the effective and efficient use of environmental, economic and product resources so that closed circuits are generated for the optimal flow of related resources [34]. The above comes in line with the purpose of reducing the use of virgin resources; therefore, as resources become scarce and production costs become higher, closed circuits become more important [35,36]. In this context, the application of the fundamental principle of waste management is identified by avoiding the generation of waste, through the application of prevention processes, which seek primarily to promote reduce, reuse, and recycle. It then rises a culture of recycling materials efficiently that benefits and is safer for the ecosystem,

in addition to allowing the reuse/remanufacturing of products in good condition, once they are considered possible waste [37,38] until their final disposal.

That is why it is important that resources are managed efficiently since they generate social and economic benefits that arise from activities in collaboration with key actors (industrial sector, commercial, manufacturers, environmental waste managers, the State, municipalities, public and private institutions), and interaction with external partners and other actors (business associations, associations, society, and academia) that do not belong to the value chain.

The waste management value chain involves a series of stages such as selective separation of this waste from the point of origin and its corresponding storage, collection, and transport to the processing destination, and, finally, the transformation stage of WEEE, in which an assessment of its possible reuse is made [39,40]. In this regard, the value chain of WEEE has similarities to the treatment of other types of waste, the characteristics of this at the time of managing show a certain degree of danger due to the components from which they are made [41].

By adopting a circular economy and circular value chain approach, businesses can reduce costs, enhance resource efficiency, and create new business opportunities. It also helps to reduce the environmental impact of production and consumption and contribute to a more sustainable and equitable future.

General guidelines for WEEE management

Collection and storage

This is one of the most important stages of management, given that the efficiency of a collection system lies in the scenarios from which WEEE is obtained, and, if these are accessible to the generator and the feasibility of channeling the information. As for the collection points, also known as green points, they can be determined by manufacturers or importers [42]. In this sense, the places must consider the fulfillment of prerequisites that they must meet according to [43], such as: the facilities must have a roof that protects them from the environment, the containers will have wooden structures so that they facilitate their mobilization, in addition to the established signage.

In the same way, it should be noted that within this stage WEEE cannot experience any type of manipulation, it is only a classification according to the types of equipment; and, in turn, generate an inventory and documentation of the process that was carried out in the storage.

Transport and logistics

At this stage, WEEE is moved from the facilities of the collection center where the waste is stored. In this regard, the transport must meet certain basic conditions [44]:

- Unauthorized personnel are not allowed access.
- Suitable to avoid contact with the weather.
- Application of proper loading of waste.
- Proper packaging.
- Comply with maximum capacity levels, and
- Separate waste that may generate spills.

Sorting and disassembly

In the classification and disassembly stage, WEEE is in the treatment plants that are part of the specialized recycling centers, which have adequate technology and highly trained personnel in the handling of this type of waste. Within this process, the waste is registered, weighed, and classified according to the group that corresponds, after this, they are correctly evaluated to go to disassembly. Regarding the latter, specialists consider the possibility that WEEE can be repaired or reused in other processes [45].

Equipment recovery and reuse

In this stage, WEEE are repaired from small failures or breakdowns for subsequent reuse, or for the assembly of new products. At this point, activities similar to those of a technical service are carried out, the equipment is repaired and adapted for sale in most cases, and, in others, it is donated [46,47].

Processing and material recovery

Valuable materials present in WEEE, such as precious metals (gold, silver, platinum), non-ferrous metals (copper, aluminum), and plastics, are recovered. Each material requires a different treatment. The recovered materials from the previous stages undergo processing to be recycled and reintroduced into the production chain [47,48].

Final disposal

Non-recyclable or non-recoverable waste, as well as by-products from treatment and recycling, are disposed of properly. This may involve sending waste to controlled landfills, treating it as hazardous waste, or using it in sanitary landfill projects [49].

MATERIALS AND METHODS

The data used for this research is collected from the Decentralized Autonomous Government (DAG) of Ambato in Ecuador. The selected DAG is considered by a list of criteria such as: its ability to venture into activities related to circular economy, its initiative towards reducing environmental impact, and its availability to be part of the study. In addition, it is a representative canton at the country level for its relevance to the economic and commercial activities it carries out.

This research is based on an exhaustive review of the existing literature and the regulations created for the Circular Economy and WEEE in Ecuador, limiting the search to the years 2019 to 2021, since these are the years in which greater attention is paid to CE. The work is exploratory in nature and constitutes a starting point for the analysis of the electrical and electronic equipment waste sector in the canton. The information obtained (Figure 3) is qualitative through observation, field visits, and interviews with the actors involved.

In this research, after three contact attempts, 5 people related to environmental and waste management, including officials, department heads and recyclers, agreed to participate. It is worth mentioning that although the number of people could constitute a limitation to this research, the people interviewed are key actors within their functions carried out in both the public and private sectors of Ambato. Likewise, it must be taken into account that the information provided by the interviewees is sufficient due to the scope of this research, which analyzes a relatively small city geographically and in terms of population. The visits for the interviews were carried out in person, opting for an open interview, allowing freedom of response, and other documents with information were delivered digitally. Regarding the interview, we worked under a script of topics related to the existing regulations and regulatory framework, information on the management and processing of WEEE and statistical data of the sector.

From the interviews and the documentation provided, some data of interest emerged. In this case, a guide of activities carried out empirically was maintained, such as: (a) Establish the study area and geographical limits, (b) Identify electrical and electronic waste and establish its value chain, (c) Estimate the generation of electronic waste and define the obsolescence or useful life of the waste through primary and secondary sources of information, (d) Project the results obtained from previous inventories, towards a local level using existing information. From this guide, data related to the WEEE collected and the management waste was obtained and presented as results.

Likewise, the information was classified, which resulted in two aspects of relevance to the research. On the one hand, the current WEEE processing chain is short and not well-defined, therefore a value chain proposal aligned with the parameters of the CE is proposed. Moreover, strengths and weaknesses in environmental and waste management are identified, so a SWOT analysis is carried out for the case study.

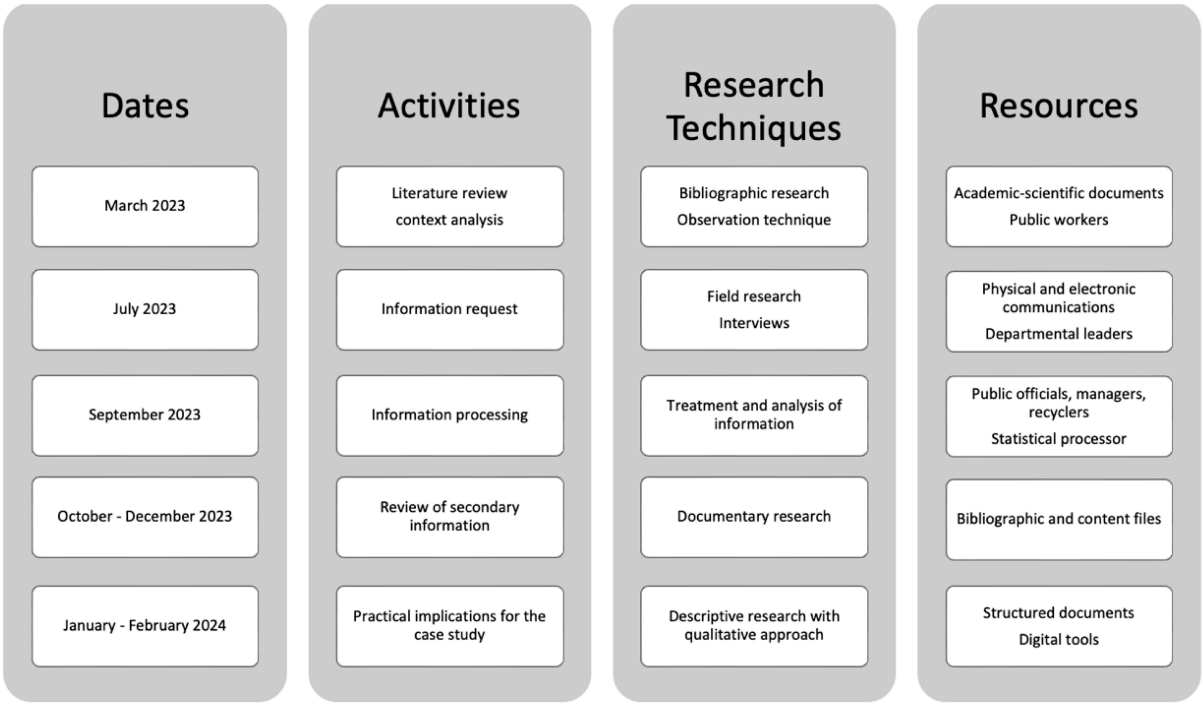

Figure 3. Case study research methodology. Source: developed by researchers.

It is worth mentioning that there are no studies related, or similar, to the sector selected for analysis from the perspective of the Circular Economy.

RESULTS

In this section, the overall characterization of WEEE generation and management in Ambato is explained.

In the canton of study, it is estimated that there are around 251,751 people, considered as Economically Active Population (EAP) [27]. This city has a garbage collection service that oversees the Public Company of Comprehensive Management of Solid Waste of Ambato EPM-GIDSA. In 2015, the need arose to manage waste correctly, since problems were detected in garbage containers, because all kinds of waste, from organic waste to construction materials, were deposited.

Faced with this situation, and pollution problems due to poor management of waste, it was decided that, in 2017 a WEEE collection plan would be implemented by the Environmental Management Directorate.

Currently “electrical and electronic waste is deposited in special containers and in most cases is disposed of in common garbage dumps; therefore, they are manipulated by people in the informal sector” mentioned by director of environmental management of the municipality of Ambato. Similarly, there is a lack of awareness in the population regarding the handling and storage of electronic waste, since they do not recycle it properly, but rather store it inappropriately until it is disposed of. In this sense, according to the data provided by those interviewed, “less than 10% is collected and recycled properly, 40% of waste remains stored

in homes or in warehouses, and 50% of WEEE is sent for final disposal" mentioned by director of a WEEE management company.

Additionally, it is important to indicate that the recycling capacity is very low in the city, to which the lack of qualified labor for recycling and the limited technology and infrastructure for the treatment of this waste are added.

The municipality in question "applies Ministerial Agreement No. MAATE-2022-067 issued by the Ministry of the Environment, Water and Ecological Transition (Ministerio del Ambiente, Agua y Transición Ecológica—MAATE), in which the Instructions for the Application of Extended Responsibility in Comprehensive Management of Electrical and Electronic Equipment Waste of Domestic Origin were issued. Likewise, Ministerial Agreement 142 of National Lists of Hazardous Chemical Substances, Hazardous and Special Waste, Ordinance for Integral Management of Solid Waste of the Ambato Canton, is executed" mentioned by expert in environmental law.

Companies that sell EEE products generally offer guarantees of repair or delivery of a new product in case the product is damaged. However, interviewees indicate that it is important to understand that there is no culture of second-hand markets. Nevertheless, "there are small craft workshops that offer repair and maintenance services of products that do not have a guarantee of commercial establishment" stated by the director of a WEEE management company.

Among the limitations found in this study lie the lack of updated and standardized statistical information, so it has been chosen to take the data extracted from the interviews and project them under a logarithmic estimate that is used when the phenomenon under study has a behavior that can be considered potential or logarithmic.

Below is the data provided by the Municipality of Ambato [50], for this research.

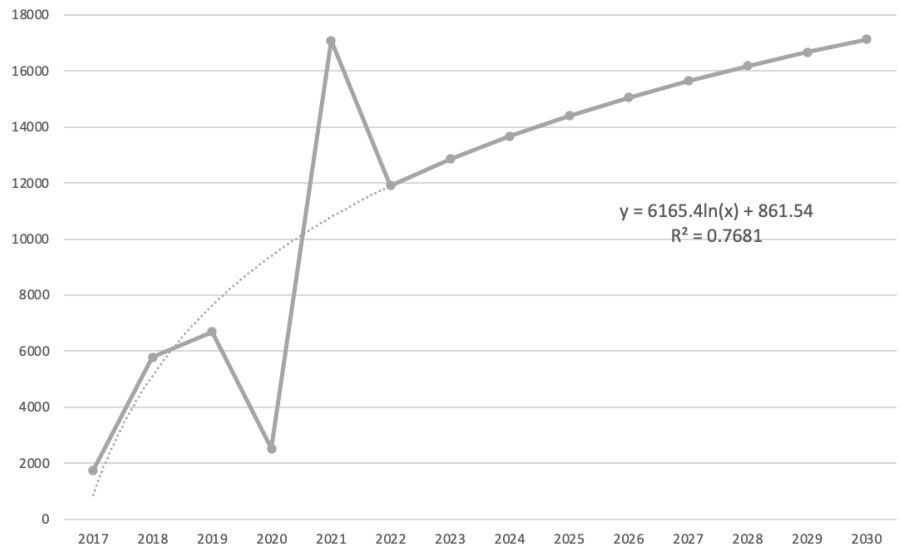

Figure 4. Amount of waste managed 2017–2021. Future estimation of e-waste 2022–2030. Source: [50].

The data presented in Figure 3 represent the amount in kilograms of waste managed by the company in charge, in this regard, the information reveals a somewhat worrying situation, given that the records per year of analysis are not representative in relation to an increasing number of types of waste. As shown in Figure 4, which presents a projection of units collected by classification groups obtained through the application of an empirical guide for waste management, WEEE (temperature exchange devices, monitors, lamps, large appliances, small and computer, and telecommunications appliances) reflect a prolonged growth in the period of analysis considered, with the most representative being waste from computer and telecommunications. In this sense, the situation shows the existing reality, in the city and the country: these types of artifacts are the ones with the highest consumption and waste due to their useful life or introduction of new technologies, and, which in turn come in greater quantities from homes.

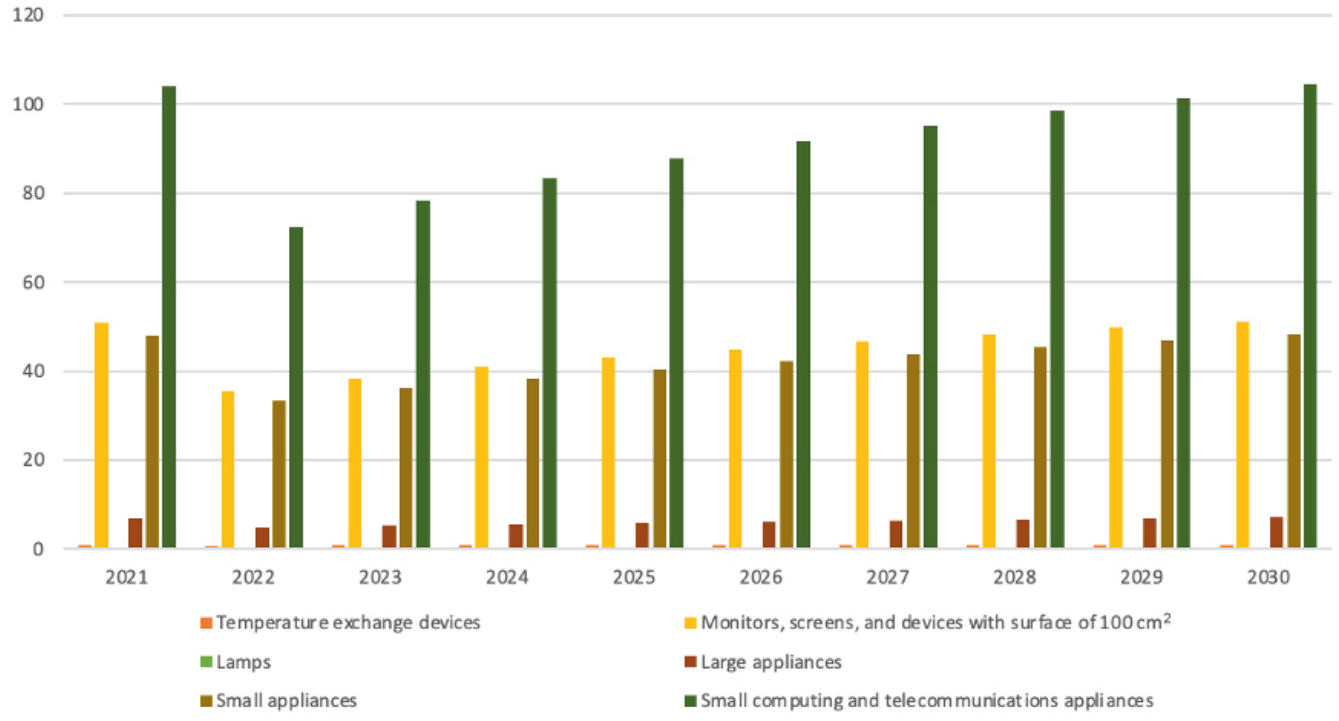

Figure 5. Units collected according to the classification of the European WEEE Directive 2012/19/EU for 2021. Future estimation of e-waste 2022–2030. Source: [50].

Likewise, in the temporal range of analysis (Figure 5), three aspects stand out: in 2020, there was a notable decrease that practically equaled that of the beginning year, which could be given by the effects of the pandemic. Secondly, between 2020 and 2021 the number of kilos increased significantly; and, finally, the projection shows that for the following years (2022–2030) although there is a decrease for 2022, the growth to the following years rises incrementally.

As it is a projection, the data may vary in the coming years depending on the social responsibility of companies in relation to compliance with the laws and regulations established to comply with circularity.

Considering the results presented, the analysis of the projected data, it is revealed that, given the current conditions of WEEE management and the uncertain panorama of information management, it could be pertinent to examine the current waste management value chain in Ambato in order to make a proposal that is somehow more functional and that helps to overcome certain limitations.

The current e-waste value chain is structured in 4 stages (Figure 6): collection, transport, temporary storage and delivery to the certified environmental manager, a process that is carried out by companies that have special permits for the treatment of this waste. However, there are non-formal companies that are dedicated to the empirical recycling treatment of WEEE putting health and the environment at risk.

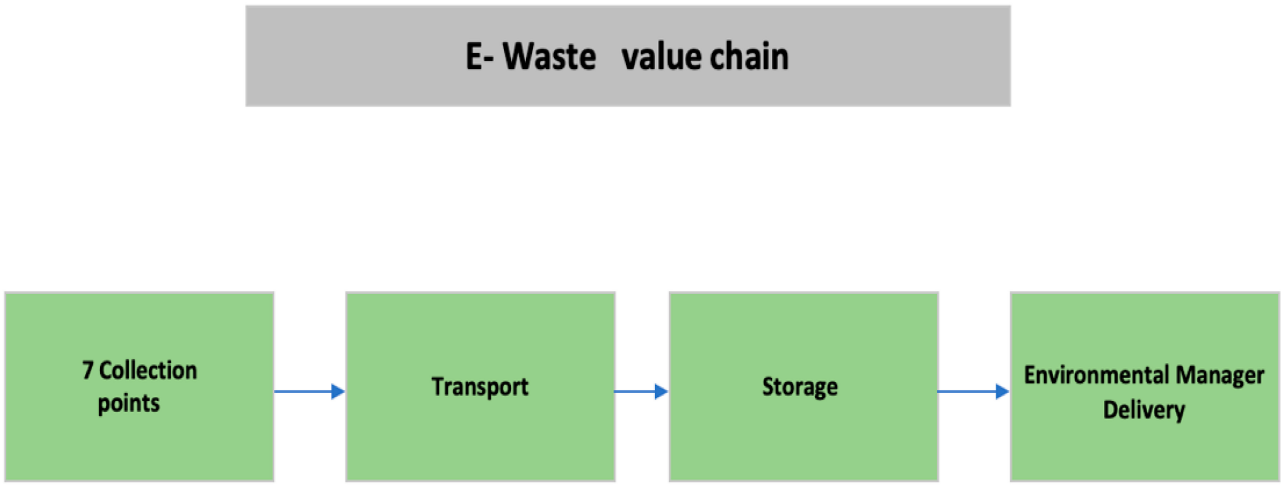

Figure 6. E-waste value chain (current process). Source: data collected from field research.

As explained in the methodological section, the information obtained made it possible to make visible some strengths and weaknesses of WEEE management in the case study. From the qualitative data collected, a SWOT analysis was carried out that allowed to extract and group highlights of WEEE management, characteristics of the study context and problems with regulations and policy instruments. Despite the limited access to information, there are certain patterns to consider that are presented below (Figure 7).

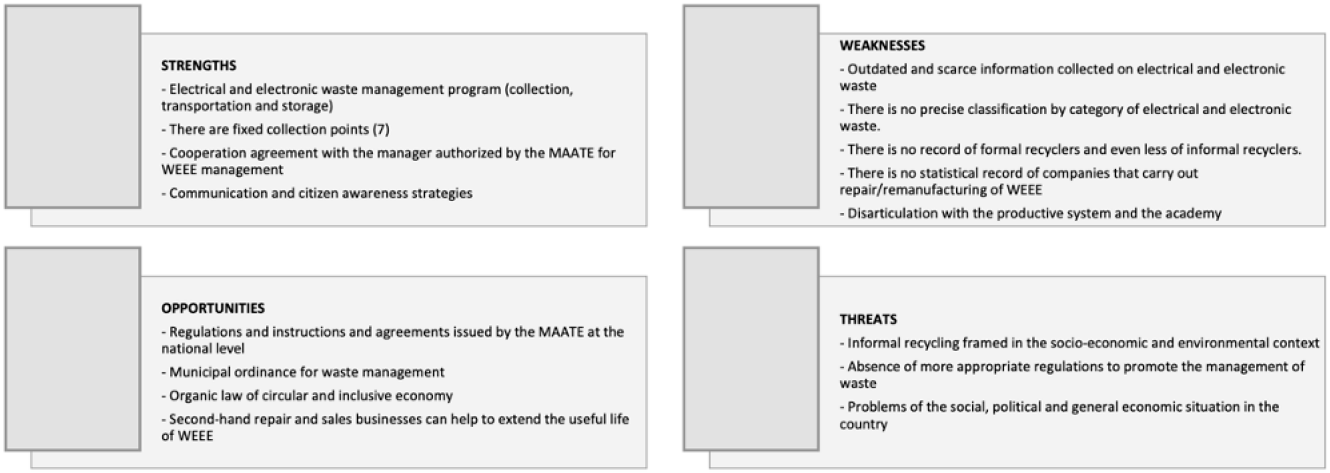

Figure 7. SWOT analysis. Source: developed by researchers.

In this sense, the strengths found are reflected in WEEE management programs, inter-institutional cooperation agreements, existence of collection points, and communication and awareness strategies for citizens. Although they are presented as strengths, they are still incipient activities that are not sufficient in the face of the number of weaknesses such as the scarce and outdated information on the collection and classification of WEEE and on the companies that are dedicated to repair and maintenance of WEEE. Without a doubt, what draws the most attention is the disarticulation with the productive system and the academy, which leads to a lack of information internally for adequate and timely decision-making in the face of an effective transition towards circularity.

Faced with the external factors analyzed, it is noted that the opportunities through regulations, ordinances and laws issued at the national and local level, which are captured on paper, can constitute an advantage to promote awareness and execution of activities aimed at the insertion of CE in society. However, the threats from the environment contrast with the above, since these are related to the existence of informal recycling that is part of the culture, adding to these problems of the social, political, and economic situation of the country, which could be putting at risk the virtuous effects of circularity.

DISCUSSION

In this exploratory study, the main observations were presented in the previous section and the limitations of the e-waste value chain in Ambato have become evident. However, the existence of a favourable regulatory-legal framework and the examination of the situation, together with the literature reviewed, allow us to propose an improvement of the chain in order to increase its circularity.

In the following, we propose the construction of a circular value chain, based on the discussion of the advantageous conditions and gaps identified in the results section.

Once the existing value chain in the geographical area of study has been shown a proposal is planned that leads to the proper management of WEEE framed in the principles of the Circular Economy. We now proceed to show these ideas (Figure 8).

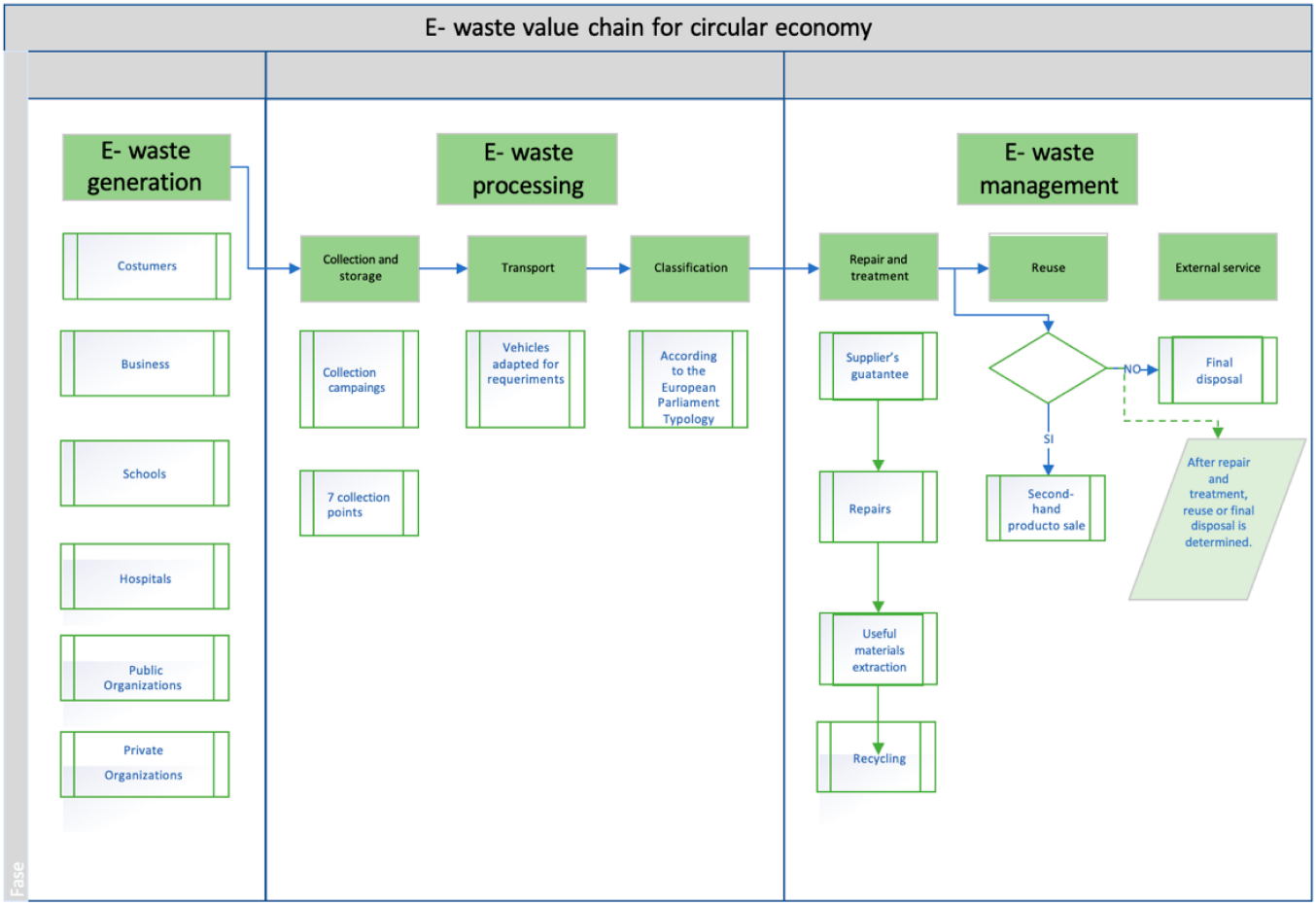

Figure 8. E-waste value chain (Towards circularity). Source: developed by researchers.

The proposal is structured in three stages: In stage 1, the case study analysis shows that there are sources of generation of e-waste (productive sectors and households). Therefore, to improve the circularity, it would be recommendable those that sources become aware of the waste they generate and develop annual plans for the repair, maintenance, and disposal of EEE.

In stage 2, the Ambato case shows some strengths, such as collection and storage, transport, and classification. Moreover, there is also room for improvement. Thus, it would be adequate to consider aspects related to the design of collection campaigns, acquisition of appropriate vehicles for transportation, and training of public officials for the proper classification of WEEE.

In stage 3, the actual management of WEEE has been considered through repair and treatment that allows parts and components to be extracted from the equipment or, in turn, recycled. It is noteworthy that

this stage includes reuse through the sale of second-hand products, and finally the final disposal is included once the equipment has finished its useful life.

The proposed changes for this new structure, in relation to the previous one, arise in line with a more holistic vision of the WEEE management process in the face of the circular transition, through a mapping of the implications, participation and collaboration of stakeholders and not only from the presentation of a series of reduced and limited processes that leave aside aspects of relevance related to compliance of the Sustainable Development Goals.

CONCLUSIONS

In this paper we have addressed the analysis of the e-waste management value chain in Ambato (Ecuador) from a circular economy perspective. The results obtained through interviews, secondary data and literature review have allowed the identification of some strengths and weaknesses of the value chain. Building upon the case study, we have suggested the configuration of a circular e-waste management value chain, which could bring benefits for the whole city, starting with avoidance of waste and health risks associated to it, and going through new economic opportunities linked to new activities and employments, to benefits for consumers of electric and electronic products. In this section, we will set a few recommendations aimed at policy makers and business managers.

The results presented allow us to advance in some reflections on the strategic axes of action, as well as the formulation of new challenges. As revealed in the results, the actions to stimulate the adequate management of WEEE through the CE must combine actions in different institutional settings, both formal and informal, such as the approach of an appropriate methodology that goes from the collection and management of WEEE to the measurement and dissemination of related information; the design of specific support programs by the local government for the adequate application of regulations aimed at the implementation and promotion of CE; as well as generating awareness-raising spaces for different interest groups (citizens, recyclers, waste collectors, producers, marketers) about the circular economy and the problem of environmentally sound management of electronic waste in society. In this sense, this study proposes a holistic approach to the treatment of this waste considering the areas of greatest implication and that can contribute to a solution, maximizing WEEE flow volumes.

However, the existing legislation in Ecuador is still insufficient to provide adequate treatment to WEEE, which is why a review and rethinking of the current environmental needs is required through changes in current regulations, or proposal of new laws in relation to the needs and opportunities that the CE can awaken for the economic sectors in particular, and citizens, in general. Likewise, it is necessary for the country to maintain a regulatory body that manages, regularizes and,

above all, complies with the processes for the treatment of this waste through a sustainable management model that allows obtaining updated and freely accessible information for researchers and policy makers.

On the other hand, a strong disarticulation of the academy, the business sector and the government are perceived, which is reflected in the few or no actions to promote an adequate transition towards the circularity of the sectors. According to the projections and trends observed, this situation could be opposing the virtuous effects that CE has on the economy, the environment and society. However, new challenges arise that suggest reinforcing aspects that are not being sufficiently considered, such as those related to informal recycling and the underground economy that is generated. It is clear that if joint strategic action is not proposed between the levels of government and the actors involved in the sector, it will be difficult to visualize and achieve favorable effects.

Among some of the recommendations that could be adopted by policy makers to promote the adoption of circular practices, is the adaptation of regulations according to the conditions of the Ecuadorian context. In addition, the improvement of WEEE management must be promoted, with an investment program of public funds for the installation of adequate infrastructure for the collection, classification and recovery of materials or for final disposal; as well as the creation of a digital database, both number of collectors/companies and the quantity of WEEE according to its category. Additionally, it is recommended to carry out recycling planning and projections for both public and private companies to maintain environmental awareness. Finally, it is important to mention that a change in tax regulations by reducing or lowering taxes for companies due to reduction, reuse and recycling could work as an interesting stimulus.

Regarding recommendations for companies dedicated to the repair and maintenance of EEE, alliances can be generated with higher education institutions to improve their skills and enhance their capabilities; develop marketing strategies aimed at consumer behavior regarding the use, repair and maintenance of EEE, in addition to providing repair guarantees and offering the option to repurchase equipment in good condition.

Finally, it should be noted that this study has not been without limitations. In fact, the number of people interviewed is small and could be expanded. However, these are key actors in the roles they play both in the public and private sectors in Ambato. Additionally, since it is a relatively small city in terms of geography and population, the interviewees provided key information, as there are not many agents involved in the sector's activities.

DATA AVAILABILITY

All data generated from the study are available in the manuscript or supplementary files.

AUTHOR CONTRIBUTIONS

DMU designed the study and conducted the fieldwork and data collection, which was then reviewed by AP. DMU and AP worked together to validate the analysis. Both authors prepared the outline and drafted the final paper.

CONFLICTS OF INTEREST

The authors declares that they have no conflict of interest.

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REFERENCES

1. Baldé CP, Forti V, Gray V, Kuehr R, Stegmann P. The global e-waste monitor 2017: quantities, flows and resources. Available from: http://collections.unu.edu/eserv/unu:6341/GEM_2017-R.pdf. Accessed on 2 Aug 2024.
2. Cui H, Anderson C. Literature review of hydrometallurgical recycling of printed circuit boards (PCBs). J Adv Chem Eng. 2016;6(1):142-53.
3. Lee D, Offenhuber D, Duarte F, Biderman A, Ratti C. Tracking global routes of electronic waste. Waste Manag. 2018;72:362-70.
4. Baldé CP, Forti V, Gray V, Kuehr R, Stegmann P. The Global e-waste Statistics Partnership. Available from: https://globalewaste.org/statistics/country/ecuador/2019/. Accessed on 2 Aug 2024.
5. Geissdoerfer M, Savaget P, Bocken NM, Hultink EJ. The Circular Economy—A new sustainability paradigm? J Clean Prod. 2017;143:757-68.
6. De Jesus A, Mendonça S. Lost in Transition? Drivers and Barriers in the Eco-innovation Road to the Circular Economy. Ecol Econ. 2018;145:75-89.
7. Kirchherr J, Reike D, Hekkert M. Conceptualizing the circular economy: An analysis of 114 definition. Resour Conserv Recy. 2017;127:221-32.
8. Korhonen J, Honkasalo A, Seppälä J. Circular Economy: The Concept and its Limitations. Ecol Econ. 2018;143:37-46.
9. Vence Deza X. Bases conceptuales para una economía circular transformadoras y un cambio sistémico [Conceptual foundations for a transformative circular economy and systemic change]. In: Vence Deza X, editor. Economía Circular transformadora y cambio sistémico: Retos, modelos y políticas [Transformative Circular Economy and Systemic Change: Challenges, Models and Policies]. Madrid (Spain): Fondo de Cultura Económica; 2023. p. 55-108. Spanish.

10. Stahel W. Policy for material efficiency—sustainable taxation as a departure from the throwaway society. Available from: https://doi.org/10.1098/rsta.2011.0567. Accessed on 2 Aug 2024.
11. EMF. Towards the circular economy: Economic and business rationale for an accelerated transition. Available from: https://www.ellenmacarthurfoundation.org/publications. Accessed on 2 Aug 2024.
12. Blomsma F, Bauwens T, Weissbrod I, Kirchherr J. The 'need for speed': Towards circular disruption—What it is, how to make it happen and how to know it's happening. Bus Strateg Environ. 2023;32(3):1010-31.
13. Lieder M, Rashid A. Towards circular economy implementation: A comprehensive review in context of manufacturing industry. J Clean Prod. 2016;115:36-51.
14. Ellen MacArthur Foundation. Cities in the Circular Economy: An Initial Exploration. Available from: https://www. ellenmacarthurfoundation.org/publications. Accessed on 21 Mar 2023.
15. Patil RA, Ramakrishna SA. Comprehensive analysis of e-waste legislation worldwide. Environ Sci Pollut R. 2020;27:14412-31.
16. Grant K. Goldizen FC, Sly PD, Brune MN, Neira M, Berg MV, et al. Health consequences of exposure to e-waste: a systematic review. Lancet Glob Health. 2013;1:350-61.
17. Shittu OS, Williams ID, Shaw PJ. Global E-waste management: Can WEEE make a difference? A review of e-waste trends, legislation, contemporary issues and future challenges. Waste Manage. 2021;120:549-63.
18. World Economic Forum. A new circular vision for electronics. Available from: www.weforum.org. Accessed on 14 Jul 2023.
19. Clarke C, Williams ID, Turner DA. Evaluating the carbon footprint of WEEE management in the UK. Resour Conserv Recy. 2019;141:465-73.
20. Baldé CP, Wang F, Kuehr R, Huisman J. The global e-waste monitor—2014. Bonn (Germany): United Nations University; 2015.
21. Wagner M, Baldé V, Luda I, Nnorom R, Kuehr G, Iattoni G. Monitoreo regional de los residuos electrónicos para América Latina: resultados de los trece países participantes en el proyecto [Regional monitoring of electronic waste for Latin America: results from the thirteen countries participating in the project]. Available from: https://n9.cl/2tdq0. Accessed on 2 Aug 2024. Spanish.
22. Babbitt CW, Williams E, Kahhat R, Babbitt GA. A review of critical materials and recycling potential in waste electronic products. Environ Sci Technol. 2017;51(9):5273-83.
23. Islam A, Ahmed T, Awual MR, Rahman A, Sultana M, Abd Aziz A, et al. Advances in sustainable approaches to recover metals from e-waste-A review. J Clean Prod. 2020;244:118815.
24. Rautela R, Arya S, Vishwakarma S, Lee J, Kim KH, Kumar S. E-waste management and its effects on the environment and human health. Sci Total Environ. 2021;773:145623.
25. Statista. Available from: https://es.statista.com/estadisticas/1218688/generacion-residuos-electronicos- ecuador/#statisticContainer. Accessed on 15 Mar 2023.

26. Li W, Achal V. Environmental and health impacts due to e-waste disposal in China—A review. Sci Total Environ. 2020;737:139745.
27. INEC. Módulo de Información Ambiental Económica de la Encuesta Estructural Empresarial [Economic Environmental Information Module of the Business Structural Survey]. Available from: https://anda.inec.gob.ec/anda/index.php/catalog/813/dataprocessing. Accessed on 16 Jun 2023. Spanish.
28. Martins B. Economía Circular para América Latina y el Caribe [Circular Economy for Latin America and the Caribbean]. Available from: https://n9.cl/f0l4l. Accessed on 2 Aug 2024. Spanish.
29. Ridaura G. Economía circular en Ecuador: perspectivas de cumplimiento de los ODS en la era Post COVID-19 [Circular economy in Ecuador: prospects for compliance with the SDGs in the Post COVID-19 era]. Available from: https://doi.org/10.33210/ca.v9i4.339. Accessed on 2 Aug 2024. Spanish.
30. Ministerio de relaciones exteriores y movilidad humana (MREYHU). Ecuador y su estrategia nacional de economía circular [Ecuador and its national circular economy strategy]. Available from: https://www.wto.org/english/tratop_e/devel_e/a4t_e/ecuador_100621.pdf. Accessed on 10 Aug 2023. Spanish.
31. Ministerio de Producción, Comercio Exterior, Inversiones y Pesca (MPCEIP). Libro Blanco de Economía Circular de Ecuador [White Paper on Ecuador's Circular Economy]. Available from: https://www.produccion.gob.ec/wp-content/uploads/2021/05/Libro-Blanco-final-web_mayo102021.pdf. Accessed on 10 Aug 2023. Spanish.
32. INEN. Ecuador proyecta una producción sostenible a través de una Norma Técnica basada en Economía Circular [Ecuador plans sustainable production through a Technical Standard based on Circular Economy]. Available from: https://www.normalizacion.gob.ec/ecuador-proyecta-una-produccion-sostenible-a-traves-de-una-norma-tecnica-basada-en-economia-circular/. Accessed on 10 Aug 2023. Spanish.
33. Ley Orgánica de Economía Circular Inclusiva (LOECI). Registro Oficial Cuarto Suplemento Nro. 488 de 6 de julio de 2021, Quito, Ecuador [Official Gazette Fourth Supplement No. 488 of July 6, 2021, Quito, Ecuador]. Available from: https://economiacircular.info/wp-content/uploads/Ley-Orga%CC%81nica-de-Economi%CC%81a-Circular-Inclusiva-RO-488-06-07-2021.pdf. Accessed on 2 Aug 2024. Spanish.
34. Chafla-Martínez P, Lascano-Vaca M. Entendiendo la economía circular desde una visión ecuatoriana y latinoamericana [Understanding the circular economy from an Ecuadorian and Latin American perspective]. Available from: https://dialnet.unirioja.es/servlet/articulo?codigo=8375194. Accessed on 2 Jul 2024. Spanish.
35. Alhawari O, Awan U, Bhutta MKS, Ali Ülkü M. Insights from circular economy literature: A review of extant definitions and unravelling paths to future research. Sustainability. 2021;13(2):859.
36. Low JSC, Lu WF, Lee HM, Song B. Methodology for an integrated life-cycle approach to product end of life planning. In: Nee A, Song B, Ong SK, editors.

Re-engineering Manufacturing for Sustainability. Berlin (Germany): Springer; 2013. p. 397-402.

37. Low JSC, Lu WF, Song B. Product structure-based integrated life cycle analysis (PSILA): a technique for cost modelling and analysis of closed-loop production systems. J Clean Prod. 2014;70:105-17.
38. Low JSC, Tjandra TB, Lu WF, Lee HM. Adaptation of the product structure-based integrated life-cycle analysis (PSILA) technique for carbon footprint modelling and analysis of closed-loop production systems. J Clean Prod. 2016;120:105-23.
39. Low JSC, Ng YT. Improving the economic performance of remanufacturing systems through flexible design strategies: a case study based on remanufacturing laptop computers for the Cambodian market. Bus Strateg Environ. 2018;27:503-27.
40. Dias P, Bernardes AM, Huda N. E-Waste Management and Practices in Developed and Developing Countries. In: Holuszko ME, Kumar A, Espinosa DCR, editors. Electronic Waste: Recycling and Reprocessing for a Sustainable Future. Weinheim (Germany): WILEY-VCH GmbH; 2022. p. 15-32.
41. ITU. Gestión Sostenible de Residuos de Aparatos Eléctricos y Electrónicos en América Latina [Sustainable Management of Waste Electrical and Electronic Equipment in Latin America]. Available from: https://www.itu.int/dms_pub/itu-t/oth/0b/11/T0B110000273301PDFS.pdf. Accessed on 2 Aug 2024. Spanish.
42. Xavier LH, Ottoni M, Lepawsky J. Circular economy and e-waste management in the Americas: Brazilian and Canadian frameworks. J Clean Prod. 2021;297:126570.
43. Clerc J, Pereira A, Alfaro C, Yunis C. Economía circular y valorización de metales: residuos de aparatos eléctricos y electrónicos [Circular economy and metal recovery: waste electrical and electronic equipment]. Available from: https://n9.cl/ck7ze. Accessed on 2 Aug 2024. Spanish.
44. Gautam A, Shankar R, Vrat P. Managing end-of-life solar photovoltaic e-waste in India: A circular economy approach. J Bus Res. 2022;142:287-300.
45. Debnath B, Das A. Towards circular economy in e-waste management in India: Issues, challenges, and solutions. In: Stefanakis A, Nikolaou I, editors. Circular Economy and Sustainability. Amsterdam (Netherlands): Elsevier; 2021. p. 523-43.
46. Sahoo S, Mukherjee A, Halder R. A unified blockchain-based platform for global e-waste management. Int J Web Inf Syst. 2021;17:449-79.
47. Calpa-Oliva J. Validación de un modelo de logística inversa para la recuperación de los RAEE de la ciudad de Cali, basado en el Pensamiento Sistémico usando una simulación con Dinámica de Sistemas [Validation of a reverse logistics model for the recovery of WEEE in the city of Cali, based on Systemic Thinking using a simulation with Systems Dynamics]. Tecnológicas. 2022;23:55-81. Spanish.
48. Ruzzo A, Rodríguez E, Costa S, Burzacca L, Deco C. Caracterización y valorización de residuos informáticos [Characterization and valorization of

computer waste]. Available from: https://sedici.unlp.edu.ar/handle/10915/151811. Accessed on 2 Aug 2024. Spanish.

49. Fernández Protomastro G. Buenas Prácticas para la gestión de los residuos de aparatos eléctricos y electrónicos—RAEE [Good practices for the management of waste electrical and electronic equipment—WEEE]. Ciudad Autónoma de Buenos Aires (Argentina): Grupo Uno; 2014.
50. Decentralized Autonomous Government (DAG). Data related to WEEE from internal institutional reports. Available from: https://ambato.gob.ec/direccion-de-gestion-ambiental/. Accessed on 25 Mar 2024.

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