

Article

End-of-Use vs. End-of-Life: When Do Consumer Electronics Become Waste?

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Abstract: This study focuses on the lifespan of consumer electronics. The article reviews end-of-life terminology in scientific literature and suggests distinguishing end-of-use and end-of-life stages. The question, when electronics become waste, is approached using the concept of a system called PSSP language, which classifies artefacts based on their attributes of purpose, structure, state and performance. It is highlighted that waste as a concept is dynamic; the same thing can be waste or non-waste at different times and places and for different people. Further, the article reviews the impact of storage behavior on the realization of the waste hierarchy, using mobile phones as a case study. Evidence suggests that over half of customers use their mobile phones for only two years, and there is little incentive to keep them in use longer. Surveys also indicate that over half of the customers do not return their phones for reuse or recycling but keep them at home. The article suggests that the three key factors, promoting the storing of an old phone, are the shortness of usage time, perceived residual value of replaced equipment and concerns of personal information security. It is also indicated that memories and the personal attachment to the device contribute to consumers' storage decision. It is concluded that, to prolong the use of mobile phones, there is a demand for changing consumers attitudes towards the return of electronics for reuse and repair to be more positive.

Keywords: lifespan; waste definition; mobile phone; storing; reuse



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1. Introduction

Rising incomes and the decreasing prices of consumer products have led to the situation where many products, including various small consumer electronics, are more replaceable than ever. Additionally, the useful lifetime of electrical and electronic equipment (EEE) has shortened due to an ever-faster release of products with new features. In consequence, the amount of electronic waste (WEEE) has grown remarkably over recent decades. In 2019, over 53 Mt of WEEE was generated globally. The amount has increased by 9.2 Mt since 2014 and is estimated to reach 74.7 Mt by 2030, which means that the generation of WEEE will almost double in only 16 years [1]. While the pace of WEEE generation is certainly a key problem, an additional challenge is that collection and recovery activities are not keeping pace with the growth of WEEE. It is estimated that less than 18% of WEEE generated was formally collected and recycled globally in 2019 [1].

In addition to shortcomings in collection networks, the lack of consumers' comprehensive participation is still a challenge, even in countries with a take-back system. Over the last ten years, numerous studies have been conducted on consumers' participation in WEEE recovery [2–10] and disposal preferences [6,11–13]. Some studies concluded that consumers are not managing their WEEE appropriately due to incomplete and/or inconvenient collection systems [4,6,8,13], whereas others argued that the key issue is the lack of incentives [6,11,12,14]. Furthermore, low levels of awareness, lack of knowledge on

recycling opportunities and local facilities are mentioned as factors hindering WEEE recycling [12,15,16]. Recently, the focus of research has shifted to consumers' storing behavior and decision-making process in replacing functional electronics, in order to reduce mobile phone hibernation [7,14,17–19].

Storage time impacts on defining the lifespan of electronics. However, prior literature has highlighted the lack of clarity in the definition of lifespan; Babbitt et al. [20] discussed whether storage is included in the lifespan or not, while Murakami et al. [21], examined lifespan from the perspective of ownership. Several studies have focused more closely on determining the lifetime of electronics [13,18,22]. Depending on the types of EEE products, storage might cover a remarkable share of total lifetime, from manufacturing to disposal of the product [18]; therefore, it has a significant influence on evaluating life cycle environmental impacts [16,20,23]. According to Thiébaud-Müller et al. [17], small EEE devices are typically stored for a longer time than large devices, compared to their active use. Moreover, Wilson et al. [22] found in their study, that the storing time of mobile phones could be even longer than the actual use time.

In this study, we aim to provide a better understanding of the concepts of lifespan, using mobile phones as a case study. We focus on consumer storing behavior, and the role of storage in the lifespan of electronics. Mobile phones have been selected as a case study due to their abundance, and remarkably short life, as compared to their economic value. The question of when electronics become waste is approached using the concept system, called the PSSP (purpose, structure, state, performance) language.

2. The Lifespan of Electronics

Lifespan is an essential parameter in life cycle assessment (LCA), as well as in material flow analysis (MFA) and substance flow analysis (SFA) studies [18,21]. Based on the literature, the different approaches in defining lifespan can be noted as follows:

1. In reference to use: the total length of time from when the product is in use.
2. In reference to ownership: the length of time a product is possessed by its first user.
3. In reference to functionality: the length of time between purchase and product obsolescence.

While approaches (1) and (2) are more indicative of user preferences, approach (3) references the designed and built-in features of the product. It has been noted that electronic product lifespans have been getting shorter [24–26]. A study by the Institute for Applied Ecology indicates that the average first useful service life of large household appliances decreased from 14.1 to 13 years, between 2004 and 2012/2013, in Germany. Thereby, a defect is the main cause of product replacement and contributed to 55.6% of the total product replacements in 2012. Most critical is the increase in the share of replaced appliances after less than 5 years of usage. The share of such young appliances in overall replacements increased from 7% to 13%, between 2004 and 2013. On the other hand, almost one-third of the replaced household appliances in 2012 were still functioning [26].

A significant variation in the lifespan of electronics led Cox et al. [24] to investigate consumers' understanding of product lifetimes and to propose a product typology based on product lifetime preferences. According to this typology, products can be categorized into the following three classes: 'up-to-date', 'workhorse' and 'investment' products. For 'up-to-date' products, an expected lifetime is less than five years, and they are typically discarded before the end of their functional life, to keep up with technological advances or personal feelings of success in life. Typical examples of 'up-to-date' products are clothes, mobile phones and small household furnishings, such as cushions, curtains, and lamps. The lifetime of the second class, 'workhorse' products, is more closely related to durability. 'Workhorse' products, such as kettles and toasters, are typically used as long as they work properly but are replaced immediately when they break down. Replacement is ordinarily practiced due to feelings of low cost of replacement versus expensive and laborious repair. The third class, 'investment' products, have generally the longest life, because of consumers' feelings of higher financial and/or emotional investment during the product's procurement. Therefore, investment products are ordinarily treated more carefully in use and consumers

are also willing to pay for repairs because of the higher initial input of investment. In many cases, ‘investment products’ also rely on brand and have an extended guarantee or warranty offered by the manufacturer [24].

2.1. End-of-Life vs. End-of-Use

The European Circular Economy Action Plan provides a future-oriented agenda for a climate neutral, resource efficient and competitive economy, where products and materials serve multiple life cycles, in various formats, and where economic growth is decoupled from resource use [27]. Moreover, the amendment to European waste directives [28] further emphasizes the need for better understanding the phases occurring after the first use of products. In circular economy terms, extending the “first life” use of a product is an ideal approach, second only to replacing with immaterial services for the product altogether. It is because repair, remanufacture and recycling activities need additional resources and result in a lowered, or even lost “identity” of the original product [29].

The inconsistency of terminology in scientific literature was pointed out by Murakami et al. [21]. They provide a comprehensive presentation of various life terminologies of consumer durables, starting from resource extraction to final disposal, including the whole device, as well as potential spare parts, and point out the different vantage points, from product in operation, up until the residential time of substances in the economy. As the purpose of this article is to point out the issue of storage, in Figure 1, we present our simplified interpretations of end-of-life (EOL) and end-of-use (EOU) cases, with reference to ownership, structural performance (functionality) and disposal times.

In Case 1 (Figure 1a), we assume EOL is the disposal time, when a product is returned for recovery immediately when it breaks down. In this case, the product has been used by multiple owners for as long as it was functional, in which case disposal is due to the loss of structural performance. As well, the first owner handed the product to a second user immediately after they no longer wished to use it. Thus, EOU parallels with EOL. For instance, passenger cars are a good example of this kind of product. In Case 2 (Figure 1b), the first owner did not immediately hand the unwanted product to a second user but kept it in storage for a while, due to the reluctance to cede ownership. A typical example is children’s clothes. This case is presented to point out that the total time of use may be considerably shorter than the time the product could have been used. Here, also, the end-of-use (EOU) by the first owner does not coincide with the time of changing ownership. Additionally, assuming there is an upper time limit, up until which the product is functional, this case is also to point out that the longer the storage time between uses, the smaller the probability that the product can be used for a second time. Also, in this case, the product is typically discarded or returned for recycling immediately after losing its functionality. In Case 3 (Figure 1c), the product is kept in storage indefinitely after the first use and, unbeknown to the owner, it has reached the end of its life in the course of the storage period. In other words, the product has turned to waste before it was eventually returned for final disposal. This case illustrates that total ownership is not a good indicator of the usefulness of the product, nor of its lifespan.

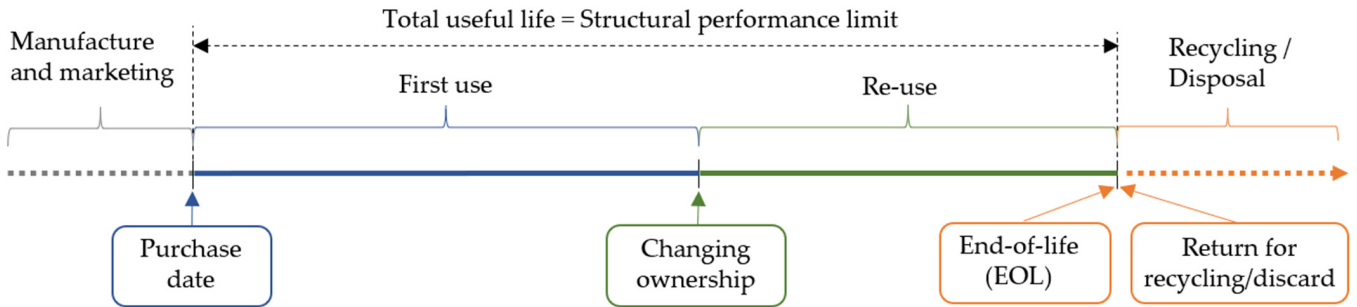
In the case of mobile phones, Case 3 is the most common. Consumers’ behavior and their recycling activity, related to mobile phones, have been studied in several surveys, globally. The main results of these surveys are summarized in the next section.

2.2. Case: Storing of Mobile Phones

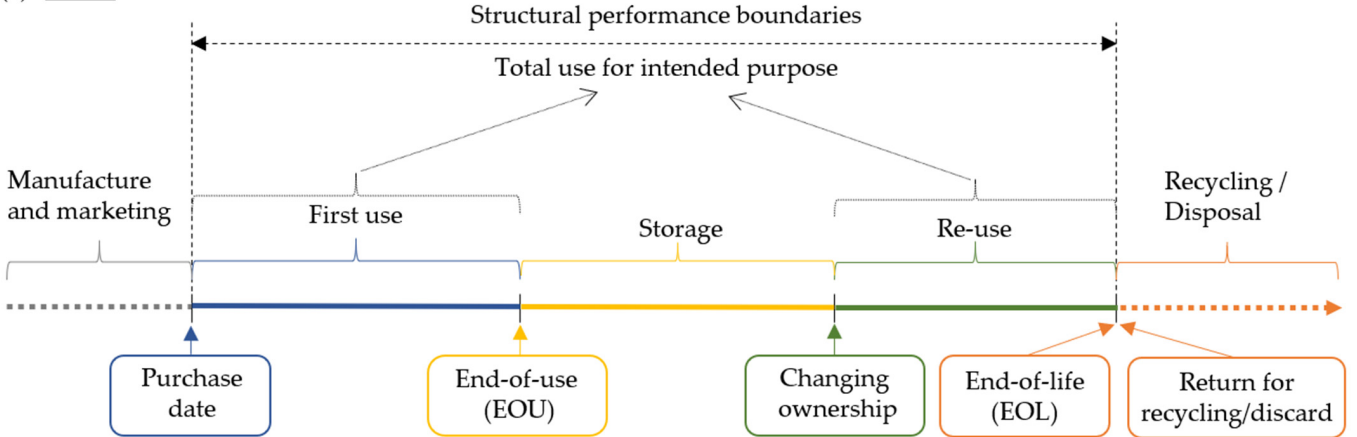
In this research, we have studied the lifespan of electronics through mobile phones as a case device. Although the mass of mobile phones in the whole WEEE stream is low, there are other justified reasons for this selection; mobile phones represent a typical high-tech consumer device, with fast technological progress and high growth of adoption rate. Furthermore, they have a substantial content of valuable trace metals; recovery and recycling of these metals is presumed to play a crucial role in meeting future demand [13,14,30]. In recent years, smartphones have almost completely occupied the market for new mobile

phones; however, this study does not differentiate between feature phones and smartphones because there are still feature phones in use or hibernating at homes.

(a) Case 1:



(b) Case 2:



(c) Case 3:

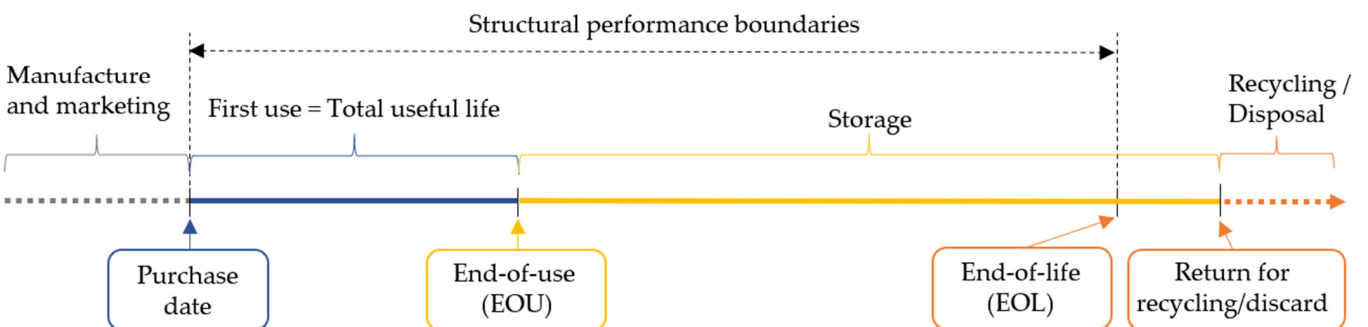


Figure 1. Illustration of end-of-life and end-of-use points within the product’s life cycle; (a) “Ideal case”, where product is used by multiple users until it breaks down (lose its structural performance); (b) “Hybrid case”, where the product is in storage between multiple uses; (c) “Worst case”, where the product turns to waste when in storage and reuse opportunity is not utilized.

Mobile phones are among those up-to-date products, defined by Cox et al. [24], that are not designed to last, or to be repaired, and, in addition, are typically replaced before they will break down. The time of mobile phones in service is reported to be from one to five years [11,12,18,31–33]. The consumer’s age is significant in terms of time of use; younger people tend to replace their mobile phones more often [15,33,34], whereas older users keep their phones longer [33,35,36]. The common consensus of several studies is that over half of users replace their mobile phone within 2 years [11,15,18,22,35]. The background for this

short time of use is the fact that, in many countries, a mobile phone as a device is tied to an existing mobile phone service subscription and the contracts are typically signed for 2 years [18,22]. Looking at the mobile phone market of today, we can also see that some of the most popular smartphones of 2021 (iPhone, Xiaomi, Samsung) have warranty times of 1–2 years for the phone, and $\frac{1}{2}$ –1 year for the battery. Thus, there is indeed currently little incentive for the customer to keep mobile phones in use for longer than 2 years.

Based on the results of several surveys conducted across the world, summarized in Table 1, the tendency is that after 2 years of use, customers are less likely to return their phones for reuse or recycling, but they tend to keep them at home.

Although these surveys were implemented with different methods, for various target groups in several countries or regions, the consumers’ storing phenomenon has become evident. Based on the results of these surveys, we can assume that the majority of users prefer storing their old mobile phones at home, rather than returning them for reuse and/or recycling, when procuring a new one. In the recent survey reported by Inghels and Bahlmann [14], as much as 61% of respondents agreed with this habit; however, even 78% of them argued that also old phones are still in use occasionally. A moderate share of used mobile phones have also been sold or donated for reuse; in these particular surveys, the share of phones channeled directly to the secondhand market varies from 14% [33] to 27% [11], whereas the portion of phones left at stores or sent to operators is substantially lower. In the context of selected surveys, it seems that a functional in-store collection/retailers’ take-back system for mobile phones exists to some extent, only in Finland [37]. The fates of used mobile phones in the selected surveys are summarized in Figure 2.

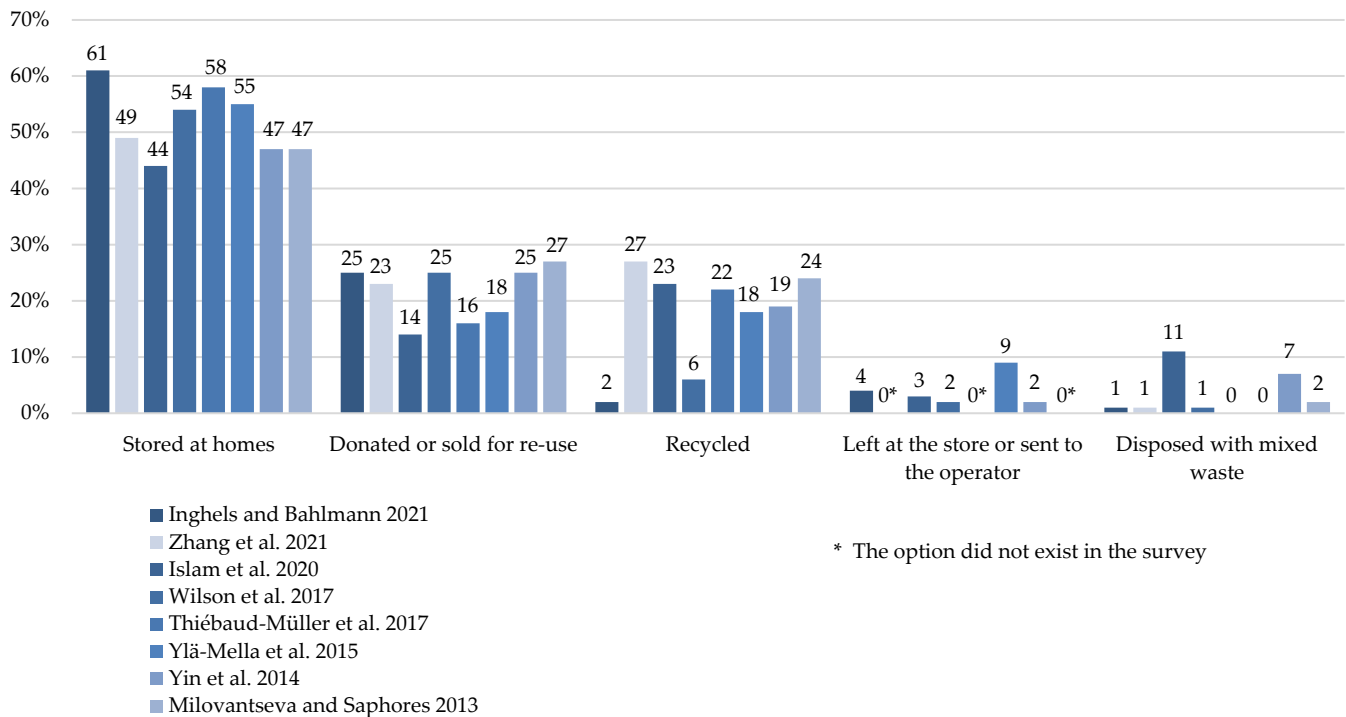


Figure 2. The fate of used mobile phones according to results of selected surveys.

Table 1. Realization and key results of selected mobile phone (MP) surveys.

Country, Year(s) Reference	Realization of the Survey, Number of Respondents	Key Results
The Netherlands [14] Inghels and Bahlmann, 2021	Online survey distributed via social media, 296 respondents	<ul style="list-style-type: none"> ➤ Technical and functional obsolescence are confirmed to be the main drivers of mobile phone replacement. ➤ The willingness to recycle is inversely proportional to the perceived value of MP and proportional to the age of the MP owner. ➤ Financial incentives are shown to be the best driver to increase the intention to recycle.
China [38] Zhang et al., 2021	Face-to-face interviews and online questionnaires, 681 respondents	<ul style="list-style-type: none"> ➤ 49% last obsolete mobile phones are stored homes, 25% recycled through formal recycling and only 2% through in-formal channels. ➤ There has been a clear shift in China from informal to formal recycling; However, the convenience of formal channels could still be improved. ➤ Privacy protection plays an important role in consumers' willingness to return phones to recycling and, therefore, official recycling channels should put more emphasis on it.
Australia [33] Islam et al., 2020	Printed and online survey, 440 respondents	<ul style="list-style-type: none"> ➤ Storing is predominant and especially younger people preferred to store their MPs at homes. ➤ There is an untapped potential in MP reuse and repair, and more incentives should be provided for extending time in active use.
Switzerland & Liechtenstein [18] Thiébaud-Müller et al., 2017	Online survey, 441 respondents	<ul style="list-style-type: none"> ➤ Storage is a significant variable when considering the product lifetime and it varies between the EEE categories. ➤ Smaller EEE devices are typically stored longer than large ones, compared to the time of active use. ➤ MPs are typically stored before being returned for collection or reuse. ➤ If the EEE device is reused, its service life will be extended by an average of at least 30%.
United Kingdom [22] Wilson et al., 2017	Online survey, 181 respondents (aged 18–25 years)	<ul style="list-style-type: none"> ➤ University students living in UK, aged 18–25 years. ➤ Mobile phones were kept stored at homes longer than they were used as a primary phone. ➤ Technological, functional and absolute obsolescence were mentioned as main reasons for replacement.
Finland [37] Ylä-Mella et al., 2015	Printed questionnaire 53 respondents	<ul style="list-style-type: none"> ➤ Consumers' awareness was high but not translated to recycling behavior. ➤ Proximity and convenience of the recovery system are inadequate for returning of mobile phones. ➤ More publicity and up-to-date information on returning options are needed.
China [12] Yin et al., 2014	On-site interviews and online survey 1035 respondents	<ul style="list-style-type: none"> ➤ Consumers' environmental awareness is low, and most MPs are stored at homes or recycled ineffectively. ➤ Establishment of a reasonable and acceptable WEEE recycling system is vital to improve recycling rates.
USA [11] Milovantseva and Saphores, 2013	Knowledge Networks' online research panel 3156 respondents	<ul style="list-style-type: none"> ➤ Recycling rate of mobile phones is only approx. 20% although variety of convenient recycling options exists. ➤ Implementing economic instruments should be considered to increase WEEE collection.

The storing habit was commonly justified by keeping them as spare phones, in case the current one is lost or suddenly breaks down. On the other hand, the malfunctioning of phones was mentioned as the major reason for mobile phone replacement, from 44% [12] to 72% [37]; therefore, it is unclear if the stored mobile phones are still functional or not. Regardless, storing deprives the functional mobile phones of reuse and delays the return of valuable components for recycling and, thus, jeopardizes the realization of waste hierarchy. Even more disturbing is the tendency reported by Murakami et al. [35]; while in 1996, more than half of mobile phones were immediately handed in for recycling and only 20% kept at home, but in 2006, less than 25% were handed in for recycling and over 60% kept at home. The Japanese study estimates that phones “hibernating” in stock make up 45% of the aggregated number of mobile phones in Japan. Surveys summarized in this study support this finding and point out that mobile phones are no longer merely phones but also have multiple additional functions, which are closely connected with reasons of personal content, mistrust in personal information security, hindering the handing over of them to a second user or for recycling.

3. Methodological Approach: PSSP Language and the Concept of Waste

The main objective of the waste hierarchy is waste prevention. In order to prevent waste, the reasons why artefacts become waste must be known. Pongrácz [39] analyzed the concept of waste through an object-oriented approach, classifying waste based on the following four attributes: purpose, structure, state and performance. Artefacts have been made for a certain purpose and are expected to perform according to their assigned purpose. Performance evaluates the goodness of the artefact with respect to the purpose. Structure is understood as topological and unit structure and is thought to be made of parts and links in between. State denotes material properties (physical, chemical, mechanical, electrical, thermal, etc.) but also the location and relation within the environment. Location wise, a device on the shelf of a shop is considered a product, whilst the same device in the waste collection bin is waste. Further, a device incompatible with the system is, in that setting, a waste. Therefore, Pongrácz [39] defined waste as a thing that is, in its structure and state, unable to provide the desired performance in respect to its purpose. This concept of waste is dynamic; the same thing can be waste or non-waste in different time and places. Based on this, waste can be categorized into the following four classes [39]:

1. Things with no *purpose*; unwanted things created unintentionally or cannot be avoided.
2. Things with finite *purpose*; things destined to become useless after fulfilling their finite purpose.
3. Dissatisfactory *performance* in respect to *purpose*; things not able to perform with respect to their intended purpose, due to change in structure or state.
4. Failed to use for its intended *purpose*; things that are able to perform, but their users fail to use them for their intended purpose.

Most WEEE fall into Class 3 or 4. Whereas WEEE of Class 3 is not functional due to damage in structure or improper state, WEEE of Class 4 incorporates devices that are waste merely due to user choices. In this case, it was not structural or other damage that impaired the performance, but the expectations of the performance changed, and the given equipment was not able to provide the higher quality performance required by the user. Ordinarily, the requirements for enhanced performance are brought by market forces, by introducing newer, superior models with novel features. When newer models appear on the market, the dissatisfaction with the ‘older’ model grows, until the user makes the decision to replace [40]. Based on these considerations, the classes of waste are summarized in Figure 3, contrasted to the EEE product types of Cox et al. [24].

	Class #1	Class #2	Class #3	Class #4
Workhorse product		<ul style="list-style-type: none"> • Things with a finite <i>Purpose</i>. • Lifetime is related to functionality. • Lifetime expectation is shaped by prices. 	<ul style="list-style-type: none"> • Dissatisfactory <i>Performance</i> in respect to <i>Purpose</i>. • Expected to perform reliably in use. • Discarded instantly when broken. 	
Up-to-date product				<ul style="list-style-type: none"> • Is able to perform but user fails to use it for its <i>Purpose</i>. • Replaced before break due to feeling of "out-of-date".
Investment product			<ul style="list-style-type: none"> • Mostly used until <i>Performance</i> ceased being acceptable. • Longer life due to feeling of a high investment. • Treated carefully. • Repaired if possible. 	<ul style="list-style-type: none"> • Failed to use for its <i>Purpose</i>. • Holds a higher reuse potential due to positive feelings of a brand and an extended warranty.

Figure 3. Classes of waste by Pongrácz [39] compared to EEE product classes by Cox et al. [24].

4. Results

While the majority of mobile phones' environmental impacts occur within extraction and manufacturing phases, extending the length of the use phase is a key to reducing these environmental impacts, through lessened requirements to manufacture new ones [41]. Regardless, numerous surveys [14,19,22,33] report that mobile phones not in use have been stored for several years, before being returned to the recovery system. In those cases, it is most likely that the phones cannot be taken into service anymore. In the worst case, the device itself is no longer functional. Even if the device is structurally functional, it is likely unable to handle the newest software or incompatible with upgraded operational systems. This leads us to discuss the issue of whether structurally intact but not-in-use devices are waste or non-waste, and when electronics become waste.

Our suggestion is to apply PSSP language for clarifying when not-in-use devices become waste. We suggest distinguishing Class 4 WEEE as end-of-use (EOU) and Class 3 as end-of-life (EOL) devices. Where EOL devices will traditionally end up being disposed and/or recycled, EOU devices carry the potential of extending life through reuse, with or without upgrade or refurbishment. The relationship between the product lifespan and classes of WEEE is illustrated in Figure 4.

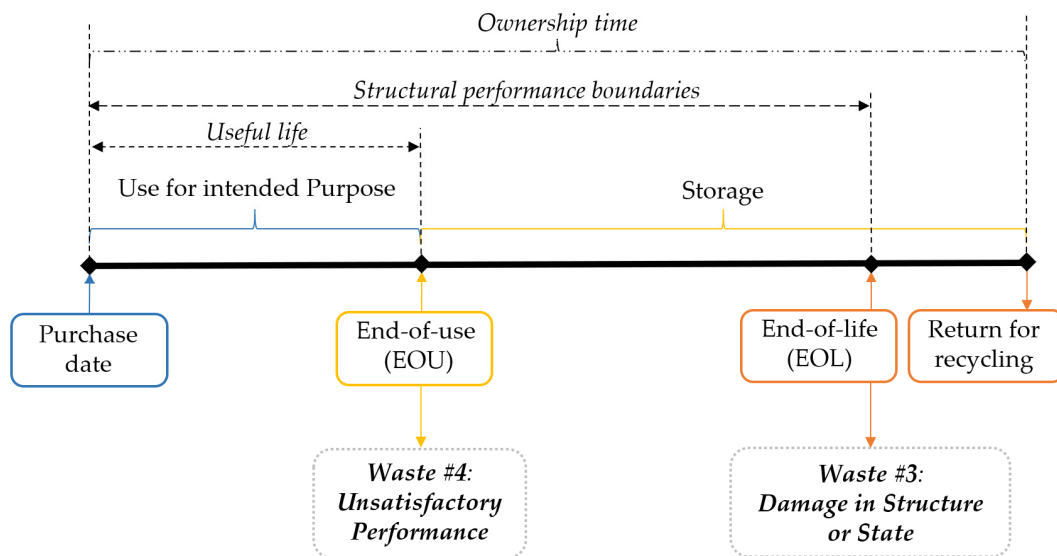


Figure 4. The relation between the product lifespan and classes of WEEE [42]. Reproduced with permission from Acta Universitatis Ouluensis.

Class 3 EOL devices are closely connected to a limited life cycle; most materials and devices are initially more useful, whereas their performance declines toward the end of their life cycle. For example, in the case of rechargeable batteries, battery chemicals are transferred into a highly active form during charging, in order to provide power. At the same time, unwanted side reactions, such as loss of active materials and impedance increase in the cells, take place and cause the gradual degradation of the battery [43]. In the most optimistic cases, the number of recharge cycles for NiMH and NiCd batteries may rise up to 400 before increased discharge rates or significant performance losses in capacity exist; however, the more realistic expectation is 50 recharging cycles [44]. In addition to the usage frequency, storage time and conditions may also affect battery performance and the potential lifetime. For example, the long storing time of batteries has been found to switch the main degradation mechanism and to accelerate the cell performance loss significantly [45]. As the chemical reactions are temperature dependent, the capacity fade of batteries is even faster at high storing temperatures [43,45].

Class 4 EOU devices are indicative of planned obsolescence. The objective of planned obsolescence is to stimulate product replacement [46]. Planned obsolescence denotes artificially limiting the durability of manufactured goods, to stimulate repetitive consumption. Guiltinan [46] recognized the following two strategies for shortening usable life: through physical obsolescence and technological obsolescence. Alternative physical mechanisms are, for example, limited functional life design and design for limited repair, which encourage disposal instead of repair, and design aesthetics, which increases dissatisfaction in the product's appearance and increases the probability of premature disposal. In addition to physical obsolescence, technological obsolescence plays a relevant role in turning electronics into waste. Technological obsolescence mechanisms include design for fashion and design for functional enhancement through upgraded features; both intensify consumers' dissatisfaction towards their existing products [46]. Packard [47] called it voluntary obsolescence and phrased it to describe the marketing strategy of "making people buy new things, even though the old ones work just fine". Consumers voluntarily render their device obsolete for no other reason than wishing to replace it with a newer model. This has also arisen in mobile phone hibernation studies by Wilson et al. [22] and Inghels and Bahlmann [14]. Echegaray [48] argued that the emerging consumer-thirsty middle class in developing countries even embrace voluntary obsolescence, as a proof of one's societal success. As a case of voluntary obsolescence, mobile phones are typical examples. Functionality is in a secondary role when the chief purpose is 'being trendy', with limited

time in use. This seems to be the case with mobile phones for the majority of users, who tend to use them only while up to date. Thus, it is argued that technological obsolescence is clearly a more significant driver for replacement, due to its voluntary nature [46].

The critical issue presented here, is that the development of products has accelerated to the point where the storage decision of EOU mobile phones is in essence a “death sentence” that renders it waste. Storage declines the performance of mobile phones and, hence, the probability of reuse decreases. Existing phones may become outmoded, even over a short storing time, if a product or service with better performance (e.g., software or network connectivity) is introduced in the meantime. In the worst case, the stored device is no longer functional due to its improper state and, thus, it shifts from Class 4 to Class 3 WEEE. Even half-year storage of EOU mobile phones can significantly reduce the possibility of reuse, and storage for more than a year inhibits it altogether, because it is highly implausible to find a second user for phones older than two years.

5. Discussion

There seems to be an immense resource potential in stored mobile phones at homes, waiting for the storage phase to end. There seems to be a consensus among researchers that the storing of electronics occurs due to the inconvenience of the current WEEE recovery systems, households’ sufficient storage capacities, as well as perceived value of the stored items. Sabbaghi et al. [49] noted the knowledge gaps regarding consumer storage behavior of useful electronics and whether storage behavior can be predicted. Therefore, they concentrated on determining whether the key design features, such as product age, brand and capacity, affect consumer storage behavior; especially in case of computer hard disc drives (HDD). Sabbaghi et al. [49] found that the storage of the youngest devices is more likely due to consumers’ feeling that the devices have not been used long enough and can be reused in the future. In addition, the higher the capacity of devices, the more likely they will end up in storage. Furthermore, the high initial purchase price paid by the consumer may also prompt storage behavior [49]. It can be argued that all these factors apply to mobile phones as well, as they can be seen as a combination of up-to-date and investment products [24]. Mobile phones keep up with technological advances, while also providing the feeling of success in life, owing to the higher financial and/or emotional investment. This typically results in the situation that mobile phones will be replaced before break-down due to the user’s out-of-date judgement. However, the user is often still reluctant to give up the device because of the expectations regarding the residual value of the investment. From the PSSP perspective, this means that the mobile phone falls into Class 4, because it still performs but the user fails to use it for its purpose. We suggest that the key reasons promoting mobile phone storing are as follows:

1. Short usage time—maximum two years use by approximately half of consumers.
2. Multi-functionality—mobile phones are no longer only phones.
3. High storage capacity—256 GB with a few high-end models featuring up to 512 GB.
4. The high purchase price of phones—up to EUR 1000 for some popular models.

Additionally, one needs to add to the initial purchase price the extra costs of purchased content (apps, games, music, e-books, etc.). During the two-year ownership, the device is likely to have amassed tens of apps, and this can boost up the cumulative value of investment. The sentimental value is also significant, as phones may contain thousands of photos and memories one wishes to maintain. As a result, it requires an effort for the owner to clean up and transfer the content and all personal data stored in the old phone before ceding it for reuse. Thus, it is not surprising that the consumer is unwilling to part with a two-year-old smart phone. This tendency needs to be acknowledged to extend the useful life of high-priced mobile phones.

Consumers’ habit of storing before final decision of disposal indicates the reluctance to cede ownership. As this phenomenon seems to be especially common for personal electronics in everyday use, we argue that one of the reasons for storing is the personal attachment to the device. In the case of mobile phones, people tend to personalize their

mobile phones and, therefore, they become a representation of their personal identity and style [24,32,50]. In addition, mobile phones are no longer merely phones. The functions of phone, camera, music player, games console, address book, calendar, navigator, and more are entwined into one. Additionally, one uses mobile phones to read their e-mails and newspapers, access social media, browse the net, keep in touch with friends, get weather forecasts, and companies offer a myriad of mobile services, from banking through booking, to various health and fitness applications. As a consequence, it takes time for this attachment to subside and for the owner to be willing to finally part with the device.

Although many surveys have pointed out the storing phenomenon, some studies have also captured the extended role of mobile phones or have enquired about the additional uses and the reasons why it is difficult to hand them to a second user or for recycling. The Japanese surveys by Murakami et al. [35] and Mishima and Nishimura [17] are among the first to point out the multiple additional functions, which relate to the reasons why it is difficult to hand them down. According to the studies, the most important reasons are (1) personal information security, (2) contents such as data, apps, or music (which may be difficult to transfer from an old to new device or store elsewhere) and (3) memories (photos, messages, etc.) captured in the device. In recent years, cloud-based service systems have been established for facilitating the transfer and storage of digital data. Consequently, speculations have arisen whether the cloud could mitigate consumers' inclination to hold onto not-in-use devices at homes. Suckling and Lee [41] have argued that cloud-based services indeed have the potential to increase business incentive, for the prompt recovery of old smartphones from users. A wide deployment of cloud services will, however, require consumers' general acceptance, which is partly hindered by uncertainty over the ownership and security issues of data stored in the cloud [41]. Although the use of cloud services has become more acceptable and widespread among consumers in very recent years, concerns about privacy and data protection issues are still mentioned as one of the main reasons for storing mobile phones at home [22,38,51].

Interestingly, some recent research on consumer attitudes and behavior towards mobile phone recycling studies shows that more and more consumers keep an old phone at home, not just as a backup but as another phone in active use [22,52]. Reasons for this are mentioned, e.g., better features of the previous phone or reluctance to use the current primary phone for fear of damage [22]. The latter reasoning fits well with the third class of Cox's typology, 'investment' products, as they are ordinarily treated more carefully in use, due to consumers' feelings of higher financial and/or emotional investment. On the other hand, this also supports Echegaray's [48] argument that mobile phones are often seen as a proof of societal success in life.

Notwithstanding, there are still consumers who are willing to use mobile phones beyond their up-to-date time. If people deliver their functional mobile phones for reuse without delay, there is a reasonable chance to find a second user—less fashion conscious or with a lower purchase power—who could still use them for at least another year [37]. According to a Swiss study by Thiébaud et al. [18], reuse of electronics prolongs lifetime by at least 30%. The indication is, however, that people may keep their old phones in storage for even longer than a year. Inevitably, during a year-long storage, it is likely that the battery is no longer in good condition and the phone is certainly out of the manufacturer's warranty time. In that case, the phone has lost most of its economic gain during storage and, therefore, is even less desirable for the reuse market.

The untapped potential of reuse is not just for mobile phones but similar consumers' behavior and storing habits have been observed for other consumer electronics types as well (e.g., [7,13,17]). For example, the reasons for keeping laptops at home are very similar to those for mobile phones, most often being stored as a backup device or because of personal attachment [7]. However, it can be assumed that laptops do not have the same reuse potential as mobile phones, due to their longer average lifespan before storage and they are less likely to be viewed as an up-to-date product.

Knowledge Gaps and Recommendations for Future Research

Interpretations of end-of-life and end-of-use scenarios, with reference to ownership, structural performance and disposal times, conducted in this article, illustrate that total ownership is not a good indicator of the usefulness of a device, nor of its lifespan, due to the high probability of devices being stored after first use.

As consumers' storing habits of not-in-use mobile phones indicates the reluctance to cede ownership, future research should focus on exploring what conditions would enhance users' willingness to hand over their phones for reuse. More efforts are also needed to survey consumers' perceptions toward the additional features of smart phones and their impacts on storing habits. This information would be valuable when promoting the reuse of mobile phones by establishing services for the upgrading of used phones for the reuse market. Currently, these kinds of services are few and far between, and this gap needs to be tackled both technically and organizationally to fuel a real change. Türkeli et al. [53] are some of the researchers who have studied mobile phone repair as a business activity.

6. Conclusions

To reduce the amount of WEEE, we need to know the reasons why it ends up becoming waste. In this article, the lifespan of consumer electronics, in particular mobile phones, has been discussed, with reference to ownership, structural performance, and disposal time. As many consumer electronics satisfy consumers' needs for only a short time because of planned obsolescence, they will probably become waste before the end of their functional lifetime. Functional WEEE could be reused if another owner is still satisfied with its performance. However, the review of surveys presented in this article showed that a large fraction of end-of-use mobile phones are still not entering the WEEE recovery infrastructure but are stored at homes. Over the course of purposeless storing, mobile phones and other end-of-use devices may turn to waste because techniques they are based on become old-fashioned and/or undesirable changes occur in their structure or state. Thus, we argue that consumers will need to be made aware that there is still value in the product that could be recovered, through reuse or refurbishment, and they should commit to return EOU electronics to WEEE recovery without delay. Additionally, more repair services need to be established to facilitate reuse and stimulate transformation towards sustainable WEEE management. In Europe, the first steps have been taken in this direction, by the New Circular Electronics Initiative and amendments to the Ecodesign Directive, which introduce concrete measures to promote the repair and recyclability of electronics.

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