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Circular Economy in Mexico's Electronic and Cell Phone Industry: Recent Evidence of Consumer Behavior

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Abstract: Circular Economy (CE) models are increasingly referenced in international fora and on many countries' climate action agendas. This emphasis is associated with the international environmental and climate crisis. The case of the electronics industry remains particularly relevant, given its background in the use of CE models and its potential to enhance their use. This work focuses on consumer behavior regarding electronics products in Mexico. This is a largely under-researched topic not only in Mexico but also in Latin America. This study demonstrates that, by trying to extend the lifespan of their electronic products, consumers have awareness of product circularity. However, there is a lack of incentives to capitalize on this consumer interest, compounded by the limited participation of manufacturers and distributors. It is concluded that with a well-designed public policy, the electronics industry (including the mobile phone sector) in Mexico can move toward a CE model more rapidly. A stronger initiative for CE by design should be part of these policies, not only in Mexico but also internationally. The role of better eco-labelling in promoting consumers' environmental awareness is essential. The lessons of this case study might be of interest to other countries as well.

Keywords: circular economy; Mexico; electronic products; e-Waste; cellphone waste; consumer behavior

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1. Introduction

Over the past few years, the Circular Economy (CE) model has been attracting a great deal of interest in both developed and developing countries. The scientific community has not yet established a widely accepted definition, making CE a continuing topic of debate. Nevertheless, it is understood that CE's main philosophy is the movement away from linear models of production, consumption, and the final disposition of products toward more circular and sustainable models that optimize the use and reuse of materials, thus avoiding the exploitation of non-renewable resources. Emerging nations have followed CE models originally from Japan, China, and the European Union (EU), adapting them to their current legislation with regards to waste management. As shown below in the literature review, however, a generally accepted definition of CE remains elusive, prompting a wide range of ideas, methods and strategies [1,2]. It is, therefore, difficult to have an agreed metric for CE. Nonetheless, most indicators gravitate around waste recollection and recycling [2].

According to the UN's Global e-Waste Monitor (2020) [3], in 2019, 53.6 million tons (Mt) of e-waste was produced globally. Consequently, this makes e-waste the world's fastest-growing domestic waste stream, generated mainly by higher consumption rates of Electrical and Electronic Equipment (EEE), short use of these products, and few options for repair and recycling. Of the 53.6 million tons of WEEE, 435 thousand tons corresponded to mobile phones. Worldwide, only 17.4% of the e-waste was collected and recycled. According to the report, Asia generated the greatest volume of Waste Electrical and Electronic Equipment (WEEE) (24.9 Mt), followed by the Americas (13.1 Mt) and Europe (12 Mt), while Africa and Oceania generated 2.9 Mt and 0.7 Mt, respectively.

There are potential economic benefits of investing in the circular economy. Cellphones are a case in point, as shown in the international literature [4–6]. More specifically, Kumar et al. [5] argue that if electrical and electronic waste were recycled locally and efficiently, the recovery of materials in Europe such as gold, copper, silver, and palladium would be worth approximately $48 billion USD. Baldé et al. [7] determined that the economic value of gold, silver, and palladium in e-waste was $15.12 million USD per year in Latin America.

The selection of Mexico as a case to study is highly relevant in the international arena. The country, with a 2015 population of almost 120 million people, is the second-largest economy of Latin America, after Brazil. These two countries are, in the same order, the largest generators of e-waste [3]. Thus, we think our findings are of interest to readers outside the country. More particularly, 1.2 Mt of e-waste was produced in Mexico [3]), within a set of low levels of circularity. Although there is little official information on this issue, it is estimated that only 10% of all WEEE is recovered through formal programs of government and private firms [8]. An additional 20% is collected via informal channels [9,10]. Thus, a gross figure of circularity would be in the range of 30%. For some authors, this is a high figure in the Latin American setting [3,11]. However, at the end of the day, roughly 70% of all WEEE is not collected. The economic losses caused by a limited reuse of this e-waste are estimated between $11.3 billion to $12.4 billion USD [12]. In addition to these economic impacts, it is estimated that the recovery of electronic waste could generate around 178,000 direct jobs by 2030 [13]).

The analysis and implementation of CE policies are done through a waste management perspective. Japan's CE model is stated as a "virtuous cycle of the environment and growth" enabled by a set of strategies to reduce, reuse and recycle, being led by the Resource Efficiency and Circular Economy Division of the Ministry of Economy, Trade and Industry [14]. China's CE model is highlighted in its "13th Five-Year Action Plan for Environmental Protection," which includes strategies for promoting circular production, resource efficiency, and responsible consumption [15]. The European Union's CE model focusses on an "Action Plan" and a "Green Deal." These include extensive initiatives along the entire lifecycle of products aimed at fostering sustainable production and consumption and ensuring that the resources used are kept in the EU economy for as long as possible [16].

In Latin America, and Mexico in particular, the concept of CE is relatively new. Circular models in the country are still in a process of discovery and analysis. Most Mexican industrial operations are based on linear processes that extract non-renewable resources and produce waste, lacking the capacity to reuse them. The Mexican government and industry do not seem to have a clear understanding of CE.

Information related to the CE and studies about the consumer behavior of electronics in Latin America, and in Mexico in particular, from an e-waste management perspective, is limited. To prove this, the authors conducted a literature review in the SCOPUS database during Autumn 2020 using three keywords—"circular economy," "e-waste," and "electronic waste"—and then filtered the 14,707 resulting documents based on their focus on Latin America and/or Mexico. The final results returned just six publications: three focused on Mexico [9,12,17], two in Brazil [18,19] and one in the Caribbean Islands (viz. Aruba, Barbados, Grenada, Jamaica, and Trinidad and Tobago) [20]. The aforementioned search results were complemented with a search of governmental reports developed by the Mexican Ministry of Environment and Natural Resources (SEMARNAT) for the last seven years [21–23], given that the unit of analysis of this research work is "Mexico." Because of this lack of studies on consumer behavior in Latin America, we have no evidence about different patterns of behavior between Mexico and other countries of the region. We can assume, however, that the behavior is similar. This claim is supported by international studies that show several similarities [24–28].

In Mexico, the electronic industry has significant potential for circularity. Since 2012, the economic production of EEE for 2020 was estimated at $76.54 billion USD [29]. This involves a high generation of WEEE in the country. Thus, new research and strategies on how to collect this waste to optimize and recover raw materials with the consumer are imperative. The research reported here contributes to the state-of-the-art knowledge about consumer behavior in Mexico regarding electronics and considering the qualitatively and quantitatively dimensions. This research is also an important driver to start and support circular modeling processes in Mexico's electronic industry. This analysis is based on a national survey carried out explicitly for this purpose in 2018. The main issues addressed were the environment, usage, consumption patterns, and how people handle their end-of-life electronic products.

This study is structured into five parts. After the introduction, a literature review is presented, analyzing aspects related to CE in the electrical and electronics industry as well as the consumer behavior surrounding these products on a national and international scale. The third section explains the survey methodology applied to 1000 people in 32 Mexican states that were analyzed using the Statistical Package for Social Sciences (SPSS) software. We also discuss the results, referring to both the national and international contexts. The last section concludes the study by demonstrating certain patterns of circularity and the consumer's limited environmental consciousness regarding extending the lifetime of electronic products. The absence of legislative instruments and government incentives, along with the lack of participation and producer/manufacturer responsibility, does not encourage consumers to properly dispose of electronic products and extend their useful lifetimes.

2. Literature Review

2.1. CE in the Electrical and Electronics Industry

A generally accepted definition of CE remains elusive, prompting a wide range of ideas and methods being analyzed to devise a concept that can relate circular models to the pillars of sustainability, as proposed by Homrich et al. [30]. Some researchers have emphasized the need for new business models that facilitate the transition from open production systems to closed systems focused on product eco-design that reuses resources and reduces energy [12,31]. Other researchers have affirmed that any circular model must point to three dimensions of impact—environmental, economic, and social [18,32]. Kirchherr et al. [33] demonstrated that CE can be implemented on the micro-level (i.e., products, companies, consumers), meso-level (i.e., eco-industrial parks), or macro-level (i.e., city, region, nation) to achieve sustainable development to create environmental quality, economic prosperity, and social equity for the benefit of current and future generations.

As it was pointed out earlier, the European Commission has adopted a new CE Action Plan whose measures consider the entire life cycle of products, as part of a green growth strategy which also gives new rights to consumers. This Action Plan focuses on sectors that are heavy users of resources and have a high potential for circularity. A circular electronics initiative is intended to provide longer product lifetimes, avoid planned obsolescence, and improve the collection and treatment of e-waste [16].

The CE in the electrical and electronics industry should focus on analyzing the various stakeholders, processes, and scenarios to optimize the use, management, and recovery of resources and materials. This research is based on the CE conceptual framework proposed by Kirchherr et al. [33], Urbinati et al. [31], and Homrich et al. [30], who established that CE is an economic-industrial modeling system that analyzes the inputs and outputs of resources, matter, and energy throughout a product's value chain. This replaces the end-of-life concept with the reuse, recycling, and recovery of secondary raw materials through eco-design, production, consumption, and responsible recycling [34,35].

In Mexico, the definition of CE is relatively new, especially in the EEE sector. A study by Cordova-Pizarro et al. [12] provided better visibility of Mexico's current situation regarding materials flow contained in WEEE (e-waste) at the end of their useful lifetimes. The research conducted a material flow mapping from electronic equipment arrival to the consumer and its repair at formal/informal stores or a recycler, where it is disassembled and its materials are recovered. Similarly, in 2017, SEMARNAT and the United Nations Development Program (UNDP) joined forces to devise essential information regarding the WEEE industry's situation and management 2018 [23].

The integral e-waste management process in Mexico is generated and managed by different actors such as manufacturers, distributors, consumers, repair shops, recyclers, etc. For this reason, electrical and electronic equipment's lifecycle must be determined. Figure 1 describes the general lifecycle of EEE, from its production, sale, and use by the consumer until the last user transforms it into waste [12]. As e-waste, electrical and electronic equipment can be stored by the user, thrown away, or sent to a recycling location. Nevertheless, the appropriate process with the least socio-environmental impact depends on the consumer since they dictate the fate of their obsolete products (for example, repair or go through a diagnosis process, analysis, and evaluation to be reconditioned/remanufactured and re-enter the market). If the operation and conditions of the equipment cannot be recovered, its components and materials are used for repair or to remanufacture other products. To achieve this, a modular eco-design of the parts and components is required for the materials to be recovered; otherwise, they are incinerated or safely disposed of [35–38].

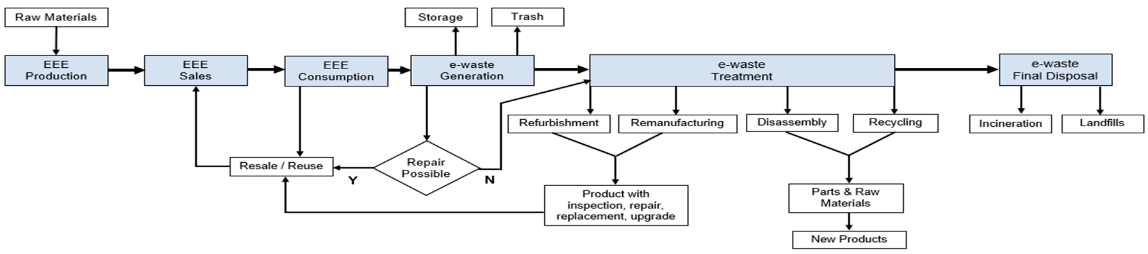

Figure 1. The lifecycle of electrical and electronic equipment (EEE) in Mexico. *Source*: Córdova-Pizarro et al. [12].

2.2. CE and Electronic Product Consumers

In the electronics industry, the CE philosophy is focused on product eco-design, reuse, repair, refurbishment, re-manufacture, and recycling to increase their useful lifetimes and recover the raw materials from their waste [12,36]. Some companies have been open to considering value-added processes based on closing-loops and reusing EEE as a cascade for multiple applications and the new product fabrication. Jianfang et al. [37] demonstrated that the eco-design of equipment is essential for closing cycles and reintroducing raw materials to the system. This process enables the disassembling of modular parts and components to recover materials to reinsert them into the process [39].

The consumer is the protagonist who can ensure the feasibility of a CE model in the electronics industry. For this reason, it was necessary to analyze the variety of angles, such as demographic and socio-economic features, length of EEE use, reasons to consider equipment obsolete, disposal modalities to extend the device's lifetime, obsolescence of equipment, repair, safe ways of recycling, and others [9,12,17]. The literature review from Bocken et al. [40] confirmed that if a user has the habit to change their device to a new model, he or she will either sell it, give it away, or deliver it to a recycler; in this way, the materials will re-enter the circular system. However, if the user throws it away or stores it, the materials will be lost and unavailable to the system. Alcantara et al. [17] determined that 40% of Mexican consumers store end-of-life cell phones for less than a year, sell them, give them away, or dispose of them, while the remaining 60% wait longer to give them away or sell them in a second-hand market. Similarly, Cruz et al. [9] noted that desktop computers and printers in Mexico often decorate home offices but have not been used for several years.

In Europe, second-hand electronic products are not attractive to consumers, based on the belief that this equipment is already damaged or that it will work only for a short time. Studies performed by Pérez-Belis et al. [41] and Parajuly et al. [38] confirmed that the main reason for not buying second-hand electronic products is because consumers associate these products with previously damage and repair, low quality, and a short lifespan. On the other hand, Pérez-Belis et al. [41] confirmed that users agree to buy in second-hand markets from friends or acquaintances whereby they can personally check the electronic product's status and operation.

The eco-design of modular electronic devices facilitates the repair of these products and reduces the cost of their components since users can change them independently. In Europe, legislation has been passed to promote the eco-design of products and the availability of repair manuals/tutorials to enable users to repair their own equipment [42]. When equipment breaks and cannot be repaired and formal repair service is very expensive, consumers prefer to store the equipment or throw it away [38]. In addition, there are also smartphone suppliers that are already performing a CE like "Shift" [43] and "Fairphone" [44]. However, even providing a CE product they still have the problem of having enough consumers. The website "iFixit.com" has generated repair manuals and diagnostic tools to help consumers repair the damage that does not require a specialized technician, such as changing a car battery or saving a wet cell phone [45].

Age, education, and socio-economic level are key aspects of a consumer behavior survey. They are related to awareness regarding end-of-life WEEE's possible environmental impacts [46,47]. Some initiatives to promote e-waste recycling, such as ecological payments or environmental deposits, have been more widely accepted by professionals, academics, and people related to the environment. In the Netherlands, Knot and Luiten [48] indicated that those with the highest income and level of education are more accepting of leaving an environmental deposit. In Europe, Parajuly et al. [38] showed that consumers with university degrees were more readily accepting of electronic recycling laws and sharing responsibility with the producer. In Brazil, ecological contributions are collected from consumers to ensure adequate and responsible WEEE recycling or payment return once the client delivers their end-of-lifetime equipment [18].

2.3. Electronic Product Consumers in Mexico and Latin America

In Mexico, knowledge about consumer behavior regarding electronics is quite limited. In 2009 and 2010, the National Institute of Ecology and Climate Change of Mexico (INECC) conducted a survey on EEE consumer behavior in the northern border and the metropolitan area of the valley of Mexico [49]. The survey covers social, environmental, and economic dimensions, such as the average useful lifetime of electronic devices, discarded equipment's final destination, and environmental and human health risks. This survey revealed consumers' knowledge regarding what ultimately happens to their e-waste, demonstrating that 71% of the population did not know their WEEE's final destination. Of the remaining 29%, 56% thought the waste went to a garbage dump, 15% that it was reused or went to a collection center, 13% to a sanitary landfill, and 10% to a landfill. Finally, 6% did not have any idea about WEEE's final destination.

In Latin America, particularly in Mexico, there is a gap in the literature about consumer behavior regarding EEE. Table 1 shows the results of a search performed during Autumn 2020, using SCOPUS database, in which three keywords—"circular economy," "e-waste," and "electronic waste"—were used as part of the search string to look for them in the title, abstract, or keywords of the indexed publications. The search string was intentionally defined with a broad scope in mind knowing based on the authors' research experience that the existing literature on e-waste management, including consumer behavior, in the circular economy context is scarce. The research string gave us a total of 14,707 documents that were screened to identify those with a focus on Latin America. Only six papers out of this total were really focused on Latin America, namely, Mexico [9,12,17], Brazil [18,19], and the Caribbean Islands (viz. Aruba, Barbados, Grenada, Jamaica, and Trinidad and Tobago) [20]. The rest of the studies were targeted to Europe and Asia, where circular economy strategies have been under development for several years [6,35,38,50,51].

Table 1. SCOPUS search results on "circular economy," "e-waste," and "electronic waste" with focus on Mexico and Latin America.

Year	Title	Authors	Summary
2016	Environmental Impacts at the End of Life of Computers and their Management Alternatives in Mexico	[17]	This study presents a lifecycle analysis of end-of-life computers for the management of computers discarded in Mexico for the year 2014 through LCA methodology (ISO 14044). All practices of management and recycling are considered in the model with changes in the recycling rates and installed infrastructure for different alternatives proposals.
2017	e-Waste Supply Chain in Mexico: Challenges and Opportunities for Sustainable Management	[9]	This study analyzes e-waste in Mexico through the active actors in the recovery chain. It proposes a management model which highlights components that must be considered in the model and the opportunities and challenges to transition from an unbundled handling, which still has practices that lack environmental and technical support, to sustainable management.
2019	Sustainability and the Circular Economy: A Theoretical Approach focused on e-Waste Urban Mining	[18]	The study reviews the main Circular Economy solutions for e-waste management, highlighting the importance of recovering and classifying mineral material according to urban mining procedures.
2020	A Circular Approach to the e-Waste Valorization through Urban Mining in Rio de Janeiro, Brazil	[19]	This study analyzes the e-waste amount generation, the location of the recycling companies of this segment and the collection routes in the metropolitan region of Rio de Janeiro. It also proposes a set of criteria and indicators to identify the best option for e-waste management.
2019	Circular Economy in the Electronic Products Sector: Material Flow Analysis and Economic Impact of Cell Phone e-Waste in Mexico	[12]	This study presents an evaluation of the current technical and economic situation of cell phone e-waste generated in Mexico. The investigation was based on surveying and analyzing the main actors that influence the management of this waste and using a material flow analysis of cell phone e-waste processing in both formal and informal channels.
2021	Electronic Waste in the Caribbean: An Impending Environmental Disaster or an Opportunity for a Circular Economy?	[20]	This study estimates EEE flows for the five island cases over a period of 60 years (1965–2025), including e-waste that these flows have and will generate using a dynamic material flow analysis. The results show the need to adopt a CE to reduce harm to the local environment, and loss of valuable resources.

Source: Own elaboration.

About Mexico, there was only one study on consumer behavior regarding WEEE and circular economy in the SCOPUS database results, which was developed by the same co-authors of this article (see reference [12]).

Furthermore, since the unit of analysis of this research work is "Mexico," a search of governmental reports developed by the Mexican Ministry of Environment and Natural Resources (SEMARNAT) for the last seven years [21–23] was conducted (see Table 2).

This literature review shows that the available information and studies on consumer behavior regarding e-waste management in Latin America are quite limited. The value of this work, therefore, lies in the fact that it is filling this gap. This factual context provides the framework for this article and its reliance on the questionnaire that was used. We now turn to these issues.

Table 2. SEMARNAT reports on electronic product consumers in Mexico.

Year	Title	Authors	Summary
2011	NOM161-SEMARNAT-2011—Criteria for Classifying Special Management Wastes and Determining which are Subject to Management Plan	[21]	The Official Mexican Norm NOM-161-SEMARNAT-2011 establishes the criteria for classifying the special management waste and determining which are subject to management plan—the list thereof, the procedure for inclusion or exclusion from said list, as well as the elements and procedures for the formulation of management plans.
2016	Inventory of Electronic Waste Generation in Mexico. National and State Scale for Jalisco, Baja California, and Mexico City	[22]	This report presents a national inventory of electronic waste generation in Mexico, with particular focus on the states of Jalisco, Baja California, and Mexico City due to their capacity to represent the regional heterogeneity of the country in terms of consumer preferences for electric and electronic products.
2017	Characterization of the Formal and Informal Electronic Waste Recycling Industry in Mexico	[23]	This report identifies and characterizes the formal and informal industry practices of electronic waste recycling in Mexico, in particular, at the states of Jalisco, Baja California, and Mexico City; and develops a forward-looking analysis of the industry for the next five and 10 years.

Source: Own elaboration.

3. Methods

3.1. Questionnaire Development

This research carried out a literature review and consultations with specialists on the circular economy, survey of consumer behavior, as well as electrical and electronic products, WEEE, repair, and recycling. The questions were of a qualitative nature and based on research previously carried out in Mexico by Cruz et al. [9], SEMARNAT [23], INECC [26], and the National Institute of Statistics and Geography (INEGI) [52]. The design of the questionnaire also considered research conducted in other countries: Brazil [53], Taiwan [47], Indonesia, the Philippines, and Vietnam [54], and Nigeria [55]. These countries may have different consumer habits but the same electronics and smartphones.

From this exploratory search, 50 questions emerged to work first in a virtual pilot survey. Co-authors discussed and analyzed the results of the virtual survey, leading to 33 final questions for the national survey. The survey's qualitative questions were categorized according to the following themes: (i) behavior in the use of electronic equipment (four questions); (ii) behavior at the end of EEE lifetime (three questions); (iii) final destination of electronic equipment (two questions); (iv) recycling (four questions); (v) repair (six questions); and (vi) socioeconomic characteristics (14 questions) (see Table 3). The national survey was conducted during the second half of 2018 by Berumen S.A. de C.V. The information was captured using the Census and Survey Processing System (CSPro) (U.S. Census Bureau. Released 2015. CSPro for Windows, Version 6.1.0. Suitland, Maryland, U.S.) that reduces human error. The informational and statistical analysis was performed using Statistical Package for Social Sciences (SPSS) software (IBM Corp. Released 2015. IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp).

Table 3. Relationship between the area of analysis and the questionnaire.

Area of Analysis	Questions of the Survey
Behavior in the use of electronic equipment (4 questions)	Q1. What electronic equipment do you have? Q2. How did the interviewee acquire the electronic equipment? Q3. In what condition did you receive them? Q4. Time of use of the equipment.
Behavior at the end of the electronic equipment use time (3 questions)	Q5. Reasons why a device is no longer functional. Q6. Equipment storage time. Q7. Ways to dispose of equipment.

Table 3. *Cont.*

Area of Analysis	Questions of the Survey
EEE final destiny (2 questions)	Q8. Knowledge about the final destination of the team. Q9. Destination options at the end of its useful life.
Recycling (4 questions)	Q10. Reasons for not delivering the equipment to the recycler. Q11. Reasons for delivering the equipment to the manufacturer. Q12. Green contribution to responsible recycling. Q13. Ecological deposit for responsible recycling.
Repair (6 questions)	Q14. Problems that the equipment may have in its useful life. Q15. Repair alternatives. Q16. Extra protection services or accessories. Q17. Battery change options. Q18. Options to use the equipment longer than expected. Q19. Trade-in programs.
Socio-economic characteristics (14 questions)	Age, gender, socio-economic level, education level, level of technological knowledge, type of work, type of dwelling, number of household members, type of floor, number of lights, number of bathrooms, number of bathrooms with shower, number car, gas, or electric stove.

Source: Own elaboration based on references [9,23,26,47,52–55].

3.2. Sample Size

The national survey was conducted in all 32 of Mexico's states. Based on the last census held by *INEGI* in 2015, the size of the national population was determined to be 119,938,473 people. This data was considered in calculating the sample population for the national survey [12]. The sample size was determined from the general parameters to be estimated in a socioeconomic investigation, with various percentages and proportions of variables referring to a set of people or households. To determine the sample size for this study, the authors referenced the work of Bartlett et al. [56] (see Equation (1)), starting by using simple random sampling with the precision and statistical confidence required for the investigation [57,58].

$$n = k^2 \cdot \frac{P \cdot (1-p)}{d^2} \qquad \text{(Equation sample size)} \tag{1}$$

From this equation, it was determined that the sample size required for a total Mexican population of 119,938,473 [8], at a 95% confidence level (k) and a maximum margin of error of 0.03 (d), which was 1067 people (~1000), as illustrated in Table 4.

Table 4. Confidence levels for calculating the sample size of a population.

Accuracy d	Confidence 95% (k = 1.96)				
	***P* = 0.05**	***P* = 0.10**	***P* = 0.25**	***P* = 0.40**	***P* = 0.50**
0.01	1825	3457	7203	9220	9604
0.02	456	864	1801	2305	2401
0.03	203	384	800	1024	1067 *
0.04	114	216	450	576	600

Note: * 1067 people were required to be surveyed; however, the pollster rounded this number to 1000. *Source*: Own elaboration from [57,58].

3.3. Sample Design

After determining the sample size, the interviews were selected according to the state. In Mexico, geographic areas for census purposes are called AGEBS (Acronym in Spanish for Basic Geostatistical Areas) [52], which from a smaller territorial and population dimension than municipalities and are formed from localities. The sampling frame was built from all AGEBS in the country. One hundred AGEBS were randomly selected, each of which had a probability of being chosen proportional to its population size. Within each sample AGEB, two neighborhoods were randomly selected, and within each block sampled, five private homes were chosen at random. Finally, during the last sampling stage, participants of legal age (18 years old) within each dwelling were selected for interviews. The distribution of the sample at the national level is presented in Table 5.

Table 5. The number of interviews for each Mexican state.

No.	State	Number of Interviews	No.	State	Number of Interviews
1	Estado de México	130	17	Oaxaca	20
2	Distrito Federal	100	18	Querétaro	20
3	Jalisco	80	19	San Luis Potosí	20
4	Veracruz	60	20	Sinaloa	20
5	Nuevo León	50	21	Yucatán	20
6	Puebla	50	22	Aguascalientes	10
7	Baja California	40	23	Campeche	10
8	Chihuahua	40	24	Colima	10
9	Guanajuato	40	25	Durango	10
10	Michoacán	40	26	Hidalgo	10
11	Tamaulipas	40	27	Nayarit	10
12	Coahuila de Zaragoza	30	28	Quintana Roo	10
13	Guerrero	30	29	Tabasco	10
14	Sonora	30	30	Tlaxcala	10
15	Chiapas	20	31	Zacatecas	10
16	Morelos	20		Total	1000

Source: Own elaboration based on Berumen (2018).

4. Results

4.1. Consumer Profile

The participants were 50% male and 50% female, most belonged to a medium socioeconomic level, and their ages fluctuated between 24 and 50 years of age. The socioeconomic level in Mexico is presented according to different strata based on monthly income. Figure 2 shows that 5% of the sample belonged to Level A/B (the stratum with the highest standard of living and income) and 70% came from the middle socioeconomic level. This level is between high C+ (similar to level A/B, it is a high social level but with limitations regarding savings and excessive expenses), medium C, and C− (medium social level, with above-average well-being) and medium-low D+ (the largest segment of the Mexican population, has the minimum domestic sanitary infrastructure). Finally, 24% belong to the lowest socioeconomic category (the poor segment, where people lack all satisfactory services and goods) and 1% belong to extreme poverty.

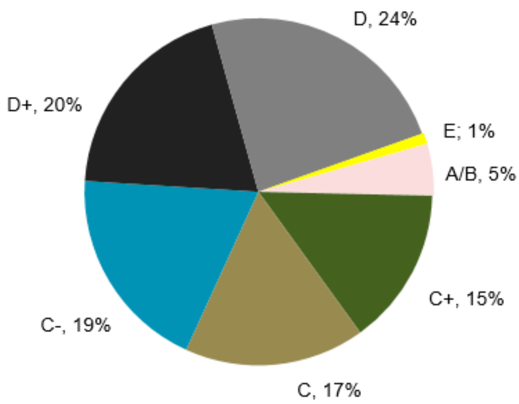

Figure 2. The socio-economic level of the 1000 people surveyed (in percent), 2018. *Source:* Own elaboration based on the results obtained from a national survey (2018). * Percentages do not add up to 100% due to the rounding of figures.

4.2. Behavior in the Use of Electronic Equipment

The results for the social behavior regarding consumption by the analyzed population are shown below. The electronic equipment most owned by the interviewees were televisions (97%), cell phones (87%), and, to a lesser extent, laptops, with 70%. Desktops and tablets were in the lowest percentage, at 24% and 22%, respectively. Of the 87% of people who have a cell phone, almost half are smartphones. Most respondents received their EEE in new condition (new packaged product or reconditioned). Over 70% of the interviewees bought their electronic equipment while 20% received it as a gift.

Depending on the type of electronic equipment, people used it for different lengths of time. In many cases, the consumer did not dispose of them and instead stored them. Figure 3 shows that 39% of the interviewees used their cell phones for between one and three years and later gave them away or sold them on the second-hand market. Nonetheless, 40% reported that they used their cell phone for less than one year since their cell phone plan allowed them to upgrade once a year. In the case of desktop computers, the average length of use is between less than one year (26%) to three years (25%); nonetheless, 30% of the respondents stored them because they did not dispose of the equipment. Laptops and tablets followed a phenomenon similar to desktop computers, their average time of use fluctuated between less than a year to one to three years. Between 30% and 35% of people did not dispose of their equipment and stored it for possible use "someday".

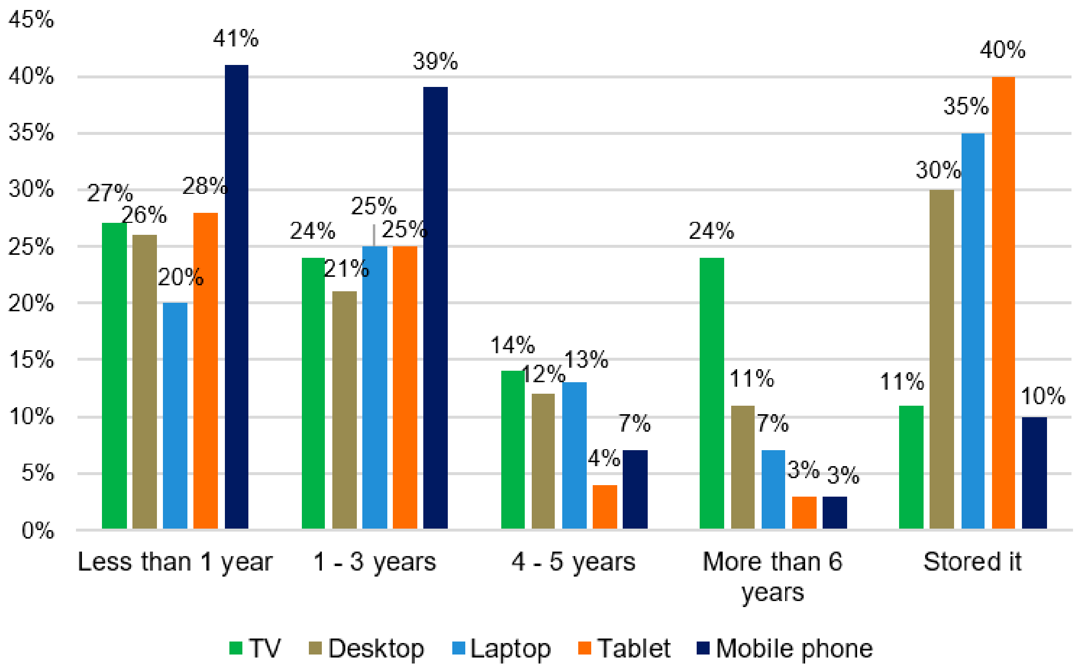

Figure 3. Time of use of electronic equipment before disposal (percentage). *Source:* Own elaboration based on the results obtained from the national survey (2018).

4.3. End-of-Lifetime Electronic Equipment Consumer Behavior

This section presents the results on why electronic equipment was no longer useful, its time in storage, and means of disposal. Personal income is one reason why EEE is considered no longer useful or obsolete. At all socioeconomic levels, electronic products are considered no longer useful when repair becomes too expensive (35%) or when it is not possible to repair the equipment (26%). Interviewees also expressed that EEE is no longer functional when its battery or operating system fails.

Electronic equipment is usually stored for one to three years when it is no longer useful to the consumer. More than half of the respondents put away televisions and cell phones for this length of time. Desktop and laptops computers (18–22%) were stored for a similar period of time. Nevertheless, a percentage of the respondents did not store their equipment (20–33%) and sought alternatives to reinsert it into the market.

Electronic products are often disposed of by giving them to another person or selling them to a relative or acquaintance. Figure 4 illustrates how respondents disposed of their electronics—31% of respondents gave them away to a family member or friend, while 22% sold them in the second-hand market. Despite it being the most harmful environmental decision with significant social externalities, 18% of interviewees just throw away their equipment. Finally, exchanging equipment for another product, recycling them, or donating them to a social program were the actions taken less frequently by respondents (fewer than 8%).

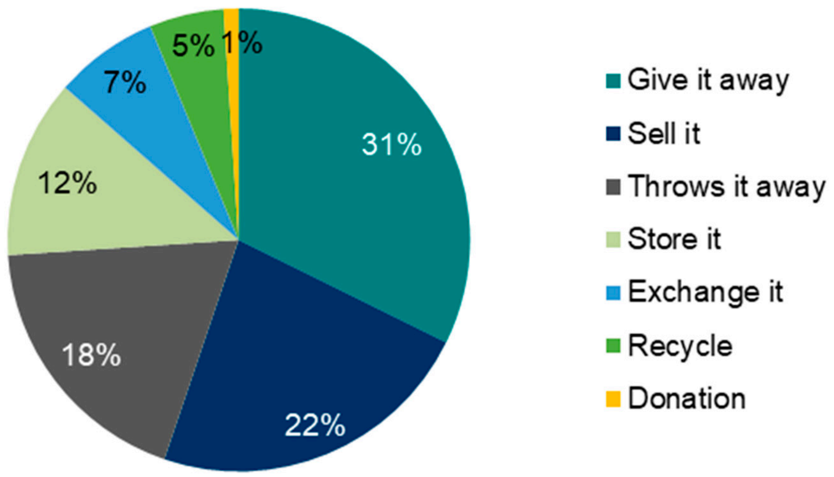

Figure 4. Ways people dispose of their electronic equipment. *Source:* Own elaboration based on the results obtained from the national survey (2018).

4.4. Final Destination of Electronic Equipment

This section presents the results regarding the disposal and final destination of electronics. A small number of people know what happens to their electronic products after they dispose of them. Regardless of gender, over 86% expressed that they did not know what happened to their devices. Over half of the remaining 14% indicated that their electronics were recycled. Interviewees over the age of 36 had more information and knowledge about their products' final destination; almost 70% indicated that their EEE went through a recycling process. People between the ages of 24 and 35 thought that their electronics were recycled (53%) or remanufactured (33%). Half of the interviewees under 23 years of age mentioned that their products were recycled. A relatively high percentage of the young and adult populations (41% and 24%, respectively) expressed that their equipment went to the landfill. A very small percentage of those surveyed believed that their equipment was incinerated.

4.5. EEE Recycling

This section presents the results of EEE recycling and why users do not deliver their products to the recycler/manufacturer at the end of their useful lifetime. Environmental contributions are made by paying a sum of money at the time of the purchase of electronics. A lack of information on disposal options for EEE prevents consumers from turning their devices over to the manufacturer for recycling. Figure 5 depicts the reasons consumers have difficulty delivering their disused electronic equipment for recycling. Almost half of the respondents indicated that a lack of information was the main reason that they did not turn in their electronic devices. The second reason is the low economic return value (21%), which can be attributed to stores not granting economic incentives (e.g., discounts or gift cards) according to consumer expectations. Interviewees stated that they earned more by selling their electronic products in the second-hand market than by handing it over to the distributor for recycling. Finally, a fifth of those interviewed indicated that there were no adequate collection channels for delivering their electronic equipment.

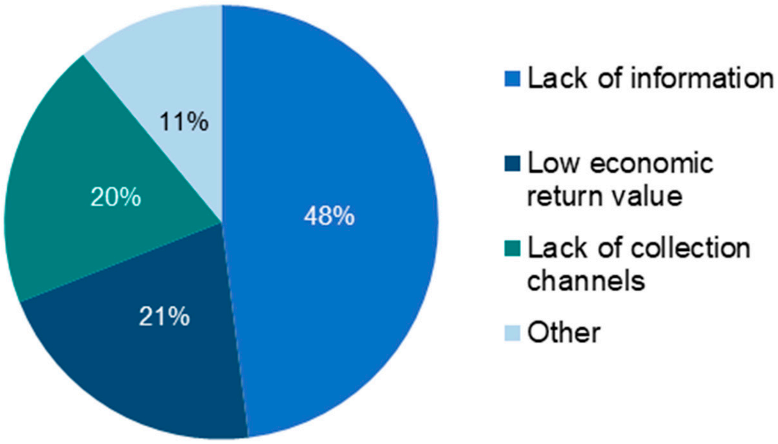

Figure 5. Reasons that make it difficult for consumers to deliver for recycling their electronic equipment at the end of its useful lifetime. *Source:* Own elaboration based on the results obtained from the national survey (2018).

The distributor must propose different mechanisms for collecting disused electronic equipment from consumers. The main reason for users delivering their electronics is to clear up their home or office (32%) or the existence of a greater number of places to deliver this equipment (23%). Respondents also mentioned that manufacturers and distributors should come to devise better monetary reward options to compete with second-hand markets (20%). The option whereby they were guaranteed that their device was going to be recycled in an environmentally responsible manner had a percentage of 10%.

In the national survey, people were asked if they were willing to pay an ecological contribution or deposit so that the best possible and responsible recycling was managed and to know the final destination of their electronic products. Over half of the respondents were not willing to pay an ecological contribution. For this reason, an alternative considered was to pay a deposit when buying a new product with the objective that when the consumer returns the electronic equipment when it is no longer useful, the distributor/manufacturer will refund the deposit and responsibly recycle the product. Over half of the interviewees (54%) were willing to leave an ecological deposit as long as it was less than 10% of the product price.

4.6. Mobile Phone Repair

This section presents the results on respondents' behavior regarding repair issues, specifically mobile phone repair, and how the economic aspect influences whether or not a consumer repairs their electronic equipment. Various physical or operational problems can occur during a cell phone's useful lifetime. The results showed that one of the main types of damage suffered by mobile phones is due to the touch screen cracks (36%), followed by liquids damage (18%). Similar percentages are observed regarding operating systems or battery damage. Finally, 12% of the interviewees reported that another problem they encountered was their mobile phone no longer turning on.

Based on the average time that interviewees had their mobile phones before disposing of them between the first and third year of ownership, they required alternatives to extend the life of their devices. Figure 6 shows that 42% of respondents would use their mobile phones for a longer period of time if the store where they purchased it offered them free service to optimize their equipment and its operating system and 31% agreed if the store included a scheduled battery change/replacement plan. Similarly, 14% mentioned that it would be better if the battery could be replaced more easily. Finally, a lower percentage of people did not agree to use their cell phone for a longer period of time because they wanted to have the latest model (7%) or because their mobile phone contract upgraded them to a new cell phone upon contract renewal.

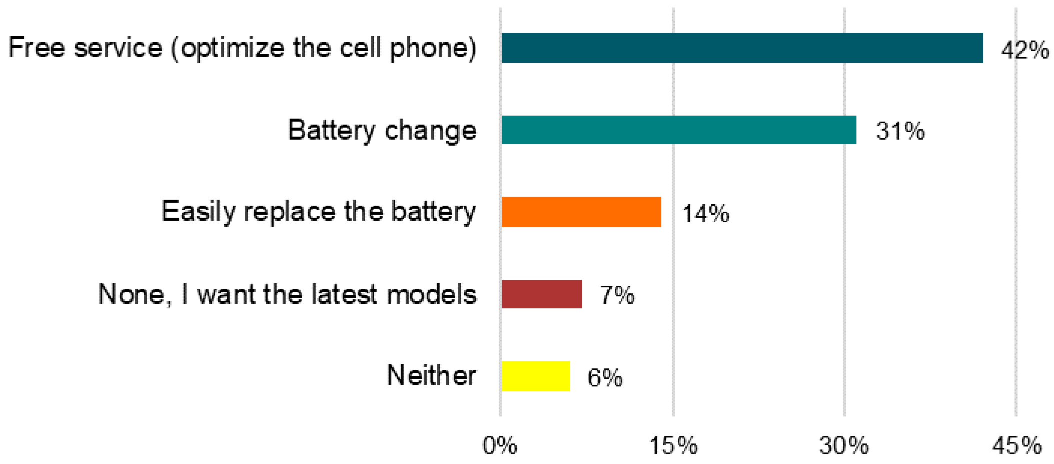

Figure 6. Options to keep mobile phones longer than expected (percentages). *Source:* Own elaboration based on the results obtained from the national survey (2018).

5. Discussion

With the correct strategy and the participation of the stakeholders—namely, the government, manufacturers, distributors, and consumers—this research demonstrates that it is possible to move toward CE in the EEE industry. Major regulatory changes might not even be required. For example, the national survey showed that recycling of EEE products could potentially be increased by establishing collection schemes to pick up devices from homes or offices (32%) and by increasing the number of equipment collection centers to drop off devices (23%). Over half of the interviewees answered that they would agree with these options. In fact, several supermarket chains in Mexico already have containers to collect cans, paperboard, paper, and plastics in their establishments. Anderson [59] and Kumar et al. [5] determined that, in the US, consumers have a better tendency to deliver their e-waste to the recycler, due to the existence of delivery channels, or the manufacturer will collect them from their homes/offices.

Nevertheless, with this possibility, the survey showed a lack of awareness and mistrust by the consumer to deliver their products to collection centers (69%). This suggests that an incentive scheme, such as a reverse logistics model, is necessary, through which consumers could return equipment to producers and/or distributors, 54% of the respondents agreed to leave a deposit scheme if it is less than 10% of the electronic final price. This might not be easy, but international experience in Brazil, the Netherlands, Japan, and Australia demonstrates that it is possible [18,19,38,46–48]. It would be helpful to develop environmental education and awareness campaigns. An incentive scheme should include economic benefits for the actors in the circular chain as well as sanctions and/or penalties that promote the responsible usage, disposal, recycling, and reuse of WEEE.

This research demonstrates that there is a wide opportunity to increase circularity in the industry, particularly in the case of mobile phones, if ways to extend usage are developed. This requires a better understanding of consumer behavior according to each type of electronic equipment. For example, unlike other electronic products—such as televisions, desktops, laptops, and tablets—mobile phone consumers use their devices for only a short time before disposing of them. Almost 80% of the interviewees used their cell phones for between one and three years. In fact, 40% used them for less than one year. Hennies and Stamminger [60] showed that the amount of obsolete equipment is driven by relatively short replacement cycles. Since technologies change rapidly, many users in Europe exchange their devices regularly and more frequently before they actually break [61].

This could have different explanations. On one hand, there are extensive programs by mobile phone companies that incentivize users to change plans in less than one year. Authorities do not regulate the marketing and advertising campaigns of distributors, exposing consumers to unnecessary purchases and accelerated consumption. EEE companies do not provide alternatives for properly disposing of equipment or collection facilities for responsible recycling. This prompts clients to discard or store their equipment without seeking mechanisms to reuse or extend the equipment lifetime or even to throw them away.

On the other hand, all socioeconomic levels, regardless of education, consider electronic equipment to be no longer useful when its repair is expensive or not possible. A high cost of repair, the high price, and availability of components (e.g., screen and battery) are the limitations for more extensive repairing of mobile phone equipment. This trend is consistent with international studies conducted by Bovea et al. [62] and Kirchherr et al. [33] that demonstrated that users prefer not to repair their equipment due to the high cost. These studies also show a lack of government legislation to encourage manufacturers to eco-design their products in a modular manner to facilitate their repair. They also show a lack of control of distributor promotions, marketing, and accelerated sales. Specifically, for the higher socioeconomic levels, electronic equipment might be considered no longer useful when a more fashionable product with better technological performance appears on the market. This encourages manufacturers and electronics stores to influence this market segment more heavily, without any regulation by authorities. This confirms the customer's exposure to unnecessary purchasing and consumption scenarios.

In this sense, it is necessary to examine in detail what this pattern requires, to design an incentive scheme to extend cell phones usage. This also implies that stronger regulation to avoid or inhibit mobile phone companies from irresponsible practices that encourage the replacement of electronics before the end of their useful lifetimes. An incentives scheme could target electronics users who store them at home, often as decorative objects, or who simply throw them away. Approximately 30% of users carry out these practices.

To create an attractive shared responsibility scheme, increased cell phone durability and reparability would extend the amount of time that users can keep them. It would also bet more on CE by creating a design in which the manufacturer facilitates both the scaling of the phone's capabilities and its repair and recycling. The survey is very revealing in this regard. About 87% of the people indicated a willingness to use their cell phones for a longer time-period if retailers provided free service to repair and optimize their equipment and operating system or included a scheduled plan to change or replace the battery. In the current system, incentives are not properly aligned for greater circularity via repair or re-manufacture. Manufacturers and distributors making these tasks easier could pay off for the entire chain. Only 13% of consumers (always) want the latest models or wait for their mobile company to deliver a new cell phone with contract renewal. Although this percentage should not be dismissed, it is relatively low, which means that the majority of users are willing to keep their equipment for longer if conditions are appropriate.

The low levels of repair and recycling indicate that both the design and implementation of measures is challenging and yet worth trying. There is no single action to this end,] but rather a myriad of well-crafted policy measures. The latter varies from augmenting the environmental awareness of consumers to compulsory measures to all those involved in the CE chain. This situation needs to be seen against the limited information provided by the government. Well-oriented economic incentives could play a significant role, and so does new technological capabilities that enable consumers to repair their electronics. Sound legislation and government regulation are key to increase the degree of formality in the industry. As we have found in previous research [12], in Mexico, only 10% of e-waste and recycling takes place in formal environments. Nationwide, there are only 153 firms that collect electrical and electronics waste [10]. So far, industries do have their own management plans, often without any connection with the established official guidelines [63].

One surprising result of the survey is that although with the right incentives, users are willing to use their equipment longer, they are unwilling to pay for its environmentally responsible disposal and reuse. More than half of the respondents were not willing to pay an ecological contribution or deposit when purchasing their equipment. Just over half of those interviewed were willing to leave an ecological deposit (especially the respondents from the highest educational levels), which would be refunded to the consumer when they returned the equipment as long as the amount was less than 10% of the purchase price. In the case of this deposit and an ecological tax, at the time of equipment purchase, consumers distrust that the government would actually use the money collected for the stated purpose.

There is still work to do regarding raising awareness among consumers about the purchasing chain, consumption, disposal, and reuse of electronic equipment and cell phones and their relationship with environmental impact. Just over 86% of those surveyed did not know the final destination of their EEE after disposal. The survey also showed positive causality between a consumer's educational level and knowledge about the final destination of their electronic equipment (i.e., remanufacturing, recycling, and incineration). The highest educational levels had a greater awareness and attitude to make an ecological contribution to ensure the responsible recycling and disposal of their electronic products. This is similar to what was found internationally, which presents a link between a consumer's educational level and how they recycle their products at the end of their useful lifetime [18,38].

Furthermore, Table 6 presents a more specific review of related studies (surveys) found in the scientific literature about electronic product consumers behavior.

Table 6. Related studies on electronic product consumers behavior.

Year	Title	Authors	Findings
2009	Understanding Preferences for Recycling Electronic Waste in California: How Environmental Attitudes and Beliefs Influence Willingness to Pay	[64]	This survey indicates that California households prefer drop-off recycling at regional centers with curbside recycling a close second. Moreover, households are willing to pay approximately $0.13 USD per equivalent mile per month to increase e-waste recycling convenience. Finally, survey results show that households are making trade-offs between cost and recycling convenience. Hence, a good understanding of these trade-offs is necessary for a successful recycling program.
2015	Electronic Waste Recovery in Finland: Consumers' Perceptions towards Recycling and Re-use of Mobile Phones	[65]	This survey points out that Finnish consumers' awareness of waste recovery systems is "high" but has not translated into recycling behavior. Also, the survey indicates that the proximity and convenience of their current waste management system are inadequate in promoting the return of small waste electrical and electronic equipment (WEEE). Moreover, the supply and demand of refurbished mobile phones are not being met due to consumer's storing habits versus expectations of recent features under guarantee and unrealistic low prices. Finally, the survey results show that to change storing habits there is a need for more information about collection programs, especially about take-back programs.

Table 6. *Cont.*

Year	Title	Authors	Findings
2020	A Survey on Factors Influencing Recycling Behavior for Waste of Electrical and Electronic Equipment in the Municipality of Volos, Greece	[66]	This survey shows that there is an underperformance of WEEE recycling in the Municipality of Volos, Greece with 57% of the sample answering that they have never participated in a WEEE recycling program. In regards to small WEEE management (e.g., mobile phones), the survey indicates that the four main ways used for recycling were: first, transport of WEEE to stores of electrical and electronic equipment; second, inappropriate disposal in the containers of other recyclable materials (i.e., blue bin); third, disposal to waste containers, which is the worst option from an environmental point of view; and fourth, no disposal at all (i.e., kept in the houses for an undisclosed amount of time). Based on the survey findings, it the study recommended the development of a sustainable long-term management plan for recycling, including a general public education campaign and a marketing campaign utilizing different psychological factors inspired by the "theory of planned behavior".

Source: Own elaboration.

Comparing the findings and recommendations of the studies (surveys) conducted by references [64–66], with the survey results of this research work, several similarities can be found:

- Any CE program should always have an awareness and information campaign about the benefits of moving towards a circular economy—targeting all relevant stakeholders.
- It is useful to promote a positive attitude towards WEEE recycling and other CE programs, taking advantage of the existing awareness in electronic product consumers about the importance of protecting the environment.
- Encouraging a culture of reduce, reuse, and recycle in society as a moral norm for all citizens toward an environmentally responsible society.
- It is critical to make recycling and other CE programs as convenient as possible for the consumer/citizen. This requires the design of convenient waste recovery systems and rewarding mechanisms for recognizing environmentally responsible behavior. According to Wagner [67], a convenient waste recovery system is characterized by its minimal knowledge requirements, proximity to its users, easy drop-off of materials, availability of services, and ease of the overall process.
- The celebration of positive outcomes, such as successful recycling programs, reinforce a positive attitude towards CE programs in society.

6. Conclusions

In Mexico, as in many other countries in the Latin American region, there is a growing demand to move towards a more circular production and consumption cycle to reduce the negative effects of linear models. In general, the electric and electronics industry, cell phones in particular, is a perfect sector for evaluating the possibility of moving towards circularity in all of the product value chain. Given the scarce research about this topic in Latin America and Mexico, this work aims to contribute to the literature and fill this research gap. The literature review clearly shows that the consumer is one of the protagonists for making CE achievable in the electronics industry. Therefore, it is essential to understand consumer behavior regarding usage time, reasons for and means of disposal, and involvement in reparation and recycling of equipment, to design suitable strategies.

The results of the current investigation demonstrate the clear potential of the country to increase the circularity of electronics in general and mobile phones in particular, in a formal and responsible way. Nevertheless, there is a lack of shared responsibility from stakeholders that are directly and indirectly involved in the value chain of electronic products. The government, as a main stakeholder for CE, has limited information about circular models and consumer behavior. Additionally, there is a lack of regulation for the integral management of WEEE in Mexico. Moreover, manufacturers and suppliers do not have the adequate tools and incentives to eco-design their products in a modular way to encourage their recovery at the end of their useful lifetime. Furthermore, there are limited alliances between universities and manufacturers for creating synergies in the eco-design of products to facilitate the material recovery at the end of their useful time. Although there are institutions like Tecnológico de Monterrey, with long-standing links with industry, the scope for increasing and fostering them is large. At the international level, an important foundation promoting such needed alliances is the Ellen MacArthur Foundation at its Circular Economy 100 program [68].

In a wider sense, it is a matter of designing the corresponding strategies and incentives with the participation of stakeholders. The consumer can assume a larger role in these strategies, as can manufacturers and suppliers. The government is a key stakeholder in articulating their efforts and strengthening the regulatory framework. Increased control and monitoring of manufacturers are required to achieve the modular eco-design of their products to promote the appropriate recovery of materials at the end of their useful lifetimes. It is also urgent to create regulations that supervise and control marketing and sales/renovation campaigns promoted by suppliers. Those that increase the number of mobile phones in the market, even though many still have one to three years of useful life, users still dispose of them. Environmental programs and ecological incentives are required to discourage this behavior. Nevertheless, sanctions and penalties along the value chain—from manufacturers to consumers—are required to increase environmental awareness and the efficient usage of resources.

Paying an ecological contribution at the time of purchase, giving the product back to the manufacturer or retailer at the end of its useful lifetime, or/and paying a deposit at purchase, seem to be distant options. Nevertheless, they are worth exploring as ways to increase this industry's circularity generally and for mobile phones specifically. With an adequate design that features transparency in the use of these resources, these options could become a reality. The demand for increased sustainability in the industry will increase and with it, the creativity for designing new mechanisms to strengthen CE. "Business-as-usual" should no longer be an option. The government should establish certain mandatory regulations that, in coordination with proactive market-based incentives, can comprehensively increase the industry's CE potential for everyone.

There is work yet to do with consumers in terms of increasing their knowledge about the purchase chain, consumption, disposal, and reuse of electronic equipment and cell phones. Supporting this education will increase the environmental awareness of this subject. This investigation revealed the consumption and use habits of electronic equipment and cell phones in Mexico and therefore illustrates priorities to account for the future actions of society, the government, and the industrial sector. Finally, the results of this research maintain high relevance for Mexico's compliance with the commitments of the United Nations Framework Convention on Climate Change (UNFCCC), and the United Nations 2030 Agenda and its Sustainable Development Goals (especially with regards to goals 9, 12 and 13). As a matter of fact, the country is not only a signatory of the 2015 Paris Agreement toward climate neutrality but was the first developing country to submit its intended nationally determined contribution to the UNFCCC [69].

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