Characterization and Assessment of Household Waste from Electrical and Electronic Devices (WEEE) in Chile. A Proposal Towards a More Eco-Efficient Product Design

Marcelo Venegas-Marcel
Maestría en Construcción en Maderas. Universidad del Bío Bío, Chile.
Universidad Técnica Federico Santa María. Viña del Mar, Chile.
E-mail: marcelo.venegas@usm.cl
orcid.org/0000-0002-6501-1312
https://www.researchgate.net/profile/Marcelo-M/research
Google Scholar

Manuel Martínez-Torán
Doctorado en Aproximaciones al Diseño Gráfico e Industrial.
Universitat Politècnica de València.
Valencia, España.
E-mail: mmtoran@upv.es
orcid.org/0000-0002-4266-3131
Google Scholar

Rubén Jacob-Dazarola
Doctorado en Diseño y fabricación de proyectos industriales.
U. Politécnica de Valencia, España
Universidad de Chile.
Santiago de Chile, Chile.
E-mail: rubenhjd@uchilefau.cl
orcid.org/0000-0002-6693-803X
Google Scholar

Francisco Miranda-Rojas
Maestría en MA in Design Products, Royal College of Art / London UK.
Universidad de Chile.
Santiago de Chile, Chile.
E-mail: franciscorojas@uchile.cl
orcid.org/0000-0002-4791-6919
Google Scholar

Recibido: marzo 15 de 2022
Aprobado: diciembre 21 de 2022

Abstract

The aim of this study is to propose a protocol for incorporating procedures to evaluate, characterize and establish general parameters applicable to the management of Waste Electrical and Electronic Equipment (WEEE). This protocol can be applied within the framework of common product design and development processes. The proposed protocol provides key information for design projects, with emphasis on the potential future recovery of parts, components and raw materials.

To achieve this objective, this article first addresses the general problem and defines the objectives, focusing on Chile as a valid case study in Latin America. The method used was applied to ten small household appliances, yielding promising results. Additionally, a user-friendly and easily applicable method is proposed, suitable for training new designers and working with small companies and relevant stakeholders in recycling and recovery processes. In conclusion, this study contributes relevant results aimed at promoting projects of technological and economic interest, with a focus on the sustainable management of waste at the end of its lifespan.

Key words:
Eco-efficiency, WEEE management, Characterization, Product design.

Revista KEPES, Año 20 No. 27, enero-junio de 2023, págs. 75-104

Caracterización y valoración de residuos de aparatos eléctricos y electrónicos, RAEE en Chile. Una propuesta hacia un diseño de producto más ecoeficiente.

Resumen

Esta investigación, tiene como objetivo proponer un protocolo de incorporación de procedimientos para evaluar, caracterizar y establecer parámetros generales aplicables a la gestión de RAEE —residuos de aparatos eléctricos y electrónicos— el cual puede también ser incorporado dentro del marco de los procesos de diseño y desarrollo de productos más usados frecuentemente; brindando así, información clave para proyectos dirigidos a la recuperación de partes, componentes y sus materias primas.

Para lograr lo anterior, este artículo primero establece los problemas generales, posicionando a Chile como un caso de estudio válido en América Latina y define los objetivos de la investigación. Posteriormente, se describe el método ocupado, el cual ha sido aplicado a diez electrodomésticos de pequeño formato, obteniendo resultados prometedores en cuanto a una rápida determinación de las posibilidades de gestión sostenible de sus residuos. Se propone un método de fácil aplicación y comprensión, el que puede funcionar en el marco de la formación de nuevos diseñadores, el trabajo con pequeñas empresas y con actores relevantes en los procesos de reciclaje y valorización. Finalmente, se presentan conclusiones respecto al logro de los objetivos propuestos y evaluaciones para futuras investigaciones. Contribuyendo de esta forma, con resultados significativos destinados a impulsar proyectos de interés tecnológico y económico con miras al manejo sostenible de los residuos al final de su vida útil.

Palabras claves:
Eco-eficiencia, gestión RAEE, caracterización, ecodiseño.

1. Introduction

The current economic system, characterized by the "buy-use-throw away" cycle (Ellen MacArthur Foundation et al., 2015, p. 46), perpetuates the concept of disposability and consumerism, contributing to the persistence of a linear economy (Murdock, 2006; Piñero, 2004). This linear economy relies on large quantities of cheap raw materials and energy, which leads to significant unprecedented industrial growth, but also draws criticism do to its negative social and environmental impacts (Sariatli, 2017). This is essentially due to its close relationship with the extractive paradigm, which, in its restless dynamics, has not yet considered the great social and environmental price that has had to be paid in exchange for prosperity. (Acosta, 2016; Krausmann et al., 2009; Schaffartzik et al., 2014). These issues directly affect the field of design, particularly industrial and product design, which forms the main focus of this academic contribution.

One category of waste that has been exponentially growing is technological waste, particularly Waste Electrical and Electronic Equipment (WEEE). These products closely associated with the work of industrial designers (EU Commission, 1991), consist of complex manufacture and assembly processes, structures, parts, and components (Cyranek and Silva, 2010, pp. 26–27) made from various materials such as polymers, ferrous and non-ferrous metals, silica, and other complex composites. David disposal or integration of these products into ecosystems, for effective restoration or regeneration poses significant challenges (Ellen MacArthur Foundation et al., 2015; Issa et al., 2015).

The Chilean case

The management of WEEE in Chile is still incipient compared to industrialized countries, making it a complex issue. While recycling rates in Europe reach approximately 40% (Forti et al., 2020, p. 41), in Chile, they only reaches 3% (Boeni et al., 2009, pp. 8–11). Therefore, the lack of parameters, obligations, and jurisdiction evidenced by the Chilean Extended Producer Responsibility (EPR) law is not surprising. The implementation of the EPR law in Chile decided to promote changes from an environmental perspective four years ago (Government of Chile. Ministry of the Environment, 2016). This law aims to shift a circular economic logic, where producers, waste collectors, and consumer are involved in closing the cycle (Balboa C. and Dominguez S., 2014; Geng and Doberstein, 2008; McDonough and Braungart, 2002, pp. 98–99).

Although the law was enacted in 2016, it is still not fully operational, resulting in a lack of relevant information for material characterization and valorization, which hinders effective waste recovery (Volker K., 2023; Fajardo C., 2018). Consequently, the basic collection work, encouraged by official business units connected with the disarmament of ESAs (Electronic Small Appliances), still seems to be an emerging reality. According to Boeni et al. (2009, pp. 8–11), these efforts mainly focus on the secondary provision of services to large companies or, alternatively, establishing informally to obtain marginal profits from households waste (Cámara de Comercio de Santiago (CCS) and Regenerativa, 2019, pp. 53–58; Boeni et al., 2009; Wolfensberger, 2009, p. 2).

This situation highlights the importance of developing methodological instruments that enable its integration into potential business models. It is particularly crucial to understand the significant projected increase in electronic waste in the future (Savino et al., 2018) attributed to the economic development level reached by the country as well as its significant progress in legal regulatory initiatives (Bautista Vargas et al., 2015; Silva, 2019, p. 10). Several reports (World Bank, 2023; Toledo, 2022; Fajardo, 2019; Silva, 2019; Bautista Vargas et al., 2015) indicate that Chile ranks among the top countries in Latin America in terms of development (Gross Domestic Product, GDP) and per capita consumption, especially in technological products. This indicates the potential for extrapolating these practices to other countries in the region in the near future.

"Eco-efficient education" in the product design field

Several authors (Meyer and Norman, 2020; Pontis and van der Waarde, 2020; Redström, 2020) have a consensus on the need to redefine the training of future industrial designers. The profession, which once had well-defined boundaries, now presents blurred boundaries, which should be seen as an opportunity rather than a problem. These authors argue for a more realistic views of how design practice should be in the present and future. These authors also agree that, central to this new conception of the design profession is the incorporation of sustainability and eco-efficiency aspects into the basic skills of designers, and for this purpose, these skills should be part of their initial training (Zainudin et al., 2021).

In a broader context, educational approaches should adapt their programs to integrate the concept of "sustainable development." This integration should involve active participation and commitment from various social groups, including the field of Design discipline, which plays a fundamental role (UNESCO, 2012, p. 7). Sustainable development is recognized as a key factor in the pursuit of social well-being and requires the effective alignment of functional, productive, and environmental variables (Manzini, 1992; Manzini and Bigues, 2000, pp. 7–9; Manzini and Jégou, 2003, p. 16). Within the realm of product development, this alignment is manifested as the sustainable management of environmental efficiency (eco-efficiency), aiming to minimize impacts, and reduce production costs within the company (Aranda U. and Zabalza B., 2010, pp. 7–8; World Business Council for Sustainable Development, 2000, p. 4).

The present study and the proposed design framework specifically target industrial designers with the goal of developing tools that can be integrated into their formative processes. By doing so, the aim is to ensure that the consideration of sustainability and eco-efficiency criteria becomes an integral part of their mainstream design practices.

The present research processes

Based on the aforementioned, this research seeks to establish a comprehensive framework of procedures for assessing, characterizing and establishing general parameters applicable to the management of WEEE. These procedures are intended to be incorporated into the common product design and development processes, providing essential information for the formulation of technological projects that prioritize the recovery of parts, components, and raw materials.

To achieve these objectives, the following procedural goals have been outlined:

a. Develop a procedure for the characterization of specific types of material waste relevant to the Chilean market.
b. Define the characteristics of recoverable waste and establish guidelines for its proper disposal.
c. Apply instruments for the classification and hierarchization of WEEE. This involves utilizing appropriate tools and procedures for effective management processes in subsequent stages.
d. Evaluate typologies of WEEE based on their prevalence and incidence rates as potential waste at the country level, according to institutional criteria (background and diagnostic data).

The research process carried out to achieve these goals is presented as follows:
1. Introduction: This section provides an overview of the sustainability issues

related to the training of new product designers and establishes the relevance of studying the case of Chile as a valid model for other Latin American countries. 2. Literature review: A comprehensive review of the literature is conducted, encompassing academic sources, international and local organizations and authoritative bodies. This review covers both general and methodological aspects. 3. Research methods: the methodology employed in the research is described in detail. 4. Findings and Discussion: the outcomes of the applied procedures and implications are discussed. 5. Conclusions: The study concludes with a summary of the achieved objectives and their implications to advance the knowledge and understanding in future research.

2. Literature review

The environmental problem posed by WEEE has significant implications for scientific research, academia, the business sector and environmental authorities. With the exception of printed circuit boards (PCBs) handling and use (Park and Fray, 2009), the focus of the WEEE sector has been to design collection, transport and disposal systems for end-of-life waste. Nevertheless, other constituents, such as polymeric components, still have relatively low recovery rates (Habib et al., 2015). This neglects the potential valorization of the physical and chemical properties present in these materials. Thus, according to Fernández (2013, pp. 13–47), the full and effective implementation of "Urban Mining", which has significant advantages in environmental terms compared to Traditional Mining, is prevented. This could become a valid management model oriented towards the recovery of raw materials through recycling, thus establishing an effective cycle lock throughout the supply chain (Koutamanis et al., 2018; Xavier et al., 2019; Zhang et al., 2019).

Estimates from the early 2000s (United nations, 2005) suggest that from 20 to 50 million tons of electrical and electronic equipment waste would be produced each year, accounting for approximately 5% of global solid waste (Schwarzer et al., 2005, pp. 1–2). By 1998, EU reports indicated the generation of 6 million tons of WEEE, with volumes increasing by 3 to 5% annually. Unfortunately, 90% of this waste was sent to landfills without further processing options (EU Commission, 2000). Projections for 2015 estimated WEEE generation at around 12 million tons, equivalent to approximately 14 kgs. per person per year (Goosey, 2004).

The literature recognized the immense potential of Electrical and Electronic Equipment (EEE) as a source of recoverable raw material. Basic metals such as copper (28%), and precious metals such as silver (23%) and gold (13%) have relatively high recycling rates, although they still fall short of desired levels (Horta Arduin, et al., 2020). Various authors have proposed methodologies for identifying materials and their relationship with manufacturing and recycling processes (Franco, 2019; De Aguiar, et al., 2017); they venture to establish diagnostic visions as results, but still based on frameworks that do not seem to be agile enough to foster their implementation. This means that the subject is still an issue with little valued potential, but with an enormous future in terms of economic sustainability, which has enabled to establish the theoretical basis for the present research.

3. Methods

The research method employed in this study focuses on WEEE units from households, specifically small household appliances (EU Commission, 2003; Government of Chile. National corporation of the Environment, 2009, pp. 12–13). The selection of these appliances is based on estimations declared by the Ministry of Environment of Chile, considering the market volumes (comprising 95% of national and imported consumption) and the average lifespan of 3 years based on expected usability time (Government of Chile. Ministry of the Environment, 2015). The methodological model utilized in this research follows a procedural approach (Figure 1) based on a sequential application described by Zeng, et al. (2017) and enables a detailed analysis of twelve WEEE devices in the laboratory across all phases.

In the research process conducted, it is worth noting that no previous evidence of the application of this method or similar methods focusing on small electrical and electronic products could be found in Chile or other countries in the region. Therefore, the implementation of this method is considered significant, particularly for industrial design professionals, as it offers simplicity and ease of application compared to other methodologies like Life Cycle Analysis (LCA), which require more extensive software support and generate purely quantitative results (Zainudin et al., 2021). This also makes it relevant not only for training new industrial designers, but also for companies and manufacturers.

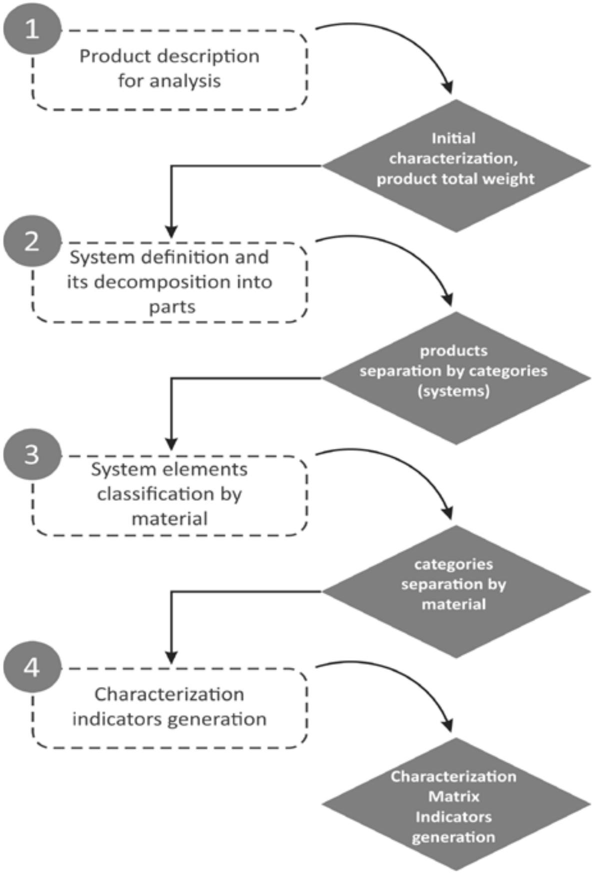

Figure 1. General flowchart of the proposed methodology.
Note: Compiled by the authors, according to Zeng, et al.2017.

The research defines four phases or steps for the characterization process and its specifications. They range from function analysis, system definition, and component classification to indicator-based characterization:

3.1. Product description for analysis

The first step involves selecting the specific unit to be analyzed. A short description of its function is provided to facilitate recognition and understanding of its purpose. Additionally, input data such as the *overall unit weight*, general dimensions, volume and other relevant data may be included to provide a comprehensive description.

3.2. Systems definition and breakdown by parts

The analysis proceeds with the manual dismantling of the selected WEEE. This step involves defining the different systems and categories within the first device. A profile is created for each system, outlining its characteristics an main functions. This is followed by the weighing of the corresponding groups, according to four (4) categories. Components that weight at least 10% of the total weight of the unit are selected for the study (Table 1).

Table 1. Categories for initial unit separation and analysis

ID	CATEGORY (Individual system)	DESCRIPTION	WEIGHT (grams.)
C1	Body	Exterior system, from the first disassembly of parts	
C2	Structure	Parts that together allow the resistance of the main form of the product	
C3	Electronic circuits	Printed circuit boards, electronic modules, wires, and connectors	
C4	Others	Other non-previously classified materials	

Note: Compiled by the authors, 2021.

3.3. Classification of components according to their materiality.

After the systems have been defined and the components have been dismantled, the next step is to classify the components into categories according to their material type. This classification allows for their individual weight contributions. Table 2 provides an itemized list of materials types found in the equipment, indicating the total volume of each material and their suitability for its examination. Furthermore, a classification is established based on the nature of each material and individualization for each one of them.

Table 2. Typologies of materials obtained from WEEE

MATERIAL	DESCRIPTION
Metals	Iron scrap, steel, copper, and aluminum
Polymers	ABS, PP, PPE, PPS, PBT
Electronic parts	Circuit board, connectors, some metals
Others	Non-classified materials, e.g., wires, screws, small pieces of polymers or metals

Note: Compiled by the authors, 2021.

The data obtained from the characterized unit and the components, and their specifications, are subsequently organized in a matrix to make an analysis based on the proposed components and material typologies categories (Velosa and González Rolón, 2016).

3.4. Characterization Indicators Generation.

This research determines percentage values, relative to their mass, of the materials obtained from the dismantled equipment. These values are calculated based on the requirements and methods established by the Chilean Institute for Standardization (Instituto Nacional de Normalización, 2013) for the characterization of solid waste in residential areas.

The materials obtained primarily consist of polymers, ferrous metals, non-ferrous metals (Al, Cu), and electronic components like integrated circuit boards, cables, and connectors. The research systematically records percentage values of these materials relative to the total weight of the equipment based on the following indicators that were previously used in a preliminary study by Venegas Marcel et al. (2020), as follows:

3.4.1. Indicator 1: Index (%) by mass per type of material.

$$\frac{m_{mat1}}{m_U} x100$$

m_{mat1}: mass in grams material 1
m_U: mass of the analyzed equipment (unit).

3.4.2. Indicator 2: Index (%) in mass per proposed category.

$$\frac{m_{catg.1}}{m_U} x100$$

$m_{catg.1}$: mass in grams category 1
m_U: mass of the equipment analyzed (unit).

3.4.3. Indicator 3: Hazard Index

The research applies the environmental regulations currently in force for the management of these wastes in Chile (Government of Chile. Ministry of Health, 2004). Sanitary Regulations on the Management of Hazardous Waste (categorization of the presence of heavy metals in its components), establishes the minimum sanitary and safety conditions that should be followed during waste management operations, including both recovery and recycling processes (Table 3).

Table 3. Hazardous material according to sanitary regulation on hazardous waste management 148/20

MATERIAL	CLASSIFICATION	DS. N° 148 ID CODE	DESCRIPTION
Metals	Non-hazardous	B1010	Solid waste of metals and metal alloys in metal form and not dispensable
Polymers	Non-hazardous	B3010	Solid waste of plastic material
Electronic parts	Hazardous	A1180	Electrical or electronic assemblies or electronic junk with components as circuit boards o connectors
Others	Not applicable	Not applicable	Non-classified materials, e.g., wires, screws, small pieces of polymers or metals

Note: Compiled by the authors, 2021.

The hazard index is obtained by calculating the partial mass of the materials classified as hazardous and the total mass of WEEE in grams:

$$\frac{m_{respel}}{m_U} x\ 100$$

m_{respel}: the total mass of materials classified as hazardous.
m_U: mass of the analyzed equipment (unit).

3.4.4. Indicator 4: Recyclability rate.

The concept of recyclability in this research is defined as the "ability of constituent parts, materials or both, to be diverted from the end-of-life flow for recycling purposes" (Spanish Association for Standardization and Certification (AENOR), 2010). To evaluate the recyclability of the characterized materials from a WEEE, two levels of recyclability are proposed:

a. Feasible recyclability: It indicates the current feasibility of entering these materials into the recycling chain in the country.
b. Potential recyclability: It signifies that the technology for recycling these materials exists but is not currently available in the country's recycling chains.

These levels reflect the current situation and may change over time. The status of recyclability should be considered and reassessed in future studies. A further point to be considered is the feasibility of recycling in the metallurgical waste sector, as pointed out by the Chilean Ministry of Environment (Amphos XXI, 2015), regarding the feasibility of industrial processing of metallurgical waste (generated by foundry processes). These discarded materials are currently the main activity that triggers recycling by official waste managers and "core recyclers" (80%). On the other hand, plastic materials derived from large and small electrical and electronic equipment have a lower recycling rate (approximately 19% and 37%, respectively); plastic materials have a potential for recycling and industrial processing of 80% in the future (add reference). This value is only foreseen from the implementation of the EPR law and the associated requirements and promotion of the industry. According to these criteria, they are assigned the quality of "feasible recyclability" or "potential recyclability" (Table 4).

Table 4. Material classification according to their potential recyclability

MATERIAL	RECYCLABILITY
Metals	*Feasible*
Polymers	*Potential*
Electronics parts	*Potential*
Others	*Potential*

Note: Compiled by the authors, 2021.

The recyclability index can be calculated using the sub-masses of materials sorted by type and the total mass of WEEE in grams. The reference for the calculation of this indicator is proposed from the UNE 26516 standard (2010), on recyclability, recoverability, and calculation method for road vehicles. The following is a calculation of the recyclability index:

Feasible Recyclability Index:

$$\frac{m_M}{m_U} x\ 100$$

Potential Recyclability Index:

$$\frac{m_p + m_{ep} + m_o}{m_U} x\ 100$$

m_M: mass of materials classified as metals.
m_U: mass of the equipment analyzed (unit).
m_p: mass of materials classified as polymers.
m_{ep}: mass of materials classified as electronic parts.
m_o: mass of materials classified as other.

The defined procedures are carried out in the laboratory to ensure a systematic record of the dismantling process of the selected equipment. This work is collected in tables as summarized information and organized for later evaluation (Figure 2). The analysis is carried out, therefore, with the following ten (10) household ESAs:

- Electric kettle
- Blender
- Food grinder
- Toaster
- Stick blender
- Microwave Oven
- Hair straightener
- Hairdryer
- Dry Iron
- Electric Shaver

4. Results and discussion.

After the application of the protocol, the following observations and arguments can be made:

Metallic components, both ferrous and non-ferrous are still present in significant proportions in the analyzed WEEE. This is a common characteristic of AEEs and it indicates that there are currently numerical estimates published (countrywide) by environmental institutions regarding the valorization of these wastes in the market. The recovery process is a frequently required activity supported by the metallurgical industry in Chile and the whole chain of business units linked to the reuse and recycling of these materials. (Wagner, et al., 2022, pp. 125; Clerc, et al., 2021, pp. 90.; Duque, 2019, pp. 17-23).

It is therefore of interest to attend to the portion of material made up of plastics, particularly ABS (acrylonitrile butadiene styrene) is and PP (polypropylene) (Table 5). According to the current institutional framework, these polymers are not frequently recycled at the country level (Government of Chile. Ministry of the Environment, 2015). This fact, in line with the new environmental requirements (Government of Chile. Ministry of the Environment, 2016), would open new opportunities for the development of projects related to the management and use of these wastes. Hence, further research on new technological concepts or to adapt the existing ones to improve the performance and valorization of polymers is essential.

Table 5. Matrix of verification and recording of indicators according to team

Electric Kettle											
Product Id.	Material	Polymers			Metals			Electrical components	Others		
 **Reference image**	**Categories**	**PP**	**Polymer (1)**	**Polymer (2)**	**Fe, ferrous materials**	**Al**	**Cu**	**Circuit boards, connectors, others**	**Wires, mixed materials**	**TOTAL category grs.**	**INDICATOR 2: % Weight by proposed categories**
	Body/structure	350,0			45,0					395,0	41,6
	Functional unity	53,0			278,0				24,0	355,0	37,4
	Others	120,0			10,0			60,0	10,0	200.0	21,1
	TOTAL. Material grams	523,0	0,0	0,0	333,0	0,0	0,0	60,0	34,0	950,0	
	TOTAL. By material	523,0			333,0			60,0	34,0	950,0	
Total weight 950 g.	**INDICATOR 1: % weight by material category**	55,1			35,1			6,3	3,6	100,0	
	INDICATOR 3: Hazard index (%)	6,3									
	INDICATOR 4: Recyclability Index (%)	Feasibility Recyclability Index		35,1	Potential Recyclability Index		64,9				

Note: Elaborated by the authors in every product, according to Velosa & González, 2016.
Complete tables of the process are available in the following link:
https://drive.google.com/file/d/1GpRCBLcWxoXD2t4kkSnHslIQgMxsr1Z3/view?usp=sharing

Table 6. Type of polymers and mass fraction of the total in analyzed equipment

Small format household appliance	% Of all polymers in the product	Individual % of polymers from total product weight					
		ABS	PPE	PP	PBT	PE	Others
Electric Kettle	55,1			55,1			
Blender	25,0	17,0				8,0	
Food grinder	37,1	29,0					8,0
Toaster	36,4	0,6	29,5				6,3
Stick Blender	27,2		27,2				
Microwave oven	17,0		17,0				
Hair Straightener	55,1	55,1					
Hairdryer	47,3	36,5					10,8
Dry iron	39,6			24,4	15,2		
Electric shaver	55,6	53,3					2,2

Note: Compiled by the authors, 2021

Eight out of the ten tested products are associated with potential recyclability (Table 6), which is directly related to the predominant material composition in its structural subsystems (over 40% polymers for the case study evaluated). The above conditions open future feasibility of advancing new projects associated with technological processes for recycling these types of waste. In view of their immediate viability, mechanic-type recycling processes should be implemented (Signoret et al., 2019), considering only parts that do not contain hazardous substances within their components when manufactured.

Table 7. WEEE characterization summary matrix, household electrical household equipment

INDICATOR 2 Index (%) mass per proposed categories			INDICATOR 1 Index (%) mass per type of material					INDICATOR 3 Hazard Index	INDICATOR 4 Recyclability Index	
Others	Functional Unity	Body/ structure	equipment	Polymers	Metal	Elec. parts	Others		Feasible	Potential
21,1	37,4	41,6	***Electric Kettle***	55,1	35,1	6,3	3,6	6,3	35,1	64,9
14,6	38,9	46,5	***Blender***	25,0	60,4	1,2	6,7	1,2	60,4	31,7
7,5	56,6	35,9	***Food grinder***	37,1	55,3	2,6	4,9	2,6	55,3	42,0
19,1	23,2	57,8	***Toaster***	36,4	48,7	4,5	10,4	4,5	48,7	51,3
13,1	59,7	27,2	***Stick Blender***	27,2	59,7	0,8	12,3	0,8	59,7	40,3
13,3	37,8	49,0	***Microwave oven***	17,0	68,4	2,4	12,3	2,4	68,4	31,6
18,4	31,0	50,6	***Hair Straightener***	55,1	27,3	2,2	15,4	2,2	27,3	72,7
35.7	31,5	32,8	***Hair Dryer***	47,3	45,3	2,5	5,0	2,5	45,3	54,7
22,5	53,5	24,1	***Dry iron***	39,6	47,3	4,2	8,9	4,2	47,3	48,5
24,4	33,3	42,2	***Electric shaver***	55,6	20,9	1,3	22,2	23,6	20,9	79,1

Note: Compiled by the authors, 2021.

Unlike other WEEE, small household appliances do not have significant portions of printed circuit boards (PCBs). This should be an interesting fact to consider when designing or planning recycling chains. Likewise, Miscellaneous (cables/ electrical conductors made of metals and composite plastic) is another group within the equipment analyzed that should be highlighted and which appears as a relevant waste. The above information, together with the high valuation of non-ferrous conductive metals (Cu), influences the implementation of formalized technological solutions for the recovery of these components.

In terms of the recycling possibilities of non-metallic materials (ferrous and non-ferrous), it is possible to observe an opportunity for polymeric materials (ABS, PP). This situation is accentuated by the fact that recycling frequency of these wastes has not yet been recorded. Therefore, the research conducted here confirms a favorable scenario for commercial and technological innovation in this field. Hence, the material characteristics for the mentioned wastes involves considering the conformity with available recycling transformation processes in a given territory and the innocuousness of their composition due to the regulations in use.

The balance, recognition, and characterization of materials (associated with functional components and subsystems) provide information that, although still nominal, inevitably opens spaces of interest to be used in the Design process. Alignment with the concept of Design for Disassembly, *DfD* (Abuzied, et al., 2020; Boothroyd and Alting, 1992; Chiu and Okudan, 2010) would make it possible to take decisions in a non-reactive way on design projects that consider the end-of-life of products and the recovery of its components. Therefore, there would be a contribution to the selection of materials with low environmental impact, the minimization of waste generated, and compliance with recycling standards.

5. Conclusions.

After applying the proposed method, the information derived from the characterization of WEEE enables a clear individualization of the material composition of waste. This becomes relevant information for estimating selective criteria for recycling and adapts the management models required for its handling. Accordingly, the proposed method assumes the fact that the weight and material composition of the equipment resulting from the characterization could eventually vary over time. This may be due to changes derived from the continuous technological evolution applied to products or to behavioral variations associated with consumption, thus determining the need for successive surveys to characterize products at their end of life. Consequently, this would contribute to clear up areas of uncertainty regarding the updating of these data.

In addition, the presented method would also constitute an effective guide for the initial stages of the Product Design process. It would enable the development of previous diagnosis approaches (from the recognition of material waste associated to parts and components of the goods) to establish material specifications that could eventually be applied in the definition of efficient product structural concepts. This would straightforwardly favor DfD and lastly raw material recovery, which consequently is the interests and associated benefit for the manufacturer.

The proposed instrument for waste characterization can indeed be adapted to other types of waste; it is also possible to collect relevant data to optimize recycling chains and improve waste management practices.

The study helped to identify different properties relevant for the Chilean market as well as to understand recoverable waste characteristics. Similarly, the instruments enabled to classify and initially hierarchize WEEE; they enabled the definitions of appropriate subsequent management conditions. Finally, it was possible to evaluate the different typologies of WEEE according to the highest ranges of incidence as potential waste at a country level under institutional criteria.

In addition, the long-term goal related to the development of a feasible method to incorporate into the training processes of future product designers is positively evaluated, since the development and implementation of the proposed method for the analysis is simple.

From the perspective of Industrial Design, the analysis of components and materials of a given product becomes significant with a view to being used as an add-on procedure towards an orientation for the Eco-design driven products with Eco-efficiency results (concepts already included in the PER Chilean Law). This is possible if the requirements of the current legislation are considered in order to meet the recovery targets set for the coming years, and with reference to the responsibilities of the producer (with regard to waste chains introduced and their recycling capacity).

References.

Abuzied, H., Senbel, H., Awad, M., & Abbas, A. (2020). A review of advances in design for disassembly with active disassembly applications. *Engineering Science and Technology, an International Journal,* 23(3), 618-624. https://doi.org/10.1016/j.jestch.2019.07.003

Acosta, A. (2016). Curses, heresies and other miracles of extractivist economy. Tabula Rasa. *Revista de Humanidades, 24*, 25–55. https://doi.org/10.25058/20112742.56

AENOR (Spanish Association for Standardization and Certification). (2010). *UNE 26516: Road vehicles - Recyclability and recoverability - Calculation method.* Madrid.

Aranda U., A., & Zabalza B., I. (2010). Ecodesign and life cycle analysis. Zaragoza University.

Balboa C. C. H. & Domínguez, M. (2014). Circular economy as a framework for ecodesign: The ECO-3 model. *Informador técnico, 78*(1), 82-90.

Bautista, M. E., Cabrera, R., Rolón, J. C., Pichardo, R., & Gordillo, A. (2015). Review of policies for the management of electrical and electronic waste for their application in Mexico. *Tamatli, 6,* 66–72.

Boeni, H., Silva, U., & Ott, D. (2009). Recycling of electronic waste in Latin America: Overview, challenges, and potential. In U. Silva (Ed.), *Management of Electronic Waste in Latin America* (pp. 8-11). Ediciones Sur.

Boothroyd, G., & Alting, L. (1992). Design for Assembly and Disassembly. *CIRP Annals, 41*, 625–636. https://doi.org/10.1016/S0007-8506(07)63249-1

Cámara de Comercio de Santiago & Regenerativa. (2019). *Sector Diagnosis. Clean Production Agreement: Implementation of Extended Producer Responsibility in the Electrical and Electronic Equipment Sector* (p. 117). Santiago Chamber of Commerce, Chile. http://www.traee.cl/multimedia/2021/07/11_04_19_Estudio_de_Diagno%CC%81stico_Sectorial_REP_RAEE_Versio%CC%81n-Final.pdf

Chiu, M.-C., & Okudan, G. E. (2010). Evolution of Design for X tools applicable to design stages: A literature review. Proceedings of the ASME Design *Engineering Technical Conference, 6*, 171–182. https://doi.org/10.1115/DETC2010-29091

Clerc, J., Pereira, A. M., Alfaro, C., & Yunis, C. (2021). *Circular economy and valorization of metals: Waste electrical and electronic equipment. ECLAC.* https://www.cepal.org/en/publications/47429-circular-economy-valorization-metals-waste-electrical-and-electronic-equipment

Cyranek, G., & Silva, U. (2010). *Electronic waste: A challenge for the knowledge society in Latin America and the Caribbean.* UNESCO, Montevideo.

De Aguiar, J., Oliveira, L. de, Silva, J. O. da, Bond, D., Scalice, R. K., & Becker, D. (2017). A design tool to diagnose product recyclability during the product design phase. *Journal of Cleaner Production, 0*(141), 219-229. https://doi.org/10.1016/j.jclepro.2016.09.074

Duque, I. (2019). *Operational framework for establishing a WEEE management system in Chile. Deliverable I: Current situation of WEEE collection and valorization in Chile, with emphasis on the integration of base recyclers (p. 56). U4E.* https://rechile.mma.gob.cl/wp-content/uploads/2021/06/Entrega-1-Recoleccion-y-valorizacion-de-RAEE-en-Chile_I-Duque.pdf

Ellen MacArthur Foundation, Stiftungsfonds für Umweltökonomie und Nachhaltigkeit (SUN), Deutsche Post Foundation, McKinsey Center for Business and Environment. (2015). *Growth Within: A circular economy vision for a competitive Europe.*

EU Commission. (2019). *Recycling is the future: this is how we do it in the EU Official website of the European Union*. https://ec.europa.eu/spain/news/20190318_Recycling-is-the-future-we-do-it-in-the-EU_es (Accessed 6.9.21).

EU Commission. (2003). *Directive 2002/96/EC*. Official Journal of the European Union. Brussels.

EU Commission. (2000). *Proposal for a Directive of the European Parliament and of the Council on waste electrical and electronic equipment (2000/C 365 E/12)*. Official Journal of the European Communities. Brussels.

EU Commission. (1991). *Directive 91/156/EEC*. Official Journal of the European Communities. Brussels.

Fajarado, D. (2018, May 16). *¿Qué falta para que se concrete la Ley de Reciclaje?* [Digital news article]. La Tercera. https://www.latercera.com/pulso/noticia/falta-se-concrete-la-ley-reciclaje/166491/

Fajardo, D. (2019, August 7). *Chilenos aumentarán en 45% su basura electrónica en 10 años* [Digital news article]. La Tercera. https://www.latercera.com/pulso/noticia/chilenos-aumentaran-45-basura-electronica-10-anos/771299/

Fernández Protomastro, G. (2013). *Urban mining and electronic waste management*. Grupo Uno.

Forti, V., Baldé, C.P., Kuehr, R. & Bel, G., (2020). *Suivi des déchets d'équipements électriques et électroniques à l'échelle mondiale pour 2020: Quantités, flux et potentiel de l'économie circulaire*. Université des Nations Unies (UNU), Institut des Nations Unies pour la formation et la recherche (UNITAR), Programme SCYCLE co-administré par l'Union internationale des télécommunications (UIT) et l'Association internationale des déchets solides (ISWA), Bonn, Genève.

Franco, M. A. (2019). A system dynamics approach to product design and business model strategies for the circular economy. *Journal of Cleaner Production, 241*, 118327. https://doi.org/10.1016/j.jclepro.2019.118327

Geng, Y., Doberstein, B., (2008). Developing the circular economy in China: Challenges and opportunities for achieving "leapfrog development." *International Journal of Sustainable Development and World Ecology 15,* 231–239. https://doi.org/10.3843/SusDev.15.3:6

Goosey, M. (2004). End-of-life electronics legislation – an industry perspective. *Circuit World, 30,* 41–45. https://doi.org/10.1108/03056120410512235

Government of Chile. Ministry of Health. (2004). *Decreto 148 [Decree 148]*. Diario Oficial. Chile.

Government of Chile. Ministry of the Environment. (2016). *Ley n°20.920 [Law No. 20.920]*. Diario Oficial. Library of the National Congress of Chile.

Government of Chile. National Corporation of the Environment. (2009). *Diagnosis of production, importation, and distribution of electronic products and management of end-of-life equipment*. Santiago de Chile.

Habib, K., Parajuly, K., & Wenzel, H. (2015). Tracking the Flow of Resources in Electronic Waste - The Case of End-of-Life Computer Hard Disk Drives. *Environmental Science & Technology, 49,* 12441–12449. https://doi.org/10.1021/acs.est.5b02264

Issa, I. I., Pigosso, D. C., McAloone, T. C., & Rozenfeld, H. (2015). Leading product-related environmental performance indicators: a selection guide and database. *Journal of Cleaner Production, 108,* 321–330.

Koutamanis, A., van Reijn, B., & van Bueren, E. (2018). Urban mining and buildings: A review of possibilities and limitations. *Resources, Conservation and Recycling, 138*, 32–39. https://doi.org/10.1016/j.resconrec.2018.06.024

Krausmann, F., Gingrich, S., Eisenmenger, N., Erb, K. H., Haberl, H., & Fischer-Kowalski, M. (2009). Growth in global materials use, GDP and population during the 20th century. *Ecological Economics, 68,* 2696–2705. https://doi.org/10.1016/j.ecolecon.2009.05.007

Manzini, E. (1992). *Limits and Possibilities of Ecodesign: From the "ecological re-design" of products to the suggestion of "new environmental scenarios"* [Web document]. sckool.org. URL https://sckool.org/limits-and-possibilities-of-ecodesign-by-ezio-manzini.html (accessed 6.10.21).

Manzini, E., & Bigues, J. (2000). *Ecology and democracy: from ecological injustice to environmental democracy, More wood.* Icaria Editorial.

Manzini, E., & Jégou, F. (2003). *Quotidiano sostenibile: scenari di vita urbana [Sustainable everyday: scenarios of urban life].* Edizioni Ambiente.

McDonough, W., & Braungart, M. (2002). *Cradle to Cradle: Remaking the Way We Make Things.* North Point Press.

Meyer, M. W., & Norman, D. (2020). Changing Design Education for the 21st Century. *She Ji: The Journal of Design, Economics, and Innovation,6,* 13-49. https://doi.org/10.1016/j.sheji.2019.12.002

Murdock, G. (2006). Under the beach, the cobblestones: Commodities, Consumerism, Contradictions. *Economía política de la comunicación, 11,* 31–46

National Institute of Normalization. (2013). *NCh. 3321: Caracterización de residuos sólidos municipales (RSM) [Characterization of municipal solid waste (MSW)].* Chile.

Park, Y. J., & Fray, D. J. (2009). Recovery of high purity precious metals from printed circuit boards. *Journal of Hazardous Materials, 164,* 1152–1158. https://doi.org/10.1016/j.jhazmat.2008.09.043

Piñero, F. (2004). The Fordist-Keynesian mode of industrial development: Characteristics, crises, and restructuring of capitalism. *Contribuciones a la economía, 1er semest, 1–18.*

Pontis, S., & Van der Waarde, K. (2020). Looking for Alternatives: Challenging Assumptions in Design Education. *She Ji: The Journal of Design, Economics, and Innovation, 6,* 228–253. https://doi.org/10.1016/j.sheji.2020.05.005

Redström, J. (2020). Certain Uncertainties and the Design of Design Education. *She Ji: The Journal of Design, Economics, and Innovation, 6,* 83–100. https://doi.org/10.1016/j.sheji.2020.02.001

Sariatli, F. (2017). Linear Economy Versus Circular Economy: A Comparative and Analyzer Study for Optimization of Economy for Sustainability. *Visegrad Journal on Bioeconomy and Sustainable Development, 6,* 31–34. https://doi.org/10.1515/vjbsd-2017-0005

Savino, A., Solórzano, G., Quispe, C., & Correal, M. C. (2018). *Perspective on Waste Management in Latin America and the Caribbean.* ONU Medioambiente.

Schaffartzik, A., Mayer, A., Gingrich, S., Eisenmenger, N., Loy, C., & Krausmann, F. (2014). The global metabolic transition: Regional patterns and trends of global material flows, 1950–2010. *Global Environmental Change, 26,* 87–97. https://doi.org/10.1016/j.gloenvcha.2014.03.013

Schwarzer, S., Bono, A., Giuliani, G., Kluser, S., & Peduzzi, P. (2005). *E-waste, the hidden side of IT equipment's manufacturing and use, Environment Alert Bulletin.* United Nations Environment Programme.

Signoret, C., Caro-Bretelle, A.-S., Lopez-Cuesta, J.-M., Ienny, P., & Perrin, D. (2019). MIR spectral characterization of plastic to enable discrimination in an industrial recycling context: II. Specific case of polyolefins. *Waste Management, 98,* 160–172. https://doi.org/10.1016/j.wasman.2019.08.010

Silva, U. (2019). *Guía para Comunicadores y Periodistas. Residuos de Aparatos electrónicos y eléctricos (RAEE). En el marco de la ley 20.920 y la Responsabilidad extendida del producto (REP). Guía informativa para Chile 2020.* Santiago de Chile.

Toledo, M. (2022, April 19). *IMF refines forecast: Now expects Chile's per capita GDP to exceed US$30,000 in 2024.* Diario Financiero [Digital newspaper article]. https://www.df.cl/economia-y-politica/macro/fmi-afina-pronostico-ahora-espera-que-pib-per-capita-de-chile-supere

UNESCO. (2012). *Education for sustainable development: Sourcebook, Learning & Training Tools.* United Nations Educational, Paris. https://doi.org/10.2753/CED1061-1932430207

Velosa, G.J., & González Rolón, B. (2016). Characterization and study of recycling of waste electrical and electronic equipment (WEEE). *Jóvenes En La Ciencia, 2,* 1870–1876.

Venegas Marcel, M.E., Navarro Carreño, A.R., & Alfaro Carrasco, E.P. (2020). Procedural model for the characterization and assessment of waste electrical and electronic equipment (WEEE). *Cuadernos del Centro de Estudios de Diseño y Comunicación.* https://doi.org/10.18682/cdc.vi87.3771

Volker, K. (2023). Karien Volker: "The LED lighting campaign marked a milestone in energy efficiency initiatives in Chile" [Guía Chile Energía, news website]. https://www.guiachileenergia.cl/karien-volker-la-campana-de-luminarias-led-marco-un-hito-en-las-iniciativas-de-eficiencia-energetica-en-chile/

Wagner, M., Baldé, C. P., Luda, V., Nnorom, I. C., Kuehr, R., & Iattoni, G. (2022). *Regional Monitoring of Electronic Waste for Latin America, results from the thirteen participating countries in the UNIDO-GEF 5554 project* (p. 286) [Project Results]. United Nations Industrial Development Organization, UNIDO. https://ewastemonitor.info/wp-content/uploads/2022/01/REM_LATAM_2022_ENG_Final.pdf

Wolfensberger, M. (2009). *Electronic Waste Management through the Informal Sector in Santiago, Chile.*

World Bank. (2023). Household final consumption expenditure per capita growth (% annual) - Latin America & Caribbean | Data [Data Bank]. World Bank Group-IBRD-IDA. https://data.worldbank.org/indicator/NE.CON.PRVT.PC.KD.ZG?locations=ZJ

World Business Council for Sustainable Development. (2000). *Eco-efficiency: Creating More Value with Less Impact.*

Xavier, L. H., Giese, E. C., Ribeiro-Duthie, A. C., Lins, F. A. F. (2019). *Sustainability and the circular economy: A theoretical approach focused on e-waste urban mining. Resources Policy.* https://doi.org/10.1016/j.resourpol.2019.101467

Zainudin, A. Z., Yunus, N. M., Zakaria, S. R. A., Mohsin, A. (2021). Design for sustainability integration in education. In *Design for Sustainability* (pp. 139-169). Elsevier. https://doi.org/10.1016/B978-0-12-819482-9.00002-2

Zeng, X., Yang, C., Chiang, J. F., Li, J. (2017). Innovating e-waste management: From macroscopic to microscopic scales. *Science of the Total Environment, 575*, 1-5. https://doi.org/10.1016/j.scitotenv.2016.09.078

Zhang, L., Zhong, Y., Geng, Y. (2019). A bibliometric and visual study on urban mining. *Journal of Cleaner Production, 239,* 118067. https://doi.org/10.1016/j.jclepro.2019.118067

Cómo citar: Venegas-Marcel, M., Martínez-Torán, M., Jacob-Dazarola, R. y Miranda-Rojas, F. (2023). Characterization and Assessment of Household Waste from Electrical and Electronic Devices (WEEE) in Chile. A Proposal Towards a More Eco-Efficient Product Design. *Revista KEPES*, *20*(27), 75-104. https://doi.org/10.17151/kepes.2023.20.27.4