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Original Article

Analysis of Electronic Waste Management and its Influence on Environmental Sustainability: Municipalities of the Northern Region of Peru

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Abstract - *The study objective of this work was to evaluate whether there is a relationship between the analysis of electronic waste management and its influence on environmental sustainability in the municipalities of the northern region of Peru 2022-2024. Methodologically, the study uses a quantitative approach with a non-experimental cross-sectional design and a descriptive scope. The sample was made up of 95 inhabitants, selected through non-probabilistic convenience sampling, representing a population of 85,467 inhabitants of the mentioned region. A questionnaire of 30 closed questions on an ordinal/Likert scale was used to collect data. This instrument was validated using Aiken's alpha coefficient, ensuring the items were relevant and appropriate for the study context. In addition, the Delphi method was applied to involve experts in electronic waste management, which allowed for obtaining a consensus on the best practices and strategies to implement. The main results indicate that electronic waste management moderately influences environmental sustainability. This is evidenced through the Spearman coefficients: 0.363 for the dependent and independent variables, 0.358 for storage, 0.376 for disposition and transformation with a p-value of 0.000, and 0.327 for handling and collection with a p-value of 0.001 in all cases. The main conclusion is that electronic waste management contributes to environmental sustainability, highlighting the importance of managing this waste for the sustainable development of our environmental environment.*

Keywords - *Electronic waste management, Environmental sustainability, Municipalities of northern Perú, Impact analysis, Sustainable development.*

1. Introduction

The management of electronic waste (WEEE) has become a vital issue within environmental sustainability, both globally and regionally, especially in northern Peru. As population growth and technological consumption increase, the need to analyze the current state and projections on the public management of this waste becomes evident, specifically framing municipalities at the district and provincial levels. Despite the growing recognition of this problem, there is a notable research gap in terms of evaluating the specific impact that inadequate management of WEEE has on environmental sustainability in local contexts.

This article presents an unpublished quantitative analysis that directly relates electronic waste management with environmental sustainability indicators in a region where the problem has historically been underestimated by the Ministry of the Environment. For the management and handling of waste from electrical and electronic equipment in Peru, a framework of responsibilities is established for the different actors involved in the life cycle of this waste. Producers have an obligation to design, implement and manage management systems, either individually or collectively, ensuring that these are managed correctly from collection to final disposal. They must submit a Management Plan to the Ministry of the Environment and guarantee the free reception of these wastes to their clients. For their part, authorized operators are responsible for treatment and recycling, while local governments must facilitate the implementation of collection programs and establish collection points.

In Peru, longitudinal studies and comparative analyses on electronic waste in the northern regions show a significant increase in generating these wastes. It is estimated that more than 100,000 tons of electrical and electronic equipment are generated each year. According to the Ministry of Environment's Solid Waste Management Information System (Sigersol), 5,724.4 tons were recycled in 2020, which increased to 11,175.8 tons in 2021 and exceeded 14,700 tons in 2022.

Fig. 1 Departmental map of peru

For 2023, it was estimated that around 129,200 tons of WEEE would be generated, coming from households, private companies and public entities. However, effective collection remains low. In regions such as La Libertad and Lambayeque, initiatives have been implemented to improve WEEE management, but a high level of informality in recycling persists. Comparatively, while Lima has developed more structured programs, the northern regions face greater challenges in raising awareness and the infrastructure necessary for the proper management of this waste. This reflects the urgent need to strengthen region-specific policies and strategies, promoting a more sustainable approach to e-waste management. Thanks to a collaboration between the Ministry of the Environment (Minam), Enel Distribución Perú and the collective waste management system Recolecc, 11 collection points for Waste Electrical and Electronic Equipment (WEEE) have been opened in various cities in Lima, Callao and the Norte Chico. This recently launched initiative aims to promote the recycling of WEEE nationwide, thus promoting the responsible disposal of disused electrical and electronic equipment and contributing to the circular economy. The new collection points are in the Enel Distribución Perú service centres in the districts of Comas, San Juan de Lurigancho, Cercado de Lima, Bellavista, San Miguel, Puente Piedra, Independencia, Callao, Huaral, Huacho and Barranca. This increase in the valorization of WEEE is due to the implementation of management plans by the producing companies, which assume the responsibility of collecting this waste under the principle of Extended Producer Responsibility (EPR), which is essential to reduce the environmental and health risks associated with inadequate management of this waste [1]. The topic of addressing electronic waste management with the passage of time has become more relevant in recent decades because population growth is proportional to technological consumption derived from a modern society that is involved in becoming aware of what it should do. The plan regarding the life cycle from the beginning of its creation until its correct recycling [2]. At the end of their useful life, a large percentage of electrical and electronic equipment ends up in informal recycling without adequate environmental measures. This practice is common due to the high cost required for good recycling management compared to common waste [3].

An objective of the research is to determine the status of treating these wastes at the local and regional levels in the municipal sector. According to Islam (2021), the technology sector in the world is growing rapidly due to the short period of technological validity and obsolescence [4]. There are currently 900 types of electrical and electronic appliance groups in the total inventory available in the global market. This number represents the diversity of electrical and electronic product categories in the global market, including a wide range of devices such as household appliances, computers, mobile phones, and audio and video equipment, among others. In 2019, it generated 53.6 million tons of waste, which implies a challenge for proper recycling and thus not negatively impacting the environment and the population's health. That is why it must be given the corresponding importance within international and local policies since it is projected for the year 2050 to have a total of 111 million tons per year [5].

Fig. 2 Technological waste

In the international context, Apprey (2024), in their research, focused on analyzing the management and recycling practices of electronic waste in the municipality of Ho, Ghana, intending to develop comprehensive strategies. They found that implementing recycling policies and initiatives in the region helps promote a better future. Based on these findings, the need for interested parties to publish and disseminate information on appropriate methods for recycling electronic waste and the associated legal framework is highlighted. Likewise, the importance of carrying out environmental awareness campaigns among repairers and the general population, aligned with the improvement of sustainable development, is emphasized[6]. On the other hand, Mir and Chang (2024) in their research analyzed the management of electronic waste in Saudi Arabia, which aimed to contribute to the current discourse around the management of this waste in the country, offering valuable ideas for formulators. Policies, researchers, and stakeholders, where improving existing strategies were implemented to address the growing dilemma of electronic waste, evaluating its effectiveness and potential areas for improvement.

These findings highlight key challenges that hinder optimal e-waste management practices, including regulatory gaps, technological obsolescence, and awareness gaps. Additionally, opportunities for innovation, collaboration and policy refinement are examined to address these challenges and build a more sustainable e-waste management ecosystem[7]. Likewise, He (2023), in their study, determined the process of gold extraction from electronic waste; the research was carried out in a laboratory, where different methods of gold recovery were evaluated, including hydrometallurgical, pyrometallurgical, mechanical, electrochemical and biotechnological. To address this problem, environmental impact assessments of different extraction methods were carried out, and possible improvements were explored. The results obtained indicate that certain methods, both mechanical and electrochemical, can significantly reduce polluting emissions by up to 99%.

It is highlighted that using electricity and force for gold extraction is positioned as a superior alternative to other methods, demonstrating effectiveness, viability and promising practical potential[8]. At the national level, Dextre Minaya (2020), in his research, quantified the environmental impacts generated by the management of electrical and electronic equipment waste carried out by the waste operating company COMIMTEL SAC. To do this, the life cycle analysis methodology was used, which is presented as an effective tool for managing electronic waste in Peru. In total, 18 environmental impact categories were considered in the analysis. As a result, it was found that this management system decreases 7 evaluated impact categories but contributes to the increase of the remaining 11 categories[9]. On the other hand, Carpio del Carpio and Cruz Calcina (2021) in their research analyzed the management of electronic waste in the municipality of Arequipa, to identify opportunities for improvement. The study, of applied type and mixed approach, collected descriptive and non-experimental data through two samples: one of 64 homes and another of this waste generated between 2013 and 2020. The findings revealed that the municipality did not have a treatment process nor adequate final disposal for this waste, but rather transferred it to an outsourcing company under the agreement. In addition, it was found that (73%) of the population did not know how to dispose of them properly, while a significant percentage (37.5%) sold them informally and another (34%) stored them in their homes. In conclusion, the municipality lacks a comprehensive management system for electronic devices, limiting itself to carrying out collection campaigns [10].

Likewise, Sifuentes (2023) study analyzed the recycling management by the students of the sixth cycle of the José Faustino Sánchez Carreón National University in the year 2022; for this, a basic methodology with a correlational scope was used, where surveys were used, documents were analyzed and SPSS 25.0 software was used, which found that there is a negative value of 1.26, which concludes that there is a negative relationship between these two components. When the proposed method was used, a positive relationship between both components was achieved [11]. In the local context, Gastelo (2019) in his research designed a management system to adequately manage electronic waste generated in homes in the Chiclayo district, doing a non-experimental descriptive study, applying surveys to 128 homes in the district to determine the amount of electronic waste generated by each home, finding differences according to the socioeconomic level, for this a management system was proposed involving various entities and the same population.

Fig. 3 Composition of electronic waste

Fig. 4 Electronic waste management stages

The purpose of this system was to collect and take this electronic waste to a treatment plant in Lima, where the usable components will be separated for recycling, thus properly disposing of the dangerous components in safe landfills. This concludes that this can help reduce the inappropriate disposal of electronic waste, control the emission of pollutants, and, in general, reduce the negative environmental impact generated by this waste [12]. Consequently, Orrillo Guerrero and Pérez Lozada (2019) in their research described the habits of use and reuse of electronic goods in public institutions of Lambayeque, such as the provincial municipality, the public benefit society, the local management unit and the national university. Pedro Ruiz Gallo. They used an applied methodology with quantitative data where variables such as "Use and reuse habits" and "Waste management" were defined, data were collected through surveys and interviews, and the information was analyzed with empirical and theoretical methods, which led to conclusions and new knowledge. Useful recommendations were formulated for future researchers, and through the findings, a proposal was created to promote a culture of electronic asset management in local public institutions, thus meeting the research objectives [13]. On the other hand, Orrego Campos and Vasquez Montaño (2021) in their study focused on evaluating the feasibility of establishing a recycling plant for electrical and electronic devices in Lambayeque in 2021, using an applied methodological approach with quantitative orientation and a descriptive design not experimental. The sample included 384 residents of Lambayeque aged 15 to 64 out of a total of 766,439 individuals. A survey was applied to collect data on demand, supply and purchasing behavior and identify potential customers. A market, technical and economic-financial feasibility analysis was carried out, where a finding of a potential demand for the collection and commercialization of this waste was obtained, along with technical feasibility and financial profitability, with a Net Present Value (NPV) of S/ 13,653.60, a cost-benefit index of 1.06 and an Internal Rate of Return of 2%. In conclusion, the proposed business plan was viable and profitable [14].

At a specific level, Mendoza (2023) in his research presented a management plan for the recycling of the electrical and electronic waste in Chiclayo, applying an ecological approach and an evaluation model for public interventions that integrate environmental social responsibility with a non-experimental quantitative approach and a sample of 385 respondents, revealing a high level of environmental pollution of 75.32% and a critical evaluation of electronic waste management practices with an index of 56.88%, requiring that authorities local communities sensitize the population on environmental issues to protect individual health and the environment, which concludes by proposing a plan that highlights the importance of environmental responsibility and community participation [15]. In general, inefficiency is observed in the municipalities of the northern region of Peru, which shows a significant accumulation of electronic waste without adequate recycling, which generates concern about its environmental impact.

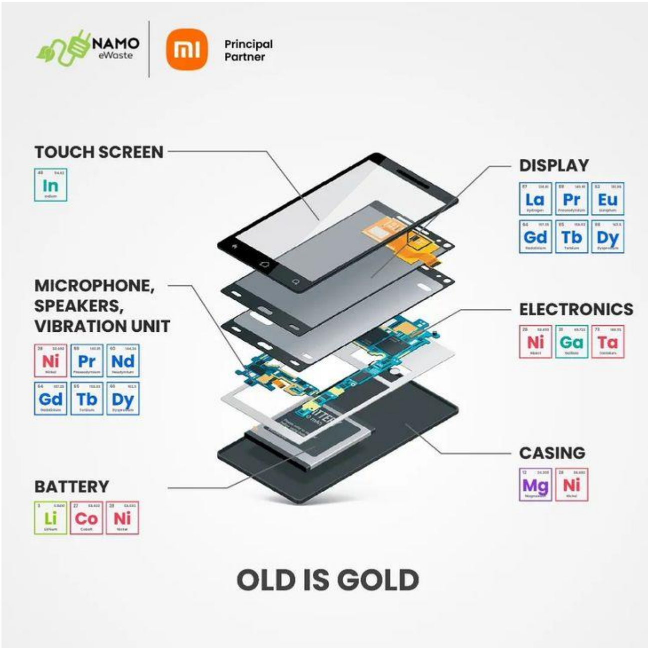

Fig. 5 Presence of lead in waste electrical and electronic equipment

Fig. 6 Only 20% of the world's e-waste is recycled, and its volume is expected to continue growing

Although sensitization and awareness efforts have been implemented, it is necessary to work on promoting sustainability and thus generate change. Consequently, the following problem was raised: i) What is the relationship between the analysis of electronic waste management and its influence on environmental sustainability in the municipalities of the northern region of Peru? In addition, the following specific problems were addressed: ii) What is the relationship between the management and collection of electronic waste and the influence on environmental sustainability in the municipalities of the northern region of Peru? iii) What is the relationship between the storage of electronic waste and the influence on environmental sustainability in the municipalities of the northern region of Peru? iv) What is the relationship between the disposal and transformation of electronic waste and the influence on environmental sustainability in the municipalities of the northern region of Peru?.

2. Theoretical Bases

From a practical justification, Daly (1996) highlighted in his visionary and exemplary approach to the theory of environmental sustainability the proposal of solutions to address environmental problems from a sustainable perspective, supporting the urgency of implementing effective strategies for the sustainable management of resources. Electronic waste [16] regarding the theoretical justification, Braungart (2007) provided us with a holistic and regenerative vision of product and waste management. Instead of focusing solely on waste disposal at the end of a product's life, he proposed a model that challenges the traditional notion of "cradle to grave" and promotes the idea of "cradle to cradle.", which seeks the reuse and recovery of materials, creating a continuous cycle of production and regeneration [17].

Likewise, Macarthur and Heading (2019) have highlighted the importance of rethinking the traditional paradigm of linear production and consumption towards a circular approach that promotes the regeneration of natural resources and the reduction of environmental impacts [18]. In terms of methodological justification, Lys and Sabino (1992) highlighted the importance of a rigorous conceptualization of the components of reasoning, which gives scientific knowledge a precise and defined interpretation [19]. This conceptual precision is crucial in quantitative research to ensure the accuracy and reliability of the results. This gives us greater focus when relating the established variables.

The general objective set was to evaluate whether there is a relationship between Analysis of electronic waste management and its influence on environmental sustainability in the municipalities of the northern region of Peru (1) In turn, the specific objectives were: (2) Analyze if there is a relationship between the management and collection of electronic waste and the influence on environmental sustainability in the municipalities of the northern region of Peru (3) Determine if there is a relationship between the storage of electronic waste and the influence on environmental sustainability in the municipalities of the northern region of Peru? (4) Evaluate whether there is a relationship between the disposal and transformation of electronic waste and the influence on environmental sustainability in the municipalities of the northern region of Peru. The following general hypothesis has been formulated: (1) There is a significant relationship between the analysis of electronic waste management and its influence on environmental sustainability in the municipalities of the northern region of Peru.

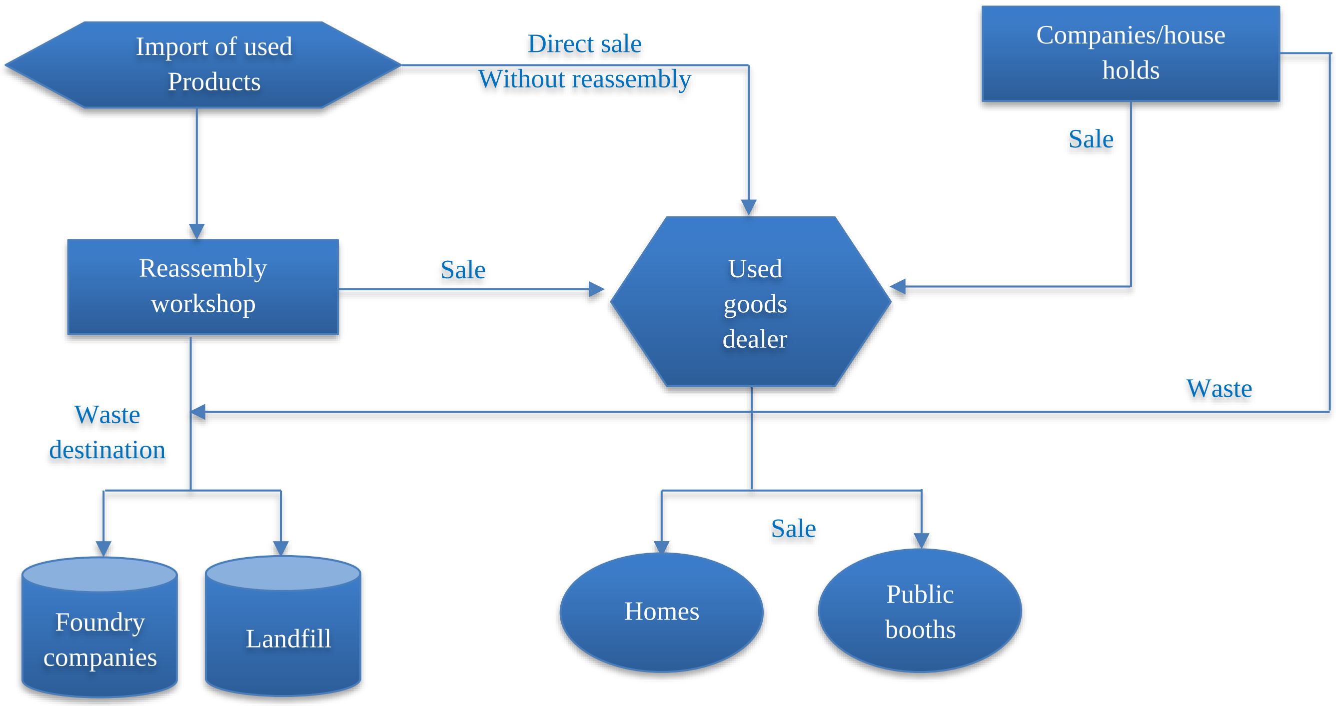

Fig. 7 Distribution chain of second-hand computer products and final disposal of waste

Likewise, the null hypothesis is the following: (2) There is no significant relationship between the analysis of electronic waste management and its influence on environmental sustainability in the municipalities of the northern region of Peru.

3. Methodology

3.1. Research Type and Design

3.1.1. Kind of Investigation

Research methodology and applied research are subjects that provide continuity and coherence to research, considering it as a transversal axis in the professional training process [20].

This study is applied, the objective of which is to generate knowledge to propose concrete solutions, focusing on results that contribute to developing and improving electronic waste management in the municipalities of the northern region of Peru.

3.1.2. Research Design

This study is based on a quantitative approach, non-experimental design, cross-sectional, with descriptive scope since if we have good electronic waste management, this will influence environmental sustainability. This means it is carried out within an established period and time [21].

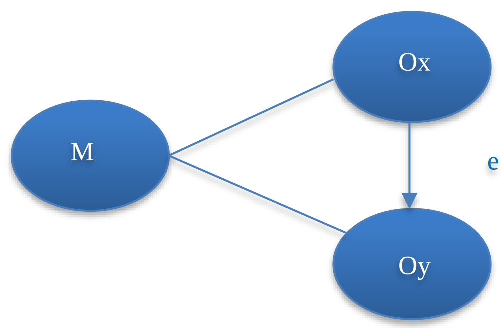

Fig. 8 Research design

Where:
M: Provincial municipalities
Ox: Electronic waste management
Oy: Environmental sustainability

3.2. Operationalization Variable

3.2.1. Independent Variable

Electronic waste management.

3.2.2. Conceptual Definition

According to Gusukum (2022), the conceptual definition of electronic waste management focuses on the study of the flows of this waste, its environmental and economic impact, and the design of strategies and policies that promote sustainable management within the framework of the economy. Circular [22].

3.2.3. Circular Economy

Proper e-waste management includes the collection, processing, and safe disposal of electronic devices to minimize the release of these metals into the environment and protect human health (de Granda-Orive & García-Quero, 2020) [23].

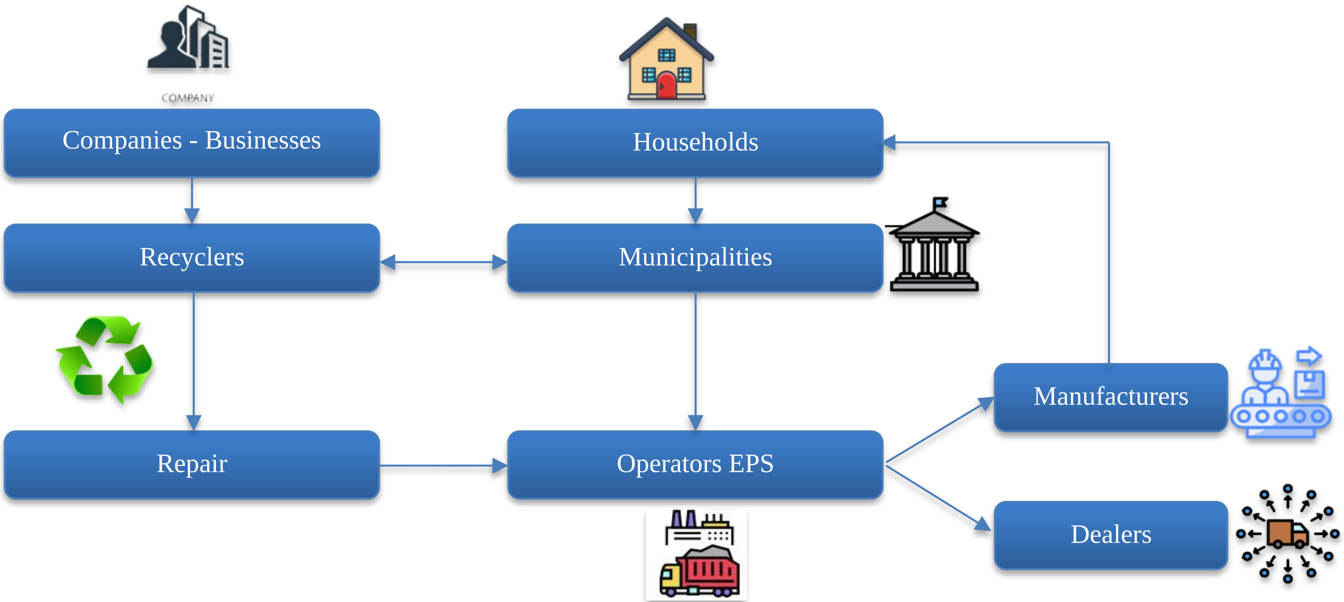

Fig. 9 Participants in the management of WEEE

3.2.4. Indicators

For the management and collection dimensions we have the following indicators: types of electronic waste, management plan and adequate mechanisms and collection.

For the storage dimension, we have the following indicators: capacity, mechanisms and treatment. For the disposal and transformation dimension, we have the following indicators: sanitary landfill, reuse and recovery.

3.2.5. Measurement Scale

Likert scales.

3.2.6. Dependent Variable

Environmental sustainability.

3.2.7.Conceptual Definition

The management of electronic waste is crucial to minimize pollution, preserve natural resources and protect biodiversity, which in turn contributes to environmental sustainability. For this to be achieved, it is essential that all actors involved, including the government, companies and society in general, participate and assume shared responsibilities [24].

3.2.8. Operational Definition

According to Sifuentes (2023), Descriptive research collects quantitative data to draw statistical conclusions about the target population, highlighting and better measuring the relevance of certain aspects through data analysis. Although it uses closed-ended questions that may limit its ability to provide unique information; when used effectively, it can help organizations better understand the importance of certain aspects to the target population and people they represent [11].

3.2.9. Indicators Assesing Social Impacts

For the social impact dimension, we have the following indicators: work opportunity, recycling and the reappearance of devices, education and awareness, and social responsibility. For the environmental impact dimension, we have the following indicators: waste from electrical and electronic devices, soil quality, and air quality. We have the following indicators for the perception dimension: special treatment, responsibility and measures.

3.3. Population, Sample and Sampling

3.3.1. Population

Refers to the totality of elements or events that share a common characteristic, being of interest for a specific study or experiment [25]. The population under study consisted of 85,467 inhabitants of the selected municipalities in the northern region of Peru. A non-probabilistic convenience sampling method was used for data collection, selecting a sample of 95 inhabitants. This approach was justified due to logistical and temporal limitations, allowing for the obtaining of representative data for analysis.

- Inclusion criterion: Inhabitants of the province of Lambayeque.
- Exclusion criterion: Inhabitants who do not live in Lambayeque.

3.3.2. Sample

In the present study, a sample size of 95 inhabitants was used, which allows inferences to be made about the total population of 85,467 inhabitants in the selected municipalities. To ensure the validity of the results, a margin of error of 5% and a confidence level of 95% were established. It is a selected part of the population extracted using specific techniques or procedures [26].

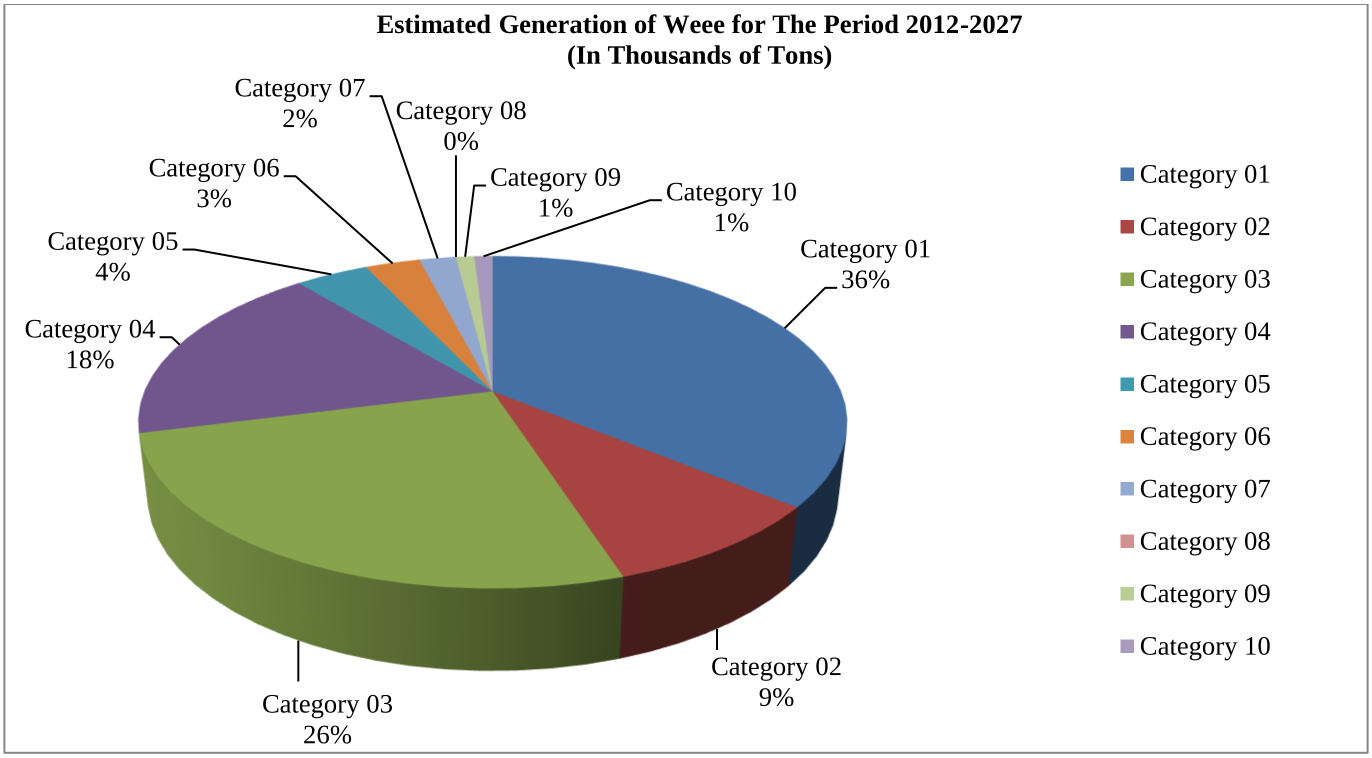

Fig. 10 Estimated generation of WWEEE for the period 2021-2027

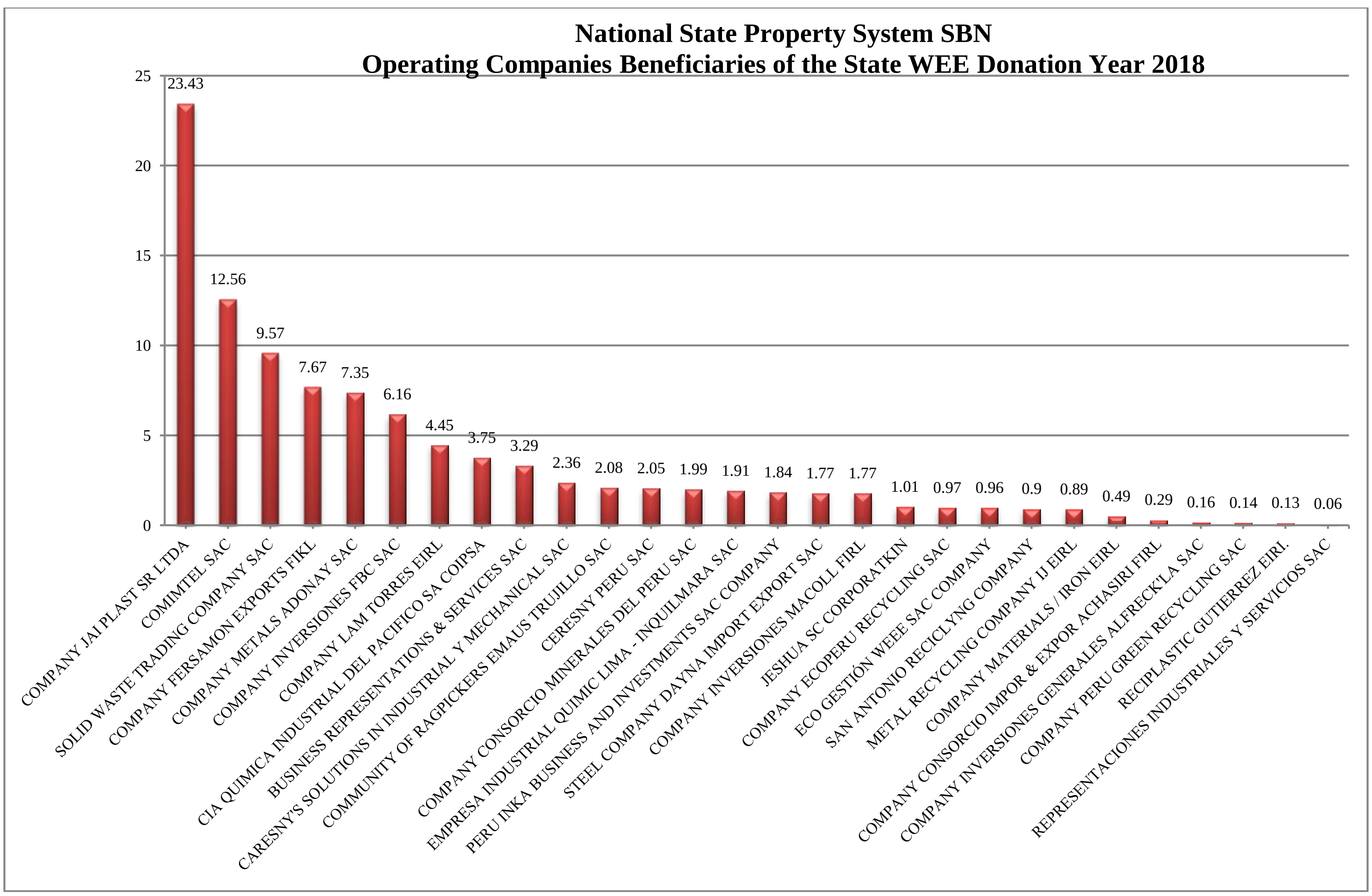

Fig. 11 Operating company's beneficiaries of the state WEEE donation

3.3.3. Sampling

It is a technique used to select a sample size. It can be probabilistic, where all elements have the same probability of being chosen, or non-probabilistic, where the selection is intentional and based on the experience or theoretical background of the researcher [27]. In our work, non-probabilistic sampling will be considered. Unit of analysis: 95 inhabitants of the province of Lambayeque.

3.4. Data Collection Techniques and Instruments

3.4.1. Data Collection Techniques

The technique to be used in our research is data collection and survey. This technique can be carried out using tools such as questionnaires, tests or knowledge tests, which allows obtaining precise and relevant data about the participants [28].

3.4.2. Data Collection Instruments

A questionnaire was designed consisting of 30 closed questions, structured on an ordinal/Likert scale. This questionnaire was validated by experts in the field, ensuring that the questions were clear and relevant to the study's objectives. The questionnaire was administered directly to the participants, ensuring adequate data collection. Validation of the questionnaire using Aiken's alpha coefficient ensured that the items were relevant and appropriate to the study context.

This rigorous approach to instrument validation goes beyond common practices in previous studies, where the lack of adequate validation could have compromised the quality of the data collected. According to Caparó (2016) they tell us that the questionnaire is an instrument that consists of a series of questions or items about a research topic that you want to know, which are applied to a specific group of people. This tool allows information to be collected in a systematic and standardized manner, facilitating the subsequent analysis of the data obtained [29].

3.4.3. Reliability

Cronbach's Alpha coefficient was used to evaluate the coherence and corroborate the consistency of the results derived from the instrument used; the coefficient showed an acceptable level of reliability.

The instrument that measures electronic waste management and environmental sustainability demonstrated a high level of reliability, with a Cronbach's Alpha of 0.868.

This indicates excellent internal consistency in its 30 elements. The instrument that measures electronic waste management showed high reliability, reflected in a Cronbach's Alpha of 0.842. This suggests a very good internal consistency in the 20 items that make up the instrument. The instrument that measures electronic waste management presented acceptable reliability, with a Cronbach's Alpha of 0.742. This indicates adequate internal consistency in the 10 elements evaluated.

Fig. 12 Electronic waste recycling symbols

Table 1. Technical sheet of measuring instruments

Instrument Technical Sheet	
Name:	Quiz
Authors:	-Castañeda Ramírez, Jean -Granda Novoa, Joser Emanuel -Izquierdo Yrigoin, Arly Briggitte -Jiménez Flores, Manuel -Medina Diaz, Lenard -Vílchez Romero, Javier
Year:	2024
Type of instrument:	Questionnaire
Objective:	Determine the relationship between variable
Population:	Inhabitants of Lambayeque
Number of items:	30 items in total, divided for variable 1, 20 items and for the other variable 10.
Application:	Direct
Administration time:	10 minutes
Scale:	Likert: (5) Always, (4) Almost Always, (3) Sometimes, (2) Almost Never, (1) Never
Level and rank:	Variable1: Bad (20-46), good (47-72) and average (73-10) Variable 2: Bad (20-46), good (47-72) and average (73-10)

Table 2. Reliability of the instrument that measures electronic waste management and environmental sustainability

Cronbach Alpha	Number of Elements
868	30

Table 3. High reliability of the instrument that measures electronic waste management

Cronbach Alpha	Number of Elements
842	20

Table 4. Acceptable reliability of the instrument that measures electronic waste management

Cronbach Alpha	Number of Elements
742	10

3.5. Data Collection Procedure

For the variables, questionnaires validated in the thesis were used; the task was carried out through Google Forms, which consists of 30 questions within the dimensions established in each variable, and the information was carried out in Microsoft Excel and then in the statistical program SPSS version 28. After extracting tabular and graphically interpreted results (descriptive statistics) and comparing each hypothesis, the principle of naturalness was considered, and the Pearson correlation coefficient was used (Parametric test) since our normality test is greater than 0.05. After obtaining this result, the corresponding interpretations are given.

3.6. Data Analysis Method

SPSS version 28 software was used to examine the data. This program facilitated the application of the Likert scale method, obtaining Cronbach's Alpha coefficient and calculating the Pearson correlation. Subsequently, Microsoft Excel spreadsheets were used to obtain the results of each variable. Then, we returned to the SPSS program to obtain the results corresponding to the study sample and to accurately express the data collected in the descriptive analysis. Finally, frequency tables accompanied by bar graphs were generated.

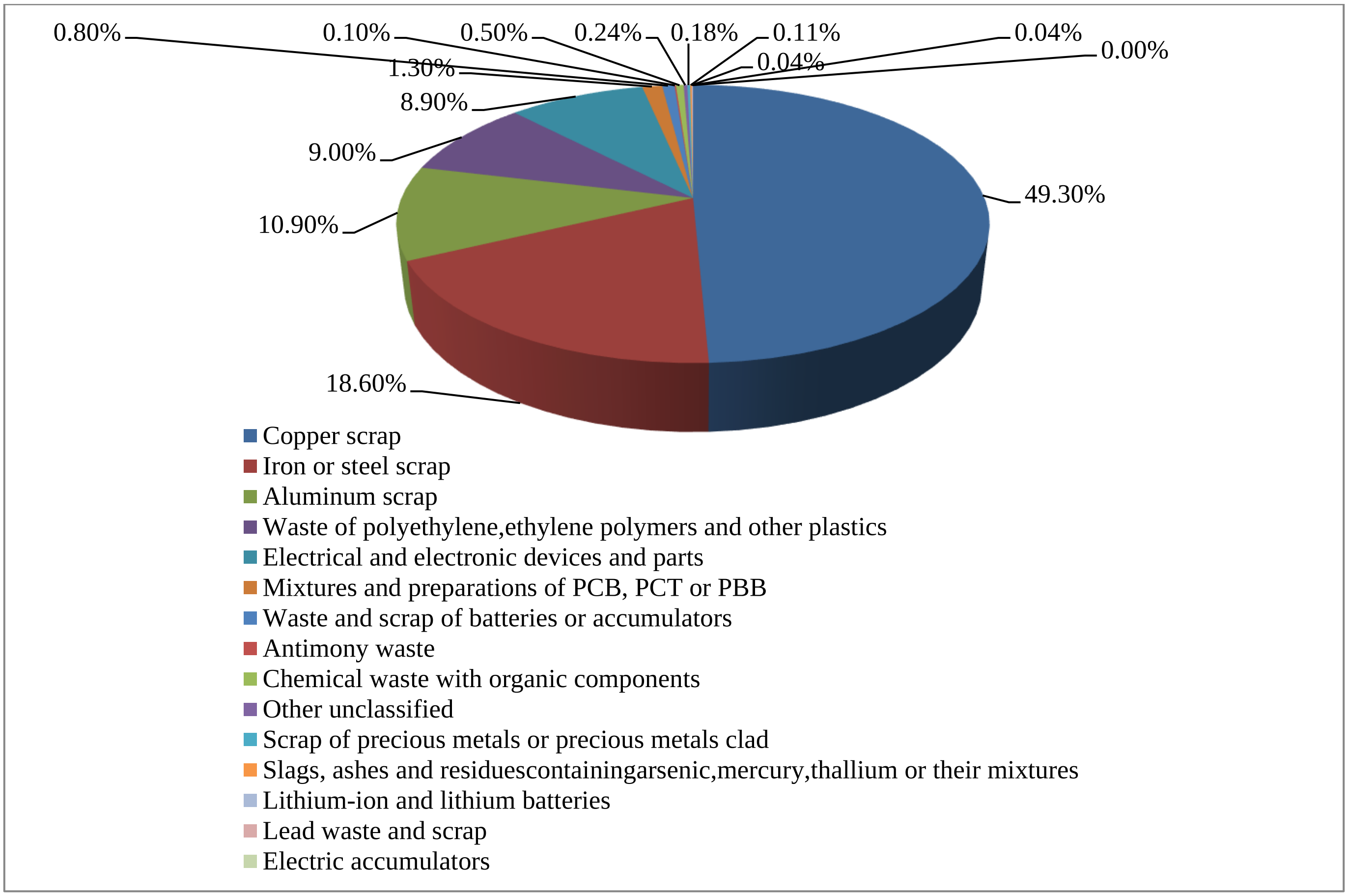

Fig. 13 Materials, devices and components recovered and exported by WEEE managers

3.7. Ethical Aspects

This research study was prepared by students under the supervision of our teacher, who emphasized the importance of values and promoted ethical research. In this sense, we have executed adequate citations, including all the necessary elements, and respecting copyright. Furthermore, we are committed to maintaining the complete privacy of respondents. This way, we ensure that the information collected is kept secure and participants' privacy is respected. This involves allowing them to ask questions and provide information, thus promoting an equitable relationship between researchers and participants. However, in accordance with University Council Resolution 0262-2020/UCV, often known as the Code of Research Ethics, particularly its article 9, which addresses the originality policy, we are committed to avoiding any form of copying. Unauthorized is considered unlawful conduct that involves representing the thoughts or works of another individual as one's own, either in whole or in part. Consequently, this work has been done with due respect to other authors, and any form of plagiarism has been avoided.

4. Results

4.1. Descriptive Analysis

4.1.1. Evaluation Scale of the Variables

Table 5 shows the scores, ranges and levels for the e-waste management and environmental sustainability variables.The electronic waste management variable was evaluated using a scale that assigned scores at three levels: bad, fair and good. E-waste management had a score range of 20 to 100; a score between 20 and 46 was considered poor, between 47 and 72 fair, and between 73 and 100 good. In the management and collection dimension, the scores ranged between 9 and 45; it was considered poor between 9 and 20, fair between 21 and 32, and good between 33 and 45. For storage, the scores ranged from 4 to 20; a range of 4 to 8 was classified as poor, 9 to 14 as fair, and 15 to 20 as good. Regarding disposition and transformation, the scores varied between 7 and 35; they were considered bad between 7 and 15, fair between 16 and 25, and good between 26 and 35. The environmental sustainability variable was evaluated using a scale that assigned scores at three levels: bad, fair and good. Environmental sustainability had a range of scores from 10 to 50; it was considered bad between 10 and 23, fair between 24 and 36, and good between 37 and 50.

In the social impact dimension, the scores ranged between 3 and 15; a score between 3 and 6 was considered bad, between 7 and 10 average, and between 11 and 15 good. For environmental impact, scores also ranged between 3 and 15; It was classified as bad between 3 and 6, fair between 7 and 10, and good between 11 and 15. Regarding perception, the scores ranged from 4 to 20; It was considered bad between 4 and 8, fair between 9 and 14, and good between 15 and 20.

Table 5. Scale of the electronic waste management variable

Variable and Dimensions	Scores		Levels		
	Minimum	Maximum	Bad	Fair	Good
Electronic waste management	20	100	20-46	47-72	73-100
Handling and collection	9	45	9-20	21-32	33-45
Storage	4	20	4-8	9-14	15-20
Layout and transformation	7	35	7-15	16-25	26-35

Table 6. The scale of environmental sustainability variable

Variable and Dimensions	Scores		Levels		
	Minimum	Maximum	Malo	Minimum	Maximum
Environmental sustainability	10	50	20-46	47-72	73-100
Social impact	3	15	3-6	7-10	11-15
Environmental impact	3	15	3-6	7-10	11-15
Perception	4	20	4-8	9-14	15-20

4.1.2. Descriptive Analysis of the Results of the Variables

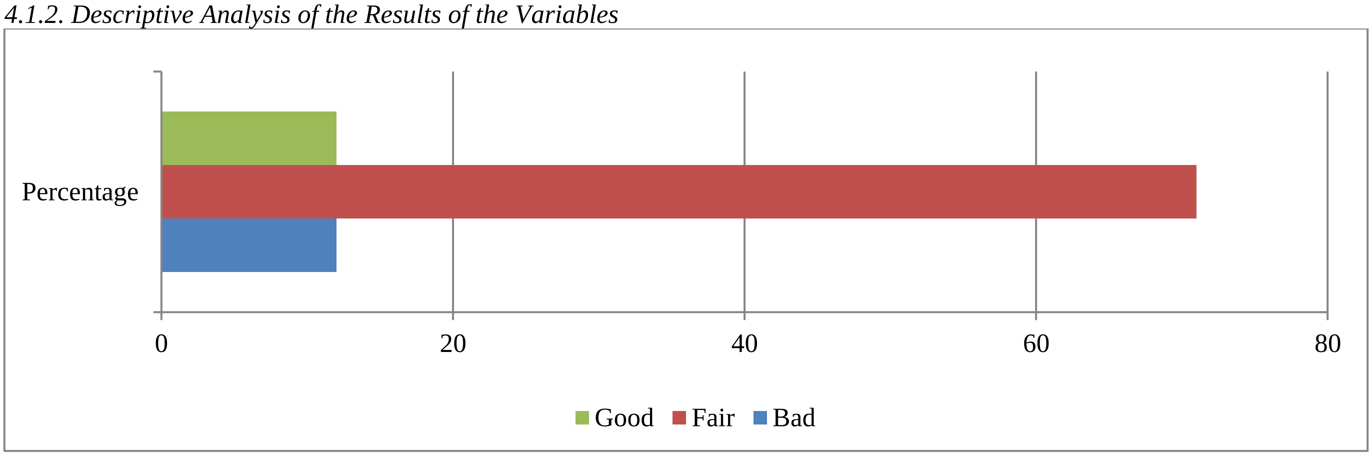

Fig. 14 Distribution of the electronic waste management variable

Table 7. Distribution of electronic waste management variable

		Frequency	Percentage	Valid Percentage	Accumulated Percentage
Valid	Bad	12	12,6	12,6	12,6
	Fair	71	74,7	74,7	87,4
	Good	12	12,6	12,6	100,0
	Total	95	100,0	100,0	

Table 8. Distribution of the dimensions of the electronic waste management variable

Variable	Bad		Fair		Good		Total	
	N	%	N	%	N	%	N	%
Handling and collection	22	23,2	57	60	16	16,8	95	100%
Storage	16	16,8	67	70,5	12	12,6	95	100%
Layout and transformation	13	13,7	65	68,4	17	17,9	95	100%

The distribution of the electronic waste management variable showed that most respondents, 74.7%, rated the management as fair; 12.6% considered it bad, while another 12.6% evaluated it as good. Of the 95 respondents, all data were valid, adding up to 100% of the total responses.

The distribution of the dimensions of the electronic waste management variable showed that, in the management and collection dimension, 60% of respondents rated it as fair, 23.2% as bad, and 16.8% as good. In the storage dimension, 70.5% evaluated it as fair, 16.8% as bad and 12.6% as good. For the dimension of disposition and transformation, 68.4% considered it fair, 13.7% as bad, and 17.9% as good. All 95 respondents provided valid answers in all dimensions, representing 100% of the total.

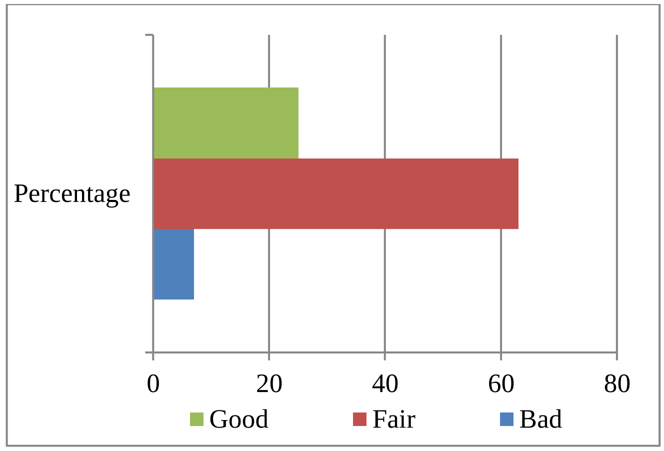

Fig. 15 Distribution of the environmental sustainability variable

Table 9. Distribution of the environmental sustainability variable

		Frequency	Percentage	Valid Percentage	Accumulated Percentage
Valid	Bad	7	7,4	7,4	7,4
	Fair	63	66,3	66,3	73,7
	Good	25	26,3	26,3	100,0
	Total	95	100,0	100,0	

Table 10. Distribution of the dimensions of the environmental sustainability variable

Variable	Bad		Fair		Good		Total	
	N	%	N	%	N	%	N	%
Social impact	10	10,5	38	40	47	49,5	95	100%
Environmental impact	15	15,8	57	60	23	24,2	95	100%
Perception	8	8,4	41	43,2	46	48,4	95	100%

The distribution of the environmental sustainability variable showed that 66.3% of respondents rated sustainability as fair, 26.3% evaluated it as good, and 7.4% as bad. Of the 95 respondents, all data were valid, representing 100% of the total responses. This suggests that the majority perceive moderate performance in terms of environmental sustainability, with a significant minority considering that good results are being achieved.

The distribution of the dimensions of the environmental sustainability variable showed that, in the social impact dimension, 49.5% of respondents rated it as good, 40% as fair, and 10.5% as bad. In the environmental impact dimension, 60% evaluated it as fair, 24.2% as good and 15.8% as bad. Regarding perception, 48.4% considered it good, 43.2% average and 8.4% bad. All 95 respondents provided valid answers in all dimensions, representing 100% of the total.

4.1.3. Two-Dimensional Descriptive Analysis of the Variables

The two-dimensional table that relates electronic waste management and environmental sustainability variables showed that, of the 12 respondents who rated electronic waste management as poor, 5 also evaluated environmental sustainability as poor, 5 as fair, and 2 as good.

Among the 71 rated e-waste management as fair, 2 rated environmental sustainability as poor, 53 as fair, and 16 as good. Finally, of the 12 that rated e-waste management as good, none evaluated environmental sustainability as poor, 5 as fair, and 7 as good. In total, 95 respondents participated.

Table 11. Two-dimensional table of the variables solid waste management and environmental sustainability

		Environmental Sustainability			Total
		Bad	Fair	Good	
Electronic waste management	Bad	5	5	2	12
	Fair	2	53	16	71
	Good	0	5	7	12
Total		7	63	25	95

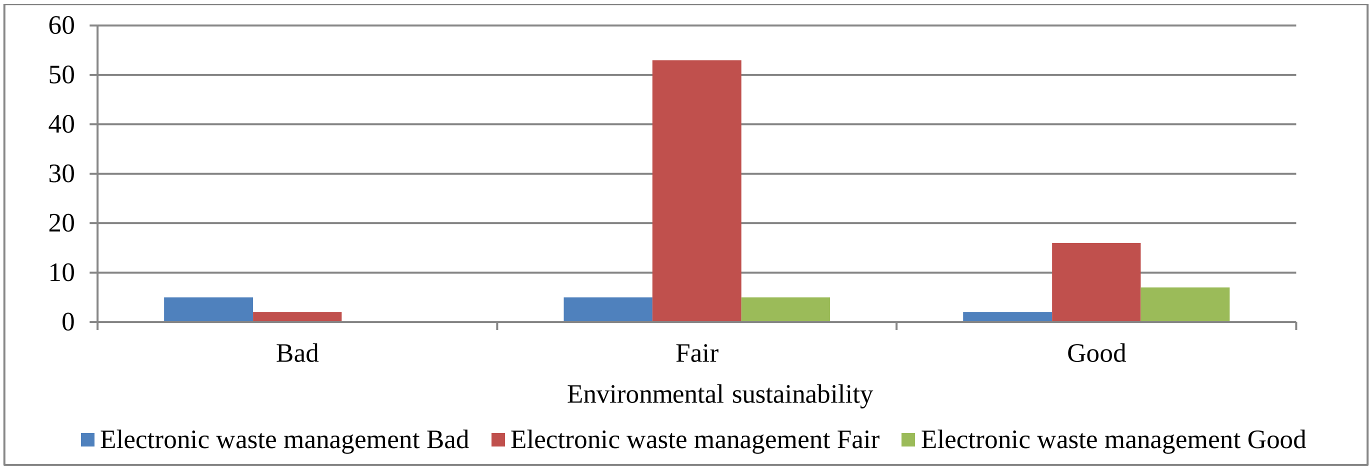

Fig. 16 Two-dimensional graph of the variables solid waste management and environmental sustainability

Table 12. Two-dimensional management and collection table and environmental sustainability

		Environmental Sustainability			Total
		Bad	Fair	Good	
Handling and Collection	Bad	5	13	4	22
	Fair	2	43	12	57
	Good	0	7	9	16
Total		7	63	25	95

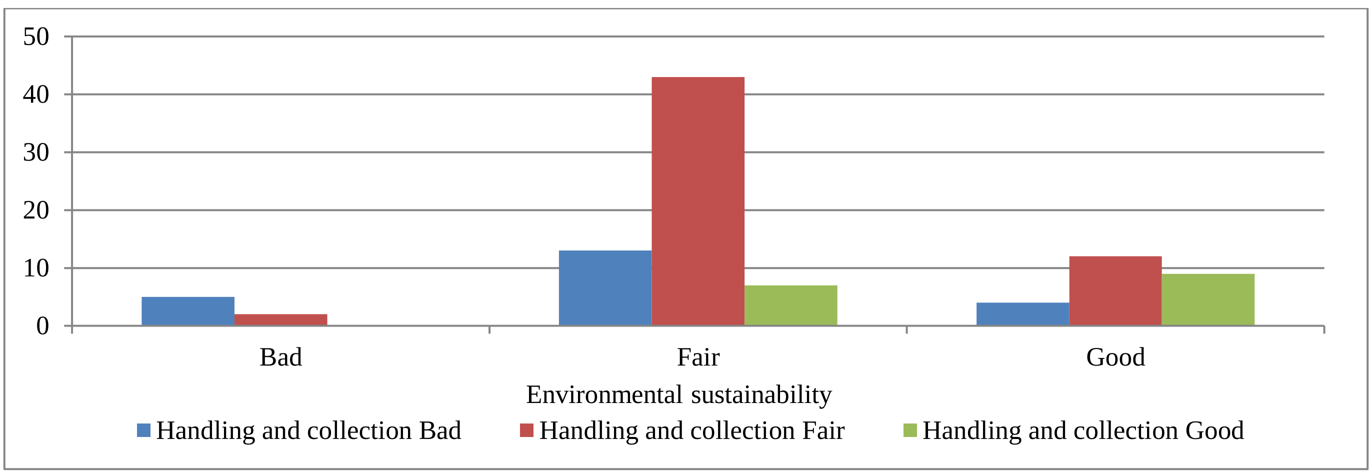

Fig. 17 Two-dimensional graph of management and collection and environmental sustainability

The two-dimensional table that relates the management and collection variables to environmental sustainability showed that, of the 22 respondents who rated management and collection as bad, 5 also evaluated environmental sustainability as bad, 13 as fair, and 4 as good. Among the 57 who considered management and collection fair, 2 rated environmental sustainability as poor, 43 as fair, and 12 as good. Finally, of the 16 that rated the management and collection as good, none evaluated the environmental sustainability as bad, 7 as fair and 9 as good. In total, 95 respondents participated.

Table 13. Two-dimensional storage and environmental sustainability table

		Environmental Sustainability			Total
		Bad	Fair	Good	
Storage	Bad	6	6	4	16
	Fair	1	53	13	67
	Good	0	4	8	12
Total		7	63	25	95

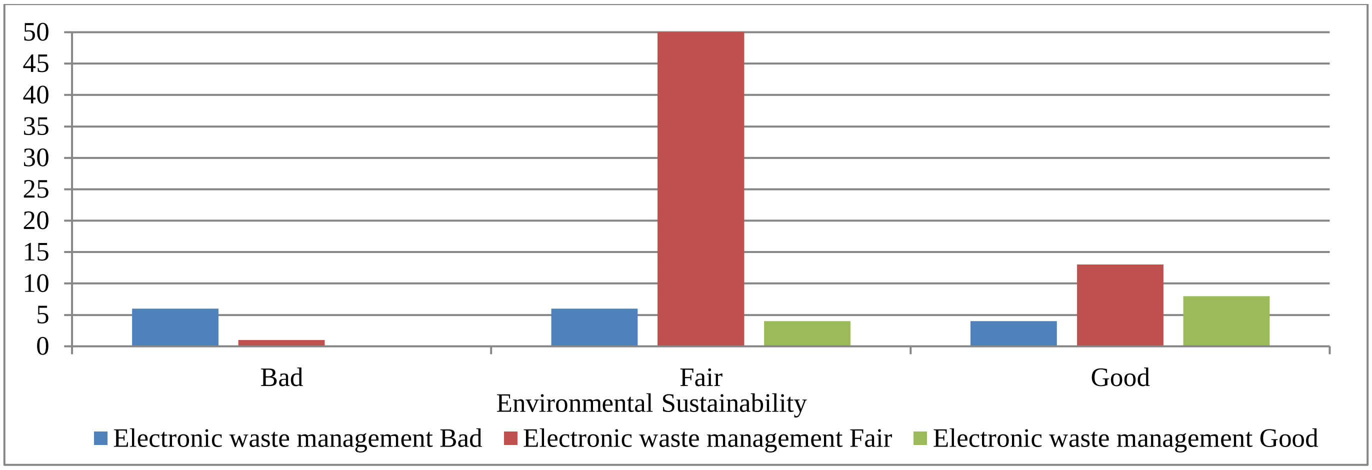

Fig. 18 Two-dimensional storage and environmental sustainability graph

The two-dimensional table relating storage variables to environmental sustainability showed that, of the 16 respondents who rated storage as poor, 6 also evaluated environmental sustainability as poor, 6 as fair, and 4 as good.

Among the 67 who rated storage as fair, 1 rated environmental sustainability as poor, 53 as fair, and 13 as good. Finally, of the 12 that rated storage as good, none evaluated environmental sustainability as poor, 4 as fair, and 8 as good. In total, 95 respondents participated.

Table 14. Two-dimensional disposition and transformation and environmental sustainability

		Environmental Sustainability			Total
		Bad	Fair	Good	
Layout and Transformation	Bad	4	8	1	13
	Fair	3	47	15	65
	Good	0	8	9	17
Total		7	63	25	95

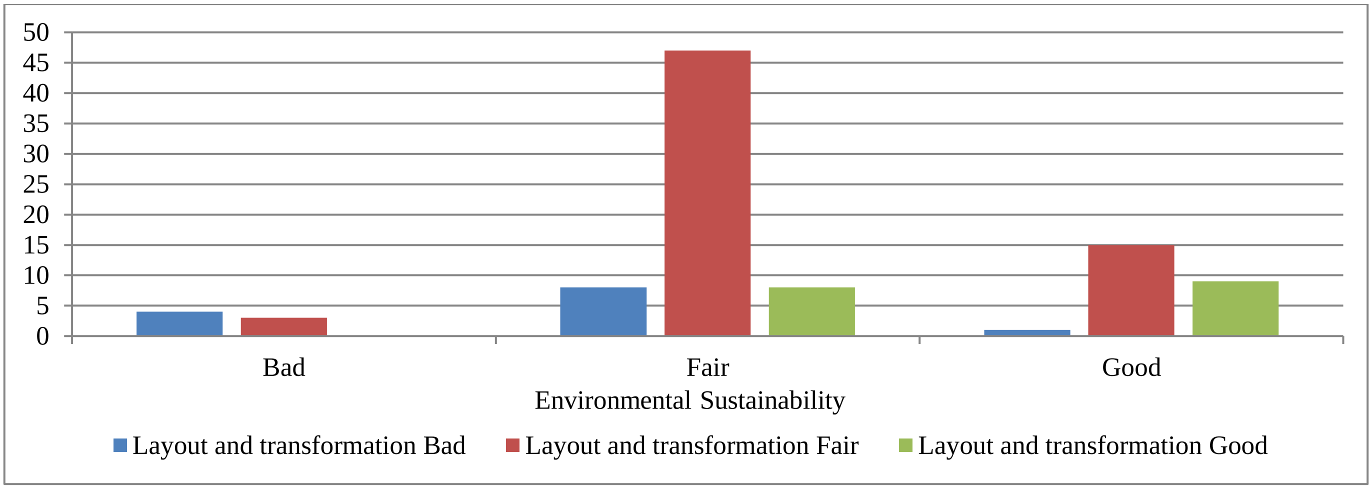

Fig. 19 Two-dimensional graph of disposition and transformation and environmental sustainability

The two-dimensional table relating the disposition and transformation variables to environmental sustainability showed that, of the 13 respondents who rated disposition and transformation as poor, 4 also evaluated environmental sustainability as poor, 8 as fair, and 1 as good. Among the 65 who considered the disposal and transformation fair, 3 rated environmental sustainability as bad, 47 as fair and 15 as good. Finally, of the 17 that rated the layout and transformation as good, none evaluated the environmental sustainability as bad, 8 as fair and 9 as good. In total, 95 respondents participated.

4.1.4. Inferential Analysis

The inferential results were analyzed in several stages. First, the regulations for decision-making were established. Then, the Kolmogorov-Smirnov normality test was applied since the sample was 95 cases. As the data did not show a normal distribution, it was decided to use the non-parametric Spearman Rho correlation technique to evaluate the hypotheses.

2nd Level of significance: α=0.05

3° We compare with the p_value

If the p_value <0.05, then the null hypothesis is rejected.

If the p_value>0.05, then the null hypothesis is not rejected.

4th Normality test

1st Hypothesis statement

Ho: The data follows a normal distribution

H1: The data does not follow a normal distribution

The Kolmogorov-Smirnov normality test applied to the managed variables yielded the following results: for electronic waste management (statistical = 0.374, p-value = 0.000), handling and collection (statistical = 0.308, p-value = 0.000), storage (statistic = 0.362, p-value = 0.000), disposal and transformation (statistic = 0.351, p-value = 0.000), environmental sustainability (statistic = 0.371, p-value = 0.000), social impact (statistic = 0.313, p-value = 0.000), environmental impact (statistical = 0.311, p-value = 0.000) and perception (statistical = 0.309, p-value = 0.000). In all cases, the p-values were less than 0.05, which leads to rejecting the null hypothesis (H0) and accepting the alternative hypothesis (H1), concluding that the data do not follow a normal distribution.

Table 15. Normality test

Variable	Kolmogorov-Smirnov[a]		
	Statistical	**gl**	**Sig.**
Electronic waste management	374	95	000
Handling and collection	308	95	000
Storage	362	95	000
Layout and transformation	351	95	000
Environmental sustainability	371	95	000
Social impact	313	95	000
Environmental impact	311	95	000
Perception	309	95	000

4.1.5. Hypothesis Testing (Spearman)

General Hypothesis

- H1: There is a relationship between the analysis of electronic waste management and its influence on environmental sustainability in the municipalities of the northern region of Peru.
- Ho: There is no relationship between the analysis of electronic waste management and its influence on environmental sustainability in the municipalities of the northern region of Peru.

In Table 16, the general hypothesis test using Spearman's Rho correlation coefficient between e-waste management and environmental sustainability yielded a result of 0.363 with a p-value of 0.000, which is interpreted as a medium positive correlation. Since the p-value is less than the significance level α = 0.05, the null hypothesis (Ho) was rejected, and the alternative hypothesis (H1) was accepted. This indicated a significant relationship between electronic waste management and its influence on environmental sustainability in the municipalities of the northern region of Peru.

Table 16. General hypothesis test

			Electronic Waste Management	**Environmental Sustainability**
Spearman's Rho	Electronic waste management	Correlation coefficient	1,000	363**
		Sig. (bilateral)	.	000
		N	95	95
	Environmental sustainability	Correlation coefficient	363**	1,000
		Sig. (bilateral)	000	.
		N	95	95
**.The correlation is significant at the 0.01 level (two-sided).				

Table 17. Specific hypothesis test 1

			Environmental Sustainability	Handling and Collection
Spearman's Rho	Environmental Sustainability	Correlation coefficient	1,000	327**
		Sig. (bilateral)	.	001
		N	95	95
	Handling and Collection	Correlation coefficient	327**	1,000
		Sig. (bilateral)	001	.
		N	95	95
**. The correlation is significant at the 0.01 level (two-sided).				

Table 18. Specific hypothesis test 2

			Environmental Sustainability	Storage
Spearman's Rho	Environmental Sustainability	Correlation Coefficient	1,000	,358**
		Sig. (bilateral)	.	,000
		N	95	95
	Storage	Correlation Coefficient	,358**	1,000
		Sig. (bilateral)	,000	.
		N	95	95
**. The correlation is significant at the 0.01 level (two-sided).				

Specific Hypothesis 1

- H1: There is a significant relationship between the management and collection of electronic waste and the influence on environmental sustainability in the municipalities of the northern region of Peru.
- Ho: There is no significant relationship between the management and collection of electronic waste and the influence on environmental sustainability in the municipalities of the northern region of Peru.In Table 17, the test of specific hypothesis 1 using Spearman's Rho correlation coefficient between the management and collection of electronic waste and environmental sustainability yielded a result of 0.327 with a p-value of 0.001, which is interpreted as a medium positive correlation. Since the p-value is less than the significance level $\alpha = 0.05$, the null hypothesis (Ho) was rejected, and the alternative hypothesis (H1) was accepted. This indicated a significant relationship between the management and collection of electronic waste and its influence on environmental sustainability in the municipalities of the northern region of Peru.

Specific Hypothesis 2

- H1: There is a significant relationship between the storage of electronic waste and the influence on environmental sustainability in the municipalities of the northern region of Peru.
- Ho: There is no significant relationship between the storage of electronic waste and the influence on environmental sustainability in the municipalities of the northern region of Peru.

In Table 18, the specific hypothesis test 2 using Spearman's Rho correlation coefficient between the storage of waste electrical and electronic equipment and environmental sustainability gave a result of 0.358 with a p-value of 0.000, which is interpreted as a medium positive correlation. Since the p-value is less than the significance level $\alpha = 0.05$, the null hypothesis (Ho) was rejected, and the alternative hypothesis (H1) was accepted. This indicated a significant relationship between the storage of electronic waste and its influence on environmental sustainability in the municipalities of the northern region of Peru.

Table 19. Specific hypothesis test 3

			Environmental Sustainability	Layout and Transformation
Spearman's Rho	Environmental Sustainability	Correlation Coefficient	1,000	,376**
		Sig. (bilateral)	.	,000
		N	95	95
	Layout and transformation	Correlation Coefficient	,376**	1,000
		Sig. (bilateral)	,000	.
		N	95	95
**. The correlation is significant at the 0.01 level (two-sided).				

Specific Hypothesis 3

- H1: There is a relationship between the disposal and transformation of electronic waste and the influence on environmental sustainability in the municipalities of the northern region of Peru.

- Ho: There is no relationship between the disposal and transformation of electronic waste and the influence on environmental sustainability in the municipalities of the northern region of Peru.

In Table 19, the test of specific hypothesis 3 using Spearman's Rho correlation coefficient between the disposal and transformation of waste electrical and electronic equipment and environmental sustainability gave a result of 0.376 with a p-value of 0.000, which is interpreted as a medium positive correlation.

Fig. 20 Electronic waste toxic waste electronic products

Fig. 21 Electronic waste, computer recycling, electronics, audio cassette, miscellaneous, company, recycling

Since the p-value is less than the significance level $\alpha = 0.05$, the null hypothesis (Ho) was rejected, and the alternative hypothesis (H1) was accepted. This indicated a significant relationship between the disposal and transformation of electronic waste and its influence on environmental sustainability in the municipalities of the northern region of Peru. These statistical parameters are essential to ensure the results are representative and reliable. Even though non-probability convenience sampling was used, establishing the margin of error and level of confidence provides a solid basis for the study's conclusions and allows for comparisons with future research. To address concerns about the sample's representativeness and improve the validity of the results, the Delphi method was adopted as a complementary approach in this research.

This method is based on the systematic collection of opinions from a panel of experts in electronic waste management, allowing for an informed consensus on best practices and strategies in the field. The responses obtained through the Delphi method were analyzed to identify consensus and divergences among the experts. This information not only complemented the study's initial findings but also provided a stronger basis for the conclusions. By integrating expert opinions, it was possible to validate and adjust the results obtained from the initial sampling, thus improving the study's credibility.

5. Discussion

The general objective was to evaluate the relationship between electronic waste management and its influence on environmental sustainability. The results of this study indicate that there is a moderate relationship (Spearman coefficient: 0.363) between electronic waste management and environmental sustainability. This aligns with the findings of Dextre Minaya (2020), who also found that inadequate management of this waste contributes to an increase in environmental impact categories, highlighting the need for effective strategies to mitigate these negative effects [9].

The first specific objective was to determine the relationship between the management and collection of electronic waste and its influence on environmental sustainability. The analysis reveals that adequate collection has a coefficient of 0.327, indicating that efficient management can significantly improve sustainability indicators. This finding is consistent with the study by Carpio del Carpio and Cruz Calcina (2021), which underlined the importance of a structured system for the collection and treatment of electronic waste in Arequipa, suggesting that better collection could reduce environmental impact [10].

The second specific objective was to analyze electronic waste storage and its influence on environmental sustainability. The results show that inadequate storage contributes to environmental problems, with a coefficient of 0.376. This is reflected in research such as that of Sifuentes (2023), where it was identified that prolonged storage without adequate treatment could lead to an increase in pollution, highlighting the need to educate the population on appropriate practices [11].

The third specific objective was to examine the disposal and transformation of electronic waste and its influence on environmental sustainability. Disposal and transformation present a significant coefficient (0.358), suggesting that improving these processes is crucial to achieving greater sustainability.

This is consistent with the findings of He (2023), who demonstrated that innovative treatment methods can significantly reduce polluting emissions, reinforcing the importance of adopting cleaner technologies in recycling. In conclusion, the results obtained in this study confirm the hypotheses initially raised and align with previous research, emphasizing the urgent need to implement effective policies to improve electronic waste management in municipalities in northern Peru, thus contributing to more robust sustainable development [8].

6. Conclusion

It was evaluated that there is a relationship between the analysis of electronic waste management and its influence on environmental sustainability in the municipalities of the northern region of Peru. This is evidenced by a Spearman correlation coefficient of 0.363 and a p-value of 0.000. This allows us to conclude that electronic waste management has a moderate positive relationship with environmental sustainability in the northern region, in this case, the region of Lambayeque. It was analyzed that there is a relationship between the management and collection of electronic waste and environmental sustainability in the municipalities of the northern region of Peru.

This is reflected in a Spearman correlation coefficient of 0.327 and a p-value of 0.001 indicate a moderate positive relationship between the management and collection of electronic waste and environmental sustainability, evidencing its effectiveness. It was determined that there is a relationship between the storage of electronic waste and its influence on environmental sustainability in the municipalities of the northern region of Peru.

This is evidenced by a Spearman correlation coefficient of 0.358 and a p-value of 0.000, indicating a medium positive correlation between both variables. It was evaluated that there is a relationship between the disposal and transformation of electronic waste and the influence on environmental sustainability in the municipalities of the northern region of Peru.

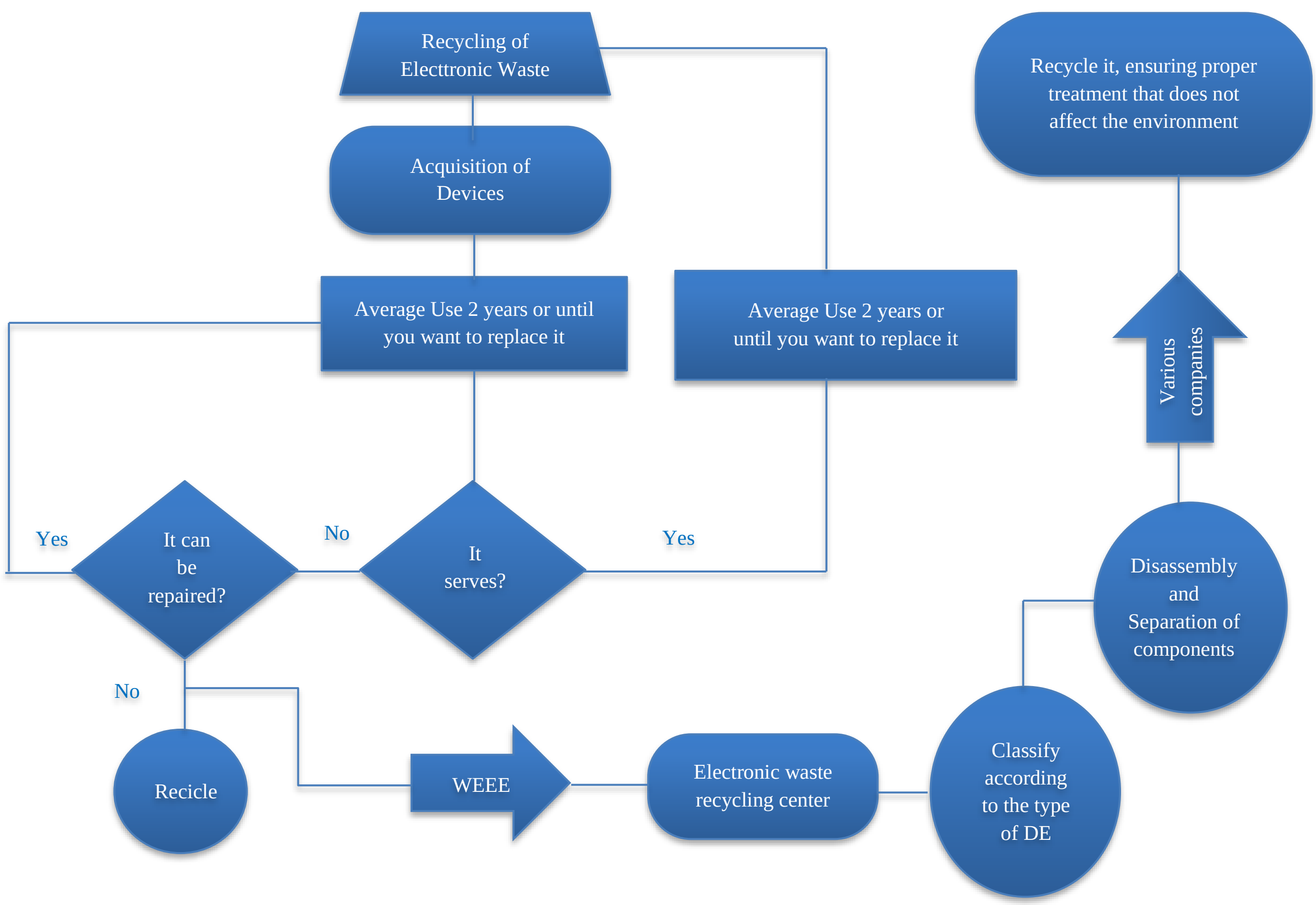

Fig. 22 Importance of recycling electronic waste

This is reflected in a Spearman correlation coefficient of 0.376 and a p-value of 0.000, indicating a moderate positive correlation and demonstrating that both variables are related and are essential to preventing environmental pollution and protecting people's health. The analysis carried out reveals a clear relationship between electronic waste management and its impact on environmental sustainability in the municipalities of the northern region of Peru, especially in Lambayeque. The results indicate that the management, collection, storage, disposal and transformation of this waste have a moderate positive correlation with environmental sustainability.

This suggests that improving electronic waste management practices is crucial to mitigating environmental pollution and plays a fundamental role in protecting the population's health. Therefore, it is imperative to implement effective strategies that promote proper management of electronic waste, thus contributing to the region's sustainable development.

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