A META-ANALYSIS TO ASSESS SMARTPHONE DISPOSAL DESTINATIONS: THE CHALLENGES OF INCREASING VALUE RECOVERY

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ABSTRACT

Providing the correct destination at the end of the product's use phase is essential for value recovery and to reduce the environmental impact at this lifecycle stage. To understand the e-waste recycling behavior among users, this article aims to identify the most common destinations given to smartphones when they are no longer used. A systematic literature review was carried out, and 13 studies were selected for a meta-analysis. The variable is the selection of the most common destinations for e-waste: reuse and recycling (recovered value), storage and informal collection (missed value), and household waste (destroyed value). The results present a summarized measure with the combined proportion of the studies for each category. Studies were weighted by the precision of confidence interval estimates presented in Forest Plots. The main results point out common problems and demonstrate how the strategies and policies adopted in each country can influence the chosen methods of disposal. These specificities require unique strategies to deal with local problems. As a secondary contribution, this study proposes guidelines to reduce e-waste generation and to create awareness and infrastructure to increase value recovery.

Keywords: Smartphone, Disposal, Social responsibility, Sustainability, Circular economy

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1 INTRODUCTION

Electronic waste (e-waste) generation is driven by rapid technological changes and the increasingly shorter life cycle of products (Sabbaghi et al., 2015; Balde et al., 2015). E-waste consists of discarded electrical and electronic equipment (EEE) such as computers, TVs, smartphones, and home appliances. This type of waste is chemically and physically distinct from other wastes, containing valuable and hazardous materials, and requires special handling to avoid environmental and human health damage (Robinson, 2009). Consequently, it is essential to reduce the environmental impact of electronic products throughout their lifecycle and, most importantly, to ensure that they are properly disposed of (Nnorom; Osibanjo, 2008; Sabbaghi et al., 2016).

As discussed by Guo and Yan (2017), smartphones are the most widespread of all types of electronic equipment. The smartphone industry's growth is significant especially in emerging economies (Borthakur and Singh, 2020). China has become the largest smartphone producer and consumer and the largest producer and receiver of global e-waste (Chi et al., 2014; Bai et al., 2018). Countries such as Bangladesh, Pakistan, and India are also experiencing e-waste growth, either due to their rapid economic growth or through illegal trade routes (Islam et al., 2017). According to Robinson (2009), despite being illegal under the Basel Convention, developed countries continue to export e-waste to developing nations.

For the electronics industry, the collection of obsolete products is challenging as it depends on "when" and "how" users dispose of their products (Sabaghi et al., 2016). According to Williams and Taylor (2004), involving users to participate in the collection process is one of the biggest problems related to product recycling. When e-waste is disposed of incorrectly, not only does it generate negative impacts on the environment but also on human health (Robinson, 2009). Providing the correct destination at the end of the product's use phase is essential for value recovery, reducing the environmental impact at this lifecycle stage. Atlason et al. (2017) emphasise that resource circulation, as advocated by the Circular Economy, requires the cooperation of all the stakeholders involved in the product lifecycle, in addition to the intentional improvements made in product design and development. Improvements in product development in search of sustainable end-of-life scenarios are fundamental, but they do not guarantee user commitment (Sonego et al., 2018).

This article aims to identify the most common destinations given to smartphones in different countries when they are no longer used. The contribution of this study lies in the presentation of destinations based on a meta-analysis of data from surveys addressing smartphone disposal in different countries. Finally, we present a panorama of smartphone disposal and propose some guidelines to reduce e-waste generation and to create awareness and infrastructure to increase value recovery.

2 METHOD

The systematic review was carried out to identify surveys with users regarding the destination given to electronic products in general. Due to the limited number of pages, the scope of this paper was reduced for an in-depth discussion, focusing on the smartphone category.

2.1 Research question and search strategy

What are the most common destinations given to electronic products when they are no longer used? We searched the Web of Science Core Collection database in October 2022, for articles and reviews published in the last 10 years (2012 – 2022). The following keyword combination was used: (disposal* OR discard* OR return*) AND (“electronic* product*” OR “consumer electronic*” OR WEEE OR “E-waste” OR “electronic waste”) AND (survey* OR questionnaire*). The keywords were chosen after a test round with related terms.

2.2 Article selection and quality assessment

We identified 158 papers in total. We scanned the papers’ titles and abstracts and selected those with the potential to answer the research question. These selected papers were fully read and the assessment

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was based on surveys addressing the smartphone category, the period and relative frequency or percentage for the destination that domestic users give to their electronic products (households), and precise quantitative data with frequencies or percentages associated with the electronics' destination. Papers that did not present numerical evidence were not considered in this study. This resulted in the selection of 13 papers presenting smartphone results.

Studies with multiple-choice questions for smartphone destination, in which respondents could designate their electronic destination to more than one category, were rescaled so that the percentage for each category represents the proportion of times that a specific destination was mentioned concerning the total number of items mentioned. For single-choice items, the proportion assigned to a given destination category is calculated concerning the total number of respondents.

2.3 Extraction and organization of the database

We analysed and grouped the destinations cited by respondents for their smartphones into the following categories: reuse, storage, formal collection, informal collection, and household waste. These five categories allow associating the destination given to the product and the value recovery. The "reuse" category is the sum of options where the product can be reused: donated to friends, family, charities, and sale to third parties. Likewise, the category "formal collection" is the sum of the responses given for all formal collections, either by delivering products in stores, at collection points, or even in take-back programs. The "storage" category refers to products being stored at home, while "household waste" refers to EEE being discarded together with common waste destined for incineration or landfill, and "informal collection" refers mostly to scrap dealers.

According to the classification proposed by Bocken et al. (2015), value can be captured (bringing benefits to stakeholders), missed (when all of the potential value is not recovered), and destroyed (bringing negative results for the system and the environment). These value categories represent a new perspective on sustainable innovation, in which value is created for all stakeholders, including the environment and society. In the reuse and formal collection, the value is captured through service life extension, refurbishment, and recycling. In the storage and informal collection, the value is missed due to delay and improper handling techniques. In household waste, the value is destroyed because there is no recovery and there is damage generation.

2.4 Analysis

Data analysis was performed using a meta-analysis based on a systematic review (Boreinstein, 2009). Meta-analysis is a combination of results from independent studies. Usually, the results are presented using Forest plots, which display random-effects models and confidence intervals for individual studies and meta-analyses. The systematic review process evaluates the quality of studies by selecting papers about different cases from different countries. This current study presents statistics from e-waste destination statistics related to each study and its specific countries. The differences among countries are to be addressed in further discussions. Our premise is that the divergences are due to adopted cultural practices and government strategies. Some previous conclusions are posed in sections 3 and 4.

In this study, the proportion of smartphone destinations was estimated based on the analysis of the 13 surveys mentioned in this section. The proportion calculated for each disposal category is the outcome of interest of this study. The response variables were converted into binary scores (0, 1), where 1 means that the category was selected as an e-waste destination, and 0 otherwise. The experimental unit was the individual. Random effects models were considered, and studies were weighted by the precision of the estimates (Egger et al., 2001). The analysis was performed in R Software® through the Metaprop package. The results were illustrated using Forest Plots.

3 RESULTS

Figure 1 shows the meta-analysis results calculated using R Software®. For each category, the Forest Plots presents four main information: (a) the quotation of the authors and the acronym of the country; (b) the events that represent the frequency with which a given category was mentioned as a disposal option; (c) the total sample size (n); and (d) the proportion of destination of each study. The dashed

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line indicates the average proportion resulting from the combination of studies weighted by the precision of 95% confidence interval (CI). Studies with overlapping CI have no significant difference (NS). For example, the highest percentage of Household waste (Figure 1e) is observed in Li et al. (2012) (CH) (p=15.03%), while the lowest result is Milovantseva and Saphores (2013) (US) (p=2.41%). The diamond represents the CI resulting from the combination of studies. The overall percentage is 6.59%. The 95% CI is (4.65% to 9.26%), considering the margin of error. The meta-analysis results and their interpretation are discussed in the following items according to each disposal category.

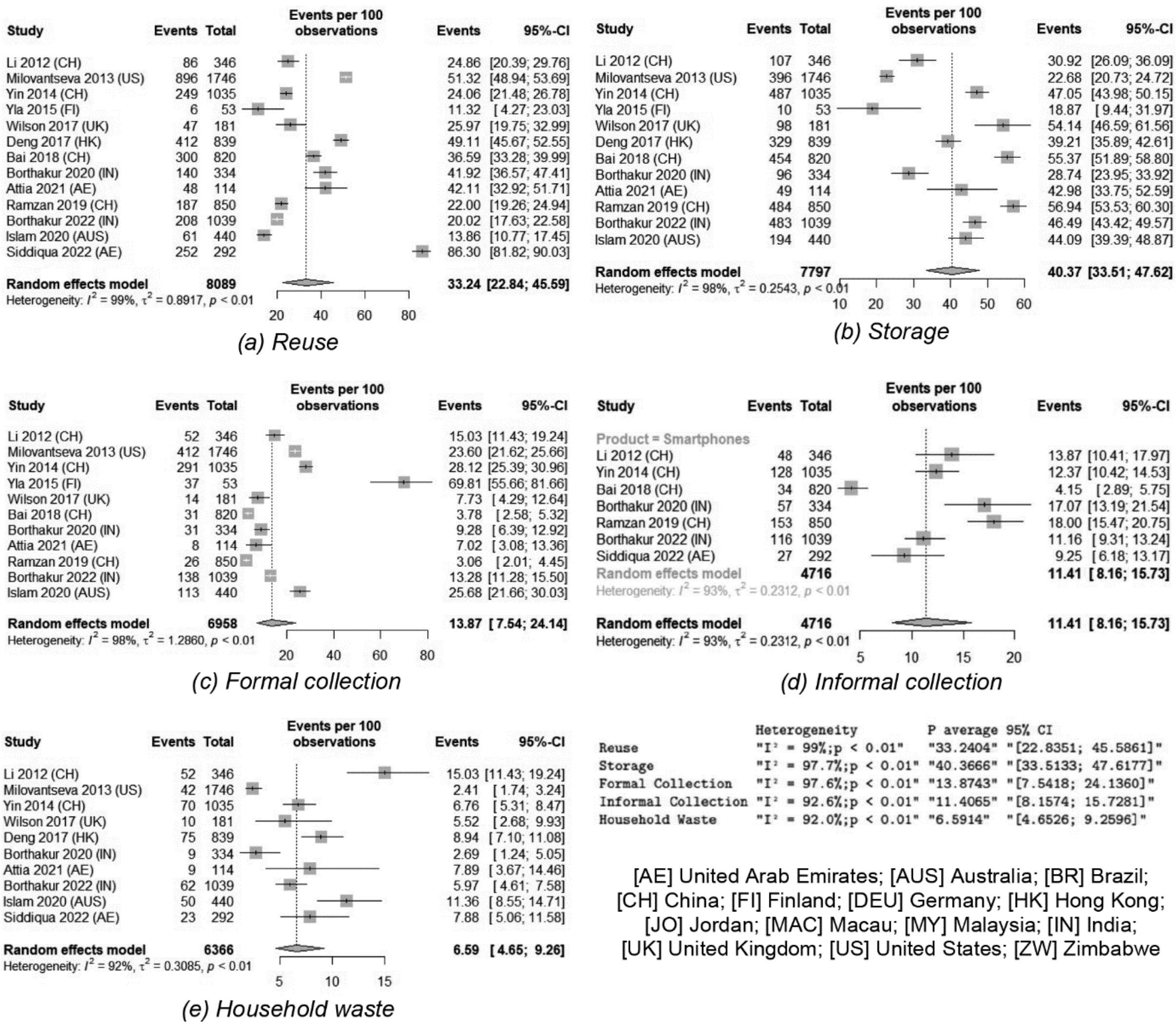

Figure 1. Meta-analysis results for each smartphone disposal category

3.1 Reuse

Reuse occurs when the product is donated or sold to friends, family, charities, or non-governmental organisations (NGOs). Such donation/sale allows for the extension of the product's service lifecycle. Of all the possible destinations, reuse has the lowest associated environmental impact, as it postpones the impacts of disposal and the impacts related to product replacement.

Products with high resale value, such as the current smartphones, have high levels of reuse, mainly for sale to third parties. As seen in Figure 1a, currently, reuse is the second most common destination for smartphones. Borthakur and Singh (2021; 2022) discuss the habit of passing smartphones to a second-hand and even a thirdhand user before discarding them as e-waste - a habit influenced by the perception that electronic equipment has some value. Although the sale of products to third parties is cited as a recurring destination, the purchase of used products is still not very common: recent studies show that between 89% and 99% of consumers surveyed do not buy used products (Pérez Belis et al., 2017; Bovea et al., 2017; Bovea et al., 2018; Wieser; Troger, 2018).

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The unrepairability of the products is cited as an important reason for purchasing a new phone (Borthakur and Singh, 2020). In addition, in the study with the highest percentage of reuse (Siddiqua et al., 2022), consumers demonstrated a great interest for repair to extend the use of products. According to the meta-analysis results, the estimated percentage of reuse is 33.24% [22.83; 45.58] with 95% CI. This is mainly due to United Arab Emirates (AE) and Hong Kong (HK) strategies (Figure 1a).

3.2 Storage

Storage is technically not a destination but a period when products are outside the economic cycle awaiting their final destination. It happens when users store their products in garages or drawers, for example. This storage period is a significant barrier to the flow of value in a circular economic model (Wilson et al., 2017).

The small size of the smartphone encourages storage and affects the perception of the environmental damage that can be caused by incorrect disposal (Deng et al., 2017; Bai et al., 2018). As seen in Figure 1b, the storage of smartphones is a global phenomenon, and nowadays, it is the most common destination when they are no longer used. The estimated percentage of storage is 11.41% [8.16; 15.73] with 95% CI. The diamond shows high variability in studies. High values are indicated in studies in China (CH) and India (IN) (Figure 1b).

As reasons for smartphone storage, users cited the possibility of parts' removal, ownership of a backup product to be used in case of problems with current devices and the concern regarding private data (Ylä-Mella et al., 2015; Deng et al., 2017; Wilson et al., 2017; Bai et al., 2018; Borthakur and Singh, 2020). Data safety is critical to reducing storage promoting reuse and recycling. The literature discusses the necessity of reliable data wiping from devices and programs to build trust in recycling parties, emphasising data safety and providing data cleaning and backup services to consumers (Bai et al., 2018; Islam et al., 2020; Attia et al., 2021).

3.3 Formal collection

Formal collection refers to all formal collection systems established by companies, governments or third parties to recover the value of electronic waste (product delivery to collection centers in take back actions and at points of sale of similar products). Among all the possible destinations analyzed, formal collection is the only option requiring users to have prior knowledge of the points and forms of collection. Additionally, it requires the user to actually go to these points. Therefore, in addition to knowledge on the subject, the existence of collection points and the ease of access for users to these points must be considered. Many countries do not have well-established formal collection systems. This can be seen in Figure 1c, where the low search for this destination is found. The estimated percentage of formal collection is 13.87% [7.54; 24.14] with 95% CI. The highest percentages are again found in Finland (FI) (Figure 1c).

Other limitations related to formal collection are the possible promotion of planned obsolescence and the discouragement of reuse. The promotion of obsolescence can occur through take back programs, which encourage users to return the old product in exchange for benefits in purchasing a new one. Kumar (2017) exemplifies this limitation by discussing that smartphone upgrades and exchange schemes aim to increase sales of new releases, and do not necessarily exist to address environmental issues. The disincentive to reuse occurs when the returned product is directly recycled or remanufactured, without considering its operating state and possibility of reuse.

3.4 Informal collection

Informal collection is when the user delivers the product to informal collectors or informal collection points that extract the valuable materials in the e-waste. According to the Global E-waste Monitor (Forti et al., 2020), in places where the management infrastructure is not well developed, the e-waste is managed mainly by the informal sector. The informal sector is dominant in countries like India (Borthakur and Singh, 2020) and China (Ramzan et al., 2019), as seen in Figure 1d. The estimated percentage of 11.40% [8.15; 15.73] with 95% CI stands out. High percentages of informal collection are observed in studies carried out in China (CH) and India (IN) (Figure 1d).

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Borthakur and Singh (2022) argue that in developing countries, e-waste is considered valuable, justifying the existence of informal collectors that buy users' scrap. The door-to-door collection done by collectors is a convenient means for product disposal, offering benefits to users but not the environment. According to Afroz et al. (2013), informal collectors aim to extract the valuable metals contained in the EEE using unsafe disassembling techniques that can generate environmental and health impacts. Chi et al. (2014) show that informal collectors in China use rudimentary techniques such as unprotected manual disassembly, acid baths, and open burning.

3.5 Household waste

Domestic waste disposal refers to users discarding electronic products in ordinary household waste, which can be sent to sanitary landfills or incineration. Despite the danger associated with e-waste disposal in landfills, according to many articles analysed in this review, household waste remains a recurring destination. When e-waste is disposed of incorrectly, it generates negative impacts not only on the environment but also on human health (Robinson, 2009). E-waste contains over 1000 different substances, many of which are toxic, such as mercury and cadmium. Even though smartphones have a high resale value and valuable components, they are still discarded in the common trash in many countries (Figure 1e), probably following a long storage period. The meta-analysis results show great variability between countries and CI with a high margin of error in the same study (country) represented in Figure 1 by the extension of the CI line. Combining the studies, the estimated percentage is 6.59% [4.65; 9.26]. However, China and Australia had percentages higher than 10% (Figure 1e).

4 DESIGN FOR SOCIETAL CHANGE

The average service time of a smartphone is becoming increasingly shorter (Wilson et al., 2017; Deng et al., 2017; Bai et al., 2018), and most of the smartphones discarded are still functional (Borthakur and Singh, 2022). Li et al. (2015) postulate that there is a lack of knowledge on the part of designers to develop projects aimed at reducing waste. According to the authors, most designers develop more sustainable projects through self-study or through their own principles. On the other hand, sustainability requirements must be incorporated into product development, providing engineers with a more holistic view of the smartphone's life cycle (Seyff et al. 2018).

Manzini (2006) highlights the need to see users as a part of the solution, with active involvement and as co-producers of the desired results. That is, users must be seen as capable of achieving such desired results because they hold the necessary intellectual and practical resources to it and because they are aware of the problems to be solved. Based on these remarks and the knowledge gathered in our study, we propose some guidelines to reduce e-waste generation and to create awareness and infrastructure to increase value recovery.

Regarding the **reduction of e-waste generation**, four guidelines were proposed:

- Offer repair and technical assistance as well as support from the manufacturer so that the phone can continue to be updated (avoiding software-enforced obsolescence). These actions allow the extension of the product service life, even if not with the first-hand user;
- Ensure reliable data wiping from devices and programs to build trust in recycling parties, emphasizing data safety and providing data cleaning and backup services to consumers. Data safety can promote reuse and avoid storage;
- Encourage the purchase of reliable second-hand smartphones with warranty;
- Create collection schemes focused on sustainability, which consider the state of the device and the possibility of reuse (refurbishment).

Regarding **awareness**, we propose four guidelines:

- Raise awareness of e-waste-related harm;
- Publicize recycling programs, collection points, and the different methods for smartphone disposal;
- Clearly define the role and responsibilities of all stakeholders. All stakeholders must participate in raising consumers awareness;
- Use the Internet and social media to improve awareness and enhance a proper collection of e-waste.

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Regarding the **development of infrastructure**, we propose three guidelines:

- Analyse the context and current disposal practices to help establish financial incentives that motivate users to use formal collection methods;
- Promote E-waste recycling bins next to general waste and plastic bins, community recycle centres, return to sale points, and pick-up stores. Those options were cited as convenient by users;
- Facilitate the separation of waste (with a coherent and standardised system).

The reduction of electronic waste through the slowdown in consumption is a long-term change that questions the established system and the logic of the constant search for new products - consumerism. The creation of awareness and new infrastructure draws attention to the problem, seeking to understand consumer's opinions and co-create results that increase value recovery while respecting local characteristics and culture. Therefore, knowing the local culture and existing practices is important to engage users in successful e-waste management (Ramzan et al., 2019). Chi et al. (2014) exemplify that China could not replicate the European system due to differences in waste flow, cheap labour costs, and established practices. However, they highlight the possibility of learning from these experiences to create a comprehensive management plan.

From a social perspective, the sustainable management of electronic waste can incorporate concern for workers' health and their relocation in the labour market (Grant et al., 2013). From an economic point of view, circularity can also generate profit through urban mining i.e. the recovering and reusing of cities' waste materials (Zhang et al., 2019).

The panorama raised by this research and reinforced by the guidelines is convergent with the idea of Design Activism (Papanek, 1971). Design Activism considers the environment and green design, but also a moral and social purpose to the design profession (Clarke, 2013). According to Souleles (2017), design activism also raises awareness to the creation of excessive and useless products. Julier (2013) discusses design activism in everyday activities, as a tool to challenge the status quo and an attempt to change it.

5 CONCLUSION

This study aimed to identify the most common destinations given to smartphones in different countries when they are no longer used. Five categories were considered with different levels of impact on sustainability: household waste, informal collection, formal collection, storage, and reuse. Each category comprises a series of actions performed by the consumer as a destination for the smartphone. Survey studies in different countries were researched to estimate the percentage of each destination category. To that end, the meta-analysis combined studies whose objective was to understand the main destinations of e-waste and estimate a summary measure represented by the proportion considering all available studies on this topic in the literature and the period of selection of these articles. The results revealed a significant difference between countries and high heterogeneity between the main disposal destinations. For example, combining the surveys, household waste is $p=6.59\%$ [4.65; 9.26]. However, countries like China estimated $p=15\%$ in surveys. At the other extreme, reuse was mainly pointed out as a destination in Hong Kong (40%) and Saudi Arabia (80%). The latter indicates what possibly happens when consumers have access to repair services and can extend the product use phase. In summary, reuse is mainly the alternative in countries where people attribute high value to electronics, such as India and China. But even with the high value, disposal and household waste are still common.

This panorama is the starting point for a discussion that, at the same time, points out common problems faced by all countries, such as storage, and also demonstrates how the local context can influence the chosen methods, requiring specific strategies to deal with local problems.

Our outreach is affected by the limitations of the surveys, such as the regional context where the surveys were applied. The combined results are an outcome of the surveys analysed, and our panorama is limited to the sampled countries. The high heterogeneity in the destination proportions between countries may be associated with the strategies and policies adopted in each country. The next

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step is to understand those strategies and practices associated with recovery value that can be broadly disseminated to encourage more sustainable product solutions, policies, and practices.

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