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SUITABLE PRACTICES OF DESIGN AND REPAIRMENT FOR REDUCING THE ENVIRONMENTAL IMPACT OF SMARTPHONES

Trabajo de Fin de Máster
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Abstract

Nowadays, smartphones are one of the most common devices in developed countries, as most citizens are owners of at least one. The lifetime of these products, however, is far from that of many other electronic devices such as laptops, tablets, eBooks or any household device. Smartphone's average lifetime is reported to be between 2 and 3 years by many studies, and the environmental impact of manufacturing, using and disposing of these products may grow to be a global issue in the years to come. This calls for a reformulation of our relationship with these devices, both from the user and design perspective, that allow us to extend their lives. But, with that purpose in mind, we first need to take a look at how this new way of thinking can greatly improve the sustainability of smartphones by evaluating how different its environmental impact would be from the one of our current consumption habits. In this work, we will explore current practises and different potential scenarios that could prevent, if only, just a small fraction of the environmental impact of smartphones.

This work shows how a change on new different kind of behaviours and habits can be a potential new path for diminishing the environmental impact of smartphones. It also reveals how easily, when faced with a component malfunction, consumers tend to replace their smartphone against the alternative of repairing them and what cost this has from a GWP perspective for the case of battery and/or display malfunctions. Finally, it estimates an average lifetime for every component and an average extended lifetime for every phone repaired.

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1 Introduction

Consumption habits of mobile phones have change substantially since the introduction of smartphones a decade ago. Almost every person in developed countries owns at least one smartphone (adult German citizens own an average of 3.22 phones per capita[1]), and the expected life of this devices is being set not only by how much time are they able to last (most prominent in more traditional household devices, such as dishwashers or fridges) but also by how willing are their users to hold on to them in a time when every smartphone gest obsolete at the one year mark. This, along with the growing demand of higher specifications, has increased the environmental impact caused by this industry.

Many studies show that smartphone's lifetime is set between 2 and 3 years. German users seem to have used their last smartphone for an average of roughly 2 years (Jaeger-Erben and Hipp, 2018), while Austrian citizens used their own for a mean average of 2.97 years (Wieser and Tröger, 2018) but a median average of 2.13 years (meaning the majority of users replace their smartphone closer to the 2 year mark than the 3 year). Most people seemed to have replaced their phone because of malfunctioning: 37% (Jaeger-Erben and Hipp, 2018) and more than 30% (Wieser and Tröger, 2018) of respondents stated defective components of their phone as the main reason for replacing it. However, the same surveys determined that only less than a 50% of the people that claimed malfunction of a component tried to repair it before obtaining a new device, mainly because of scepticism towards the repair system and the chances of their device to get fixed. This could be related to how consumers tend to "use minor malfunctions and imperfections to excuse new purchases" (Jacoby et al., 1977). Despite this, when asked about how much time smartphones should last, users answered up to 4 years (Jaeger-Erben and Hipp, 2018) and 5.2 years (Wieser and Tröger, 2015). This may show there really is an interest in long lasting devices, but also that most people find repairment too of a complicated or expensive process for them to take the risk, whether this is caused by misinformation or by really lacking repair policies. In these circumstances, Sabbaghi and Behdad (2018) estimated their own consumer's average expected life for a smartphone (2.84 years) from a survey focused on students while also proving how the smartphone retail price and the time passed

[1] Greenpeace: https://www.greenpeace.de/sites/www.greenpeace.de/files/publications/zusammenfassung-smartphone-umfrage-2016.pdf

since the purchase are critical for comprehending how willing are users to repair their phones. They verified two facts: 1) that people who spend more money on their smartphone are also more inclined to pay greater prices for repairing it, and 2) how the passing of time devaluates smartphones and the top price consumers are willing to pay for repairing them.

Against this kind of obsolescence, Fairphone (an Amsterdam-based smartphone manufacturer) has launched two modular smartphones that isolate their main components in independent parts (or modules). Every one of these modules can be accessed and replaced by their users just by taking out 3 or 4 screws in a time period of merely minutes, and spare parts are available on their website for purchasing. This way, they intend to empower users and increase the lifetime of their phones. It remains to be seen how much of a difference this kind of design and policy will make, though, since most users are not accustomed to self-repairing their smartphones.

On the other hand, and with climate change already knocking on the door and the whole of the scientist community warning about the more harmful RCP (Representative Concentration Pathway) scenarios we are globally heading to, measuring all kind of industry or services-related emissions has become one of the major tasks we face on the XXI century, as shown by the 2030 Agenda for Sustainable Development, The Paris Agreement, and many national and regional projects and policies. The Life Cycle Assessment (LCA) methodology presents itself as the best way to achieve these goals via the environmental footprint measurement, which includes the carbon footprint (or Global Warming Potential, GWP) measurement. By analysing the GWP from cradle to grave (this means, from the very extraction of the raw materials to the end of life) of a product, we can estimate its related CO_2e emissions (carbon dioxide equivalent, the sum of all greenhouse gases emissions). This tool has been applied in some occasions to calculate the CO_2e emissions of smartphones production, use and end of life. Results vary, especially since not every study uses the same operating time (lifetime) to analyse the emissions associated to the use stage and thereby cannot be compare to each other. But there are some, like the Xperia Z5 (Ercan et al., 2016) and Fairphone 2 (Proske et al., 2016) LCAs, that employ a use stage time of 3 years and are similar enough for the purpose of comparison.

Considering all the above, the aim of the present work is the study of consumption habits to promote suitable practices of design and repairment for reducing the environmental impact of smartphones. With this in mind, we launched an online survey in the fall of 2019 meant for all kind of Spanish citizens, which results we could use to understand everything we needed about their experience with their last smartphone. These results, along with those provided by the beforementioned LCAs, allowed us to present some scenarios of how different decision-making has an impact on the environment and to question ourselves how responsible we are as consumers of the harm that comes to it. We also took the opportunity to study the willingness of the surveyed smartphone users to repair their devices, as seen in the results of Sabbaghi et al. (2018).

2 Methodology

This section is composed of 2 sub-sections: the first one dedicated to the survey, and the second to the elaboration of the variables and scenarios we will use to compare the effects of different lifetimes of smartphones and consumer behaviour.

2.1. Survey

Both of qualitative and quantitative nature, this online survey took place between the months of October and December of 2019. It was designed and hosted in the Google Forms platform, and consisted in 6 sections and a total of 25 questions (Annex 1), though not every one of them had to be answered by all the surveyed people, since entire sections were subordinate to specific answers in the previous ones. It was focused on the last smartphone owned by the respondent. Most of the questions were a single-answer/select the answer type, but there were also some writing answers. The survey was developed in a time frame of a month, in which many potential misguiding questions were tested with a selected group of 8 people to ensure they were not misleading, redesigning every one of them when found necessary. This trial and error methodology continued until every person fully understood what every question was asking for.

The final sample size resulted of 672 residents in Spain, between the age of 14 and 72 years old. Further characterisation of the sample is detailed in Table 1.

Table 1. Characterization of the sample.

	Category	n	%
Gender			
	Male	210	31.25
	Female	447	66.52
	Non-conforming	15	2.23
Age			
	14 - 19	18	2.68
	20 - 29	266	39.58
	30 - 39	112	16.67
	40 - 49	98	14.58
	50 - 59	112	16.67
	60 - 72	66	9.82
***Household* income**			
	Up to 499 €	11	1.64
	500 - 999 €	42	6.25
	1000 - 1499 €	105	15.63
	1500 – 1999 €	102	15.18
	2000 – 2499 €	114	16.96
	2500 – 2999 €	87	12.95
	3000 – 4999 €	159	23.66
	5000 € or more	52	7.74

The first section, which gave name to the whole survey, was titled “The story of your phone”. It included a description of the survey as a way of engaging with the people being surveyed. This description was as follows (in its original language):

> *“¡Bienvenido/a! Esta encuesta está diseñada como parte de un Trabajo de Fin de Máster sobre sostenibilidad, economía circular y el impacto que tiene el consumo de teléfonos inteligentes (smartphones) y el trato que les damos. ¿Sabías que las emisiones de gases de efecto invernadero que genera un smartphone, suponiendo que dura 3 años, llegan a alcanzar hasta casi 60 kg de* CO_2 *equivalente? No es una cifra particularmente alta, pero si sumamos la de todos los móviles de, por ejemplo, España... ¡resultan unos 2.500 millones de toneladas que se emiten cada 3 años como consecuencia de este producto! Además, la mayoría de estudios coinciden en situar la duración real de estos*

dispositivos no en 3 años, sino en torno a los 2, multiplicando todavía más estas cifras. Gracias a tu colaboración con este proyecto, intentaremos determinar cómo consumimos smartphones, cómo deberían los fabricantes modificar su diseño para hacerlos más sostenibles y qué decisiones podemos tomar para reducir el impacto que generan. Como, para ello, es vital analizar la vida completa de estos dispositivos, te preguntaremos cuestiones básicas sobre el smartphone que usaste ANTES del actual. ¡Todo lo que recuerdes nos será de gran ayuda!"

The description was followed by 6 questions about:

- The smartphone's brand and model (open writing question).
- Its price divided in 11 equidistant intervals of 100 € plus a "don't know" option (selection question).
- Whether it was a new product or second handed (selection question).
- The time that the surveyed used the smartphone as the primary phone before replacing it for another, divided in 12 intervals from "less than half a year" to "seven years or more" (selection question).
- What the surveyed did with the smartphone after acquiring the new one (selection question with a personalized "other" option).
- The reason behind replacing the smartphone (selection question with an open "other" option).

The second section, titled "In case you replace your phone because of malfunctioning of the previous one…", was only available to those who answered the last question of the first section with a malfunctioning issue being the main reason for replacing their phones. It consisted of 2 questions:

- The first one asked the surveyed to quantify how severe were the issues they were experiencing with each component before replacing the phone, in a scale from 1 to 8 where 1 meant they were experiencing no issue at all and 8 meant they couldn't use the phone because of this issue. We defined the following components: screen, battery, USB port, microphone, mini Jack port, camera, case and other.
- The second one asked whether the surveyed had tried to repair the smartphone instead of immediately replacing it (selection question).

The third section was titled “In case you replaced it without trying to repair it…” and was only available to those who answered that to the final question of the previous section. Again, two questions comprised this section:

- The first one asked about the motive behind not trying to repair the phone, offering 6 options to choose from (selection question with an open “other” option).
- The final question asked about modularity: after a description of how modular smartphones were supposed to work and the potential benefits of being able to self-repair one’s own phone, respondents were asked whether they would have considered repairing their smartphones had the phone been modular. The possible answers were “yes, I would have tried to repair it”, “no, I would have replaced it anyway” and “maybe” (selection question).

The fourth section, called “Your smartphone’s war injuries”, was common for all respondents and was focused on getting to know every malfunction users had experienced with their phones. For every component, respondents were asked at what time from the moment of purchase did the component fail/break, how many times the component failed/broke until they replaced the phone, whether they used the phone for a time while experiencing issues with the component, and if they ever repaired their phone. These questions were all except the final one selection questions comprised of different options for each component, as previously seen in the second question of section 2. For time-frame related questions, different intervals were used for better accommodation to the expected answers: for example, it should be expected that the answer given to how much time someone spent using a malfunctioning phone would be of a lower time period than the answer given to how much time did any component of the phone lasted before showing any issue.

The fifth section dealt with repairment and was exclusive to the respondents that answered they had repaired their last phone at least once. Three questions were asked: where had the respondents repaired their smartphones (selection question with an open “other” option) and, again for each component, how many times had they repaired the component (selection question) and how much time passed between each component’s defect and its repairment (selection question).

The sixth and last section consisted of 8 questions:

- The two first questions aimed at finding how much time the respondents thought their actual smartphone will last and how much time smartphones as devices should last (selection questions).
- The third one asked about the price every surveyed would be willing to pay for repairing their smartphone at different times since purchase (selection question).
- The remaining questions were used for gathering all the characterisation information needed of the sample taken (the one previously presented in Table 1). The survey ended with the chance to submit an email for contacting when this study is published, so that every respondent gets future access to the results achieved.

2.2. Model

In order to build scenarios for comparing different environmental impacts, some variables needed to be stablished. The first step we had to do was the estimation of a mean average for the lifetime of the surveyed people's smartphones. For that purpose, we estimated a "previous use time" from all the respondents who had sold their smartphones. This lifetime would be later added to that of the second handed smartphones to obtain the whole life of every smartphone, whether they had been used previously or not.

Since getting to know how consumers' choice of not to repair their phones was one of our main objectives, we needed to know, for each component (these were: screen, battery, USB port, microphone, mini Jack port, camera and case), how much time passed between the acquisition of the smartphone and the moment a component malfunctioned. Since this was the exact question we had early asked on the survey, we simply determined the mean average malfunction time for each component.

We also needed to calculate how much extra time those respondents who decided to repair their phones were able to keep using it before replacing. For every surveyed user who had repair one single component of his/her smartphone in its life, we chose to estimate the extra life that resulted from this operation by subtracting the malfunction time of this component to the whole life he/she had given to his/her smartphone, minus the time lapse between this malfunction and the moment of repairment (since we know many people choose to hang on to their damages phones/components for some time to make the most of them). With this, we managed to obtain the mean average “extra lifetime” that every smartphone with specific component issues could achieve by repairing them. Whenever 2 or more components were malfunctioning, we chose to consider the extra lifetime added in case of repairment as the lesser one of the extra lifetimes associated to those components.

On the other hand, for properly understanding the environmental impact caused by any replace/repair choice, we reached for the Xperia Z5 LCA (Ercan et al., 2016). This study calculated the GWP for “the assessed smartphone (a Sony Mobile Z5) including accessories to 57 kg CO_2e for an assumed operating lifetime of 3 years, excluding the network usage”[2]. Some clarifications should be made:

- Usually, LCAs of smartphones neglect the environmental impact of the network usage when presenting this kind of results. This is not because it cannot be estimated (this LCA actually does it), but because it doesn’t serve the purpose of comparing and understanding the GWP caused by the device itself, since emissions produced by mobile and data networks are dependent of every country’s phone operator companies infrastructure. For this reason, we will be referring to the amount of 57 kg of CO_2e as the GWP of an average smartphone for the rest of this work, even though this number does not include the network usage impact.

- The functional unit of this and the Fairphone 2 LCAs are both ‘3 years of time usage’. This has many implications and is important for understanding how these numbers are managed on this work. When analysing the GWP of the use stage, the smartphone’s energy consumption (in other words, the consumption of electricity when charging it) is estimated through several scenarios of usage intensity and is always related to the periods of time the product is used. The Xperia Z5 has a 7.2 kg CO_2e emission associated to its 3 years average use. If, however, we were to define a new functional unit of 6 years of use, this quantity would be doubled as well with this lifetime, but all the production/transport/end-of-life associated GWP would not be altered at all. For this reason, we used a linear correlation between total GWP (for the smartphone’s whole lifetime) and

[2] Xperia Z5 LCA.

the years of use given to the smartphone (the lifetime itself), assigning a base quantity of 49.8 kg CO_2e for all stages except the use one: 57 kg CO_2e minus 7.2 kg CO_2e for the use-stage on a functional unit of 3 years. To this value we would later add the 2.4 kg CO_2e related to the use of the smartphone for every year of lifetime:

$$GWP_i(kg\ CO2e) = 49.8 + 2.4 * i; i = 1,2,3 \ldots$$

where i equals the number of years of use. After estimating the lifetime's associated GWP, we normalised it uniformly as a GWP per year for later comparing different scenarios.

For the repair-scenario estimated GWP, we looked at the isolated GWP of the display and battery components as seen in the LCA in order to calculate the GWP that would take to repair each component. The production and internal transportation stage of the LCA of the smartphone reported a GWP of 3.5 kg CO_2e for the screen and 1.4 kg CO_2e for the battery. For the final transportation, we needed to make some assumptions about how the transport was managed. The LCA only studied the environmental impact of the final distribution of the final product (the smartphone packaged with every accessory) to retailers through Sony internal data of transportation vehicles and distances. 3 kg CO_2e were assigned to this transportation[3]. Since no information is available about how official repair centres are distributed among regions, countries or cities, we weighted the LCA results for final deliveries of the final product with the weight (grams) values of battery and display plus the delivery and transport packages, as follows:

$$Battery\ delivery\ GWP\ = \frac{Battery\ weigth + packaging\ weight}{Final\ product\ weight} \times Final\ product\ delivery\ GWP$$

$$Display\ delivery\ GWP\ = \frac{Display\ weigth + packaging\ weight}{Final\ product\ weight} \times Final\ product\ delivery\ GWP$$

A hypothesis had to be made in order to do this operation: the Xperia Z5 LCA article, which contained a Z3 LCA as well, did not depict the Z5 components weight. However, it did of the Z3 ones. Since both the Z5 smartphone and its components would have different weights than the Z3 one's, but cannot be found on the study, we

[3] Xperia Z5 LCA.

made the assumption that the ratio component 'weight/smartphone weight' would be constant from the Z3 to the Z5 (since both display and battery had to be adjusted to the larger Z5 size). This way, and since the Z5 phone only weights 4.5 g more than the Z3[4], we could use the Z3 data without incurring in much of an error.

Every GWP scenario in this work is presented as an accumulated individual (per person) carbon footprint per year. For this purpose, we normalized the GWP of every consumption choice as an emissions/year variable. This way, we make consumption habits out of accumulated choices: we are able to observe how, by making a habit of choosing to replace or repair our smartphone at a given time, we have more of a long-term environmental impact than a short or one-time only one. We expect to replace our phone for a new one in the coming years, we most likely will replace that one in the following ones, and so forth… so we present this kind of scenarios to analyse how should we behave and what kind of relationship should we have with our smartphones on the long term. This approach will be further explained at the results section.

Finally, we also worked on estimating the emissions that could have been saved by choosing to repair rather than replace when a single component malfunction was the reason behind getting a new phone. We took the information on replacing time and time of malfunction of every respondent whose battery and/or display malfunction were the reason for replacing. Along with the extended lifetime we had estimated earlier for every single component repairment, we managed to individually calculate an alternative scenario on which every one of these respondents had repaired their phones and what GWP per year was associated to both the real (replace) scenario and this one. By comparing them, we obtained a sum of potential GWP saved per year for our sample. Although the same operation could have been made for the rest of components, display and battery are, as we will see later, the most common malfunctions and reasons behind replacing the phone, and thus it made sense for the limited reach of this work to abstain to go any further.

[4] https://www.xataka.com/moviles/xperia-z5-analisis

3 Results and discussion

3.1. Survey results

Most of the respondents purchased a brand-new smartphone rather than buying or receiving a used one, as Figure 1 shows. This result matches the one of Wiser and Tröger (2015), who reported a 11% of the smartphones being bought second hand.

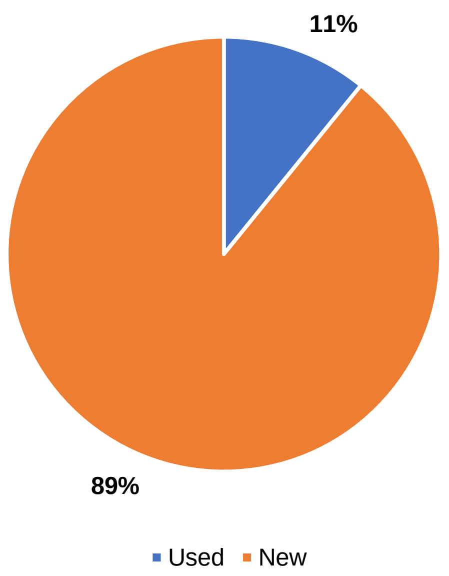

Figure 1. State of the respondent's last smartphone at the time of purchase/obtention.

The average price each respondent paid for his/her last smartphone was obtained from the distribution of each one's given answer in the survey (Figure 2), resulting in a value of 247.4 €. This proved that, even when so many smartphones surpass the 500-800 € price point and are usually the most marketed products, most of the respondents were not interested in that kind of smartphones: almost 75% of them did not paid more than 300 € for their las smartphone.

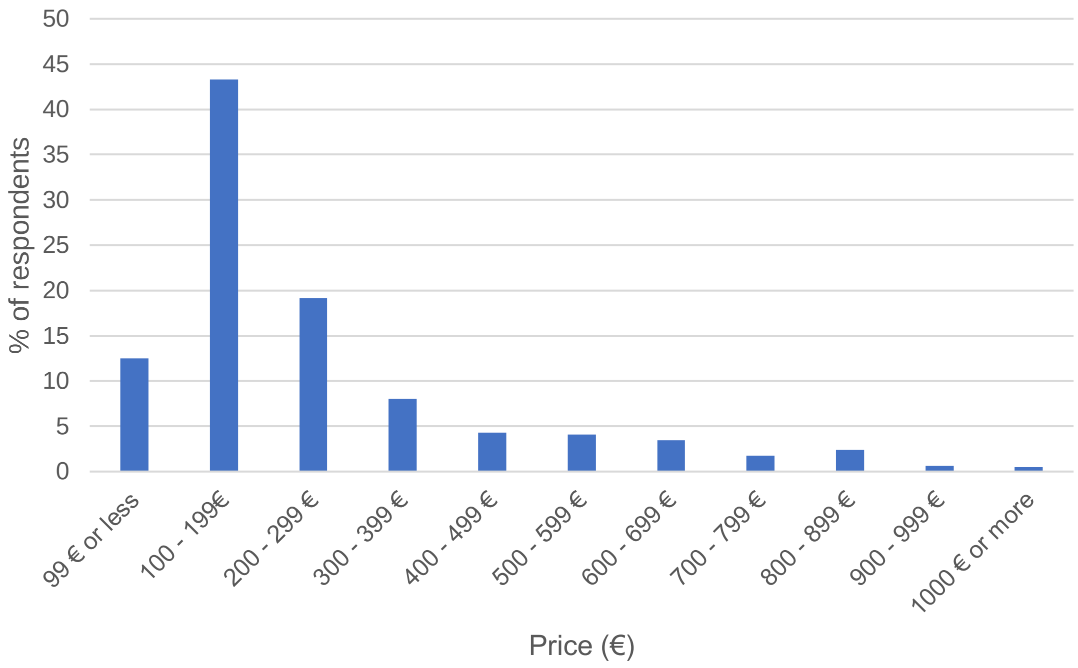

Figure 2. Price paid for the respondents last smartphone.

A most interesting observation could me made of the smartphone's lifetime related questions: people tend to be very positive and optimistic about how much time will their actual smartphones last in comparison with how much the last ones did. It would seem either people expect for their devices to be more long-lasting than the previous one, or they expect themselves to behave in a different way than they ultimately do (the replace/repair dilemma). This is proven by the 2.81 years average lifetime of the respondents last smartphone (the one we asked most of the questions about) and the 3.32 years average of their current smartphone's expected life. An even greater gap can be found between these numbers and the ones given as an answer to the "how much do you think smartphones should last?" question: more than a 36% of the respondents thought smartphones should last at least 7 years, a lifetime not even manufacturers themselves support with security updates or even spare parts. The average lifetime smartphones should have, according to the respondents, was that of 4.67 years. These results are also similar to those of Jaeger-Erben and Hipp (2018): 2 years for the last smartphone's lifetime and 2.56 years for the current smartphone's lifetime (an expanded life of 6 months). A full comparison between lifetimes can be found in Figure 3.

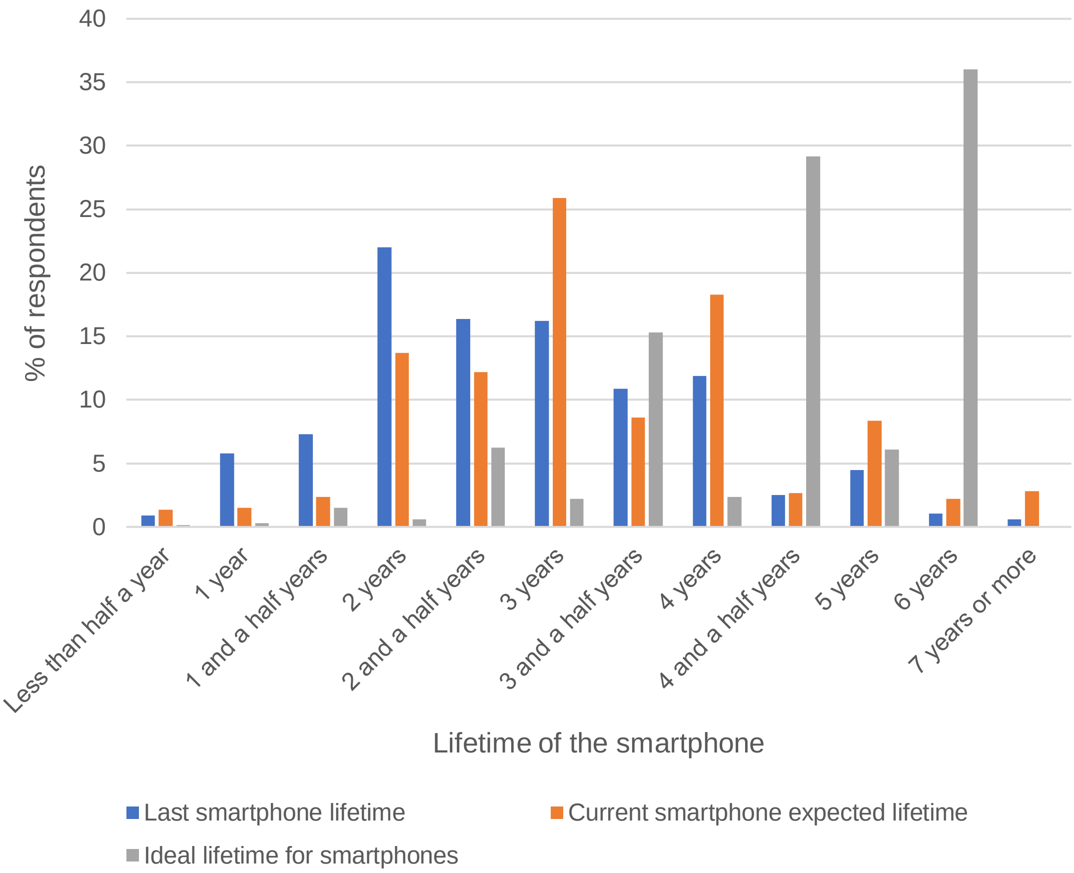

Figure 3. Distribution of the respondent's last smartphone lifetime, actual smartphone expected lifetime and their thought on how much time should smartphones last.

Until this point, we have merely explored each smartphone's lifetime as seen by the respondent's individual experience. However, circular economy should be included in this analysis when trying to fully comprehend how much time these devices are actually being used. With this in mind, we estimated a mean average of the time the respondents who sold their phones actively used them before handing them over. Adding this average "previous lifetime" of 2.64 years to the lifetime of those used smartphones that were bought in second-hand stores or obtained by any other means, the previously seen average lifetime of 2.81 years was increased to 3.30. This average "previous lifetime" matches the results of Wiser and Tröger (2018), according to whom "second-hand devices are used as long as new devices". Since our focus in this study is to design scenarios for the purpose of understanding the environmental impact not from a user perspective, but from a wider and collective one, we will be referring to this value as the average lifetime of a smartphone.

From this circular economy perspective, it is also interesting determining what usually consumers do with their smartphones once they no longer have a use for them (Figure 4). Two thirds of the respondents kept their phones, while only 6% of them disposed of it (either donating them for recycling or throwing them to the general waste). This results are quite different from the ones of Wieser and Tröger (2018), which showed how, even if most of the Austrian population seems to keep their old smartphones as well (although only 51% in their case), almost 20% of them donated them for recycling or took them to recycling centres themselves. This little regard for recycling may depict an entirely different culture of how we perceive the recycling and reuse of electronic devices.

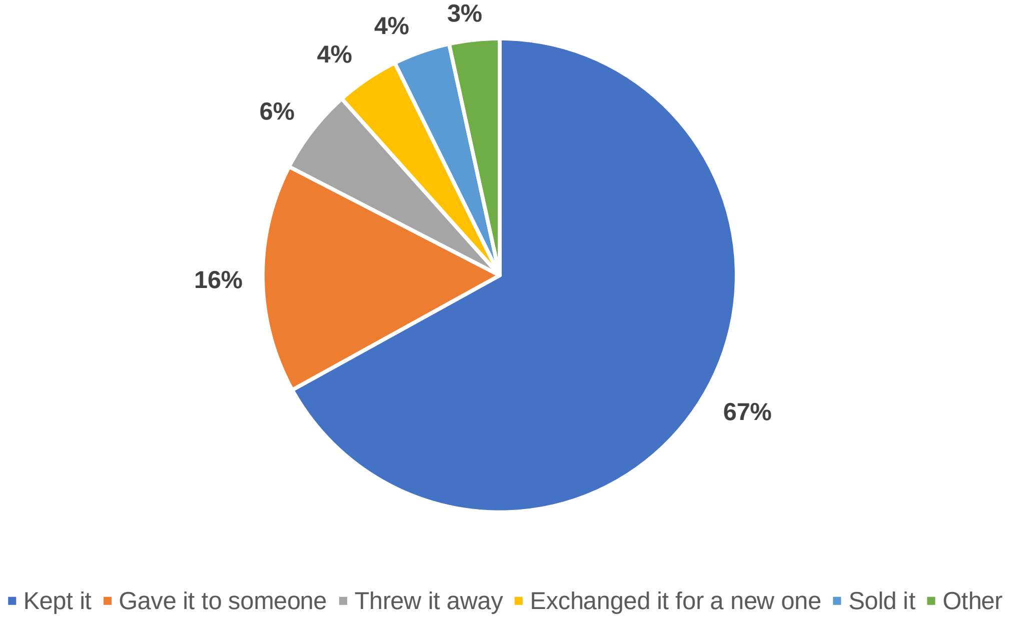

Figure 4. Destination of the respondent's smartphones once they replace them.

The main reason pointed for replacing a smartphone (Figure 5) was some kind of malfunction (69%), followed by obsolescence (14%), having been gifted a new one (9%) and simply wanting a new model (5%).

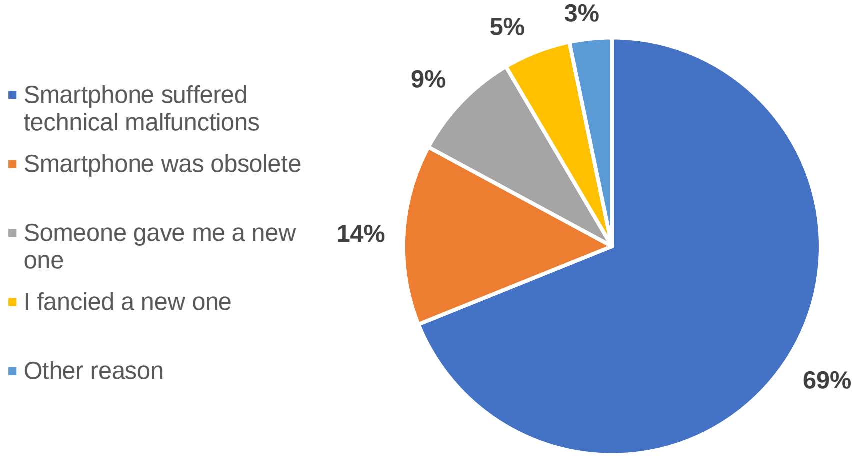

Figure 5. The reason behind replacing their last smartphone.

Eighty respondents (about 12%) answered that a lack of memory for apps, photos, etc. forced them to purchase a new phone with larger memory space. Storage limitation is one of the most easily fought kinds of obsolescence, solved just by installing an extended storage option such as a micro *sd* card port. It would seem that, nowadays, almost every modern smartphone is equipped with this kind of port, so it could be safe to assume that this kind of motive for the replacement of a phone is destined to fade away. This does not guarantee in any way, of course, that the lifetime of this technology will be increased, especially since we can increasingly observe how every year more smartphones are designed with a less repair-friendly set of mind[5].

All the respondents who had answered they replaced their phones because of different kind of malfunctions were asked if they tried to repair them before acquiring a new one (figure 6). Most of them did not, and gave the reasons observed in Figure 7 for not doing it. Wieser and Tröger (2018) reached similar conclusions for the tried-to-repair ratio, with 66% of the surveyed responding they did not attempt to repair their phones. A different methodology was employed in their study, however, as this question was made to all surveyed instead of only to those who had changed their phone because of malfunction, and more than a 10% of them reported to have successfully repaired their phones (while our respondents could not have, since they were not offered that option because of how our own survey was structured).

[5] https://www.androidauthority.com/device-repairability-807585/

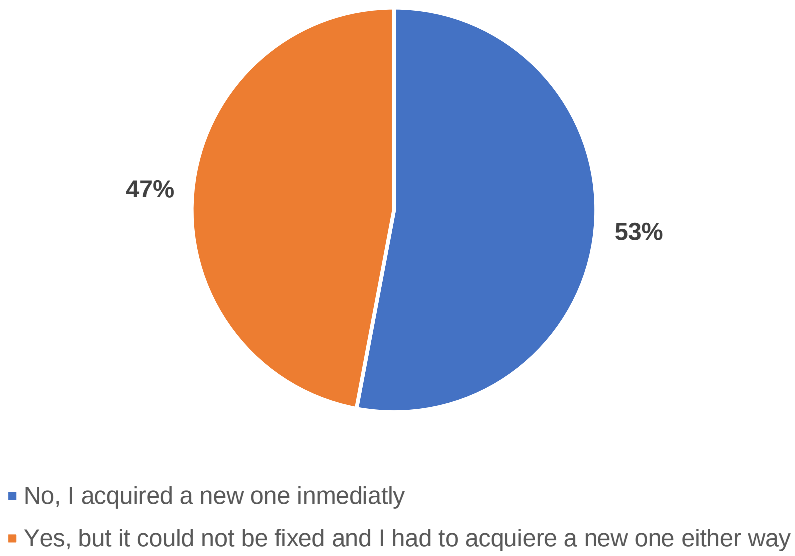

Figure 6. Answers to whether the respondents tried to repair their malfunctioning phones or did not.

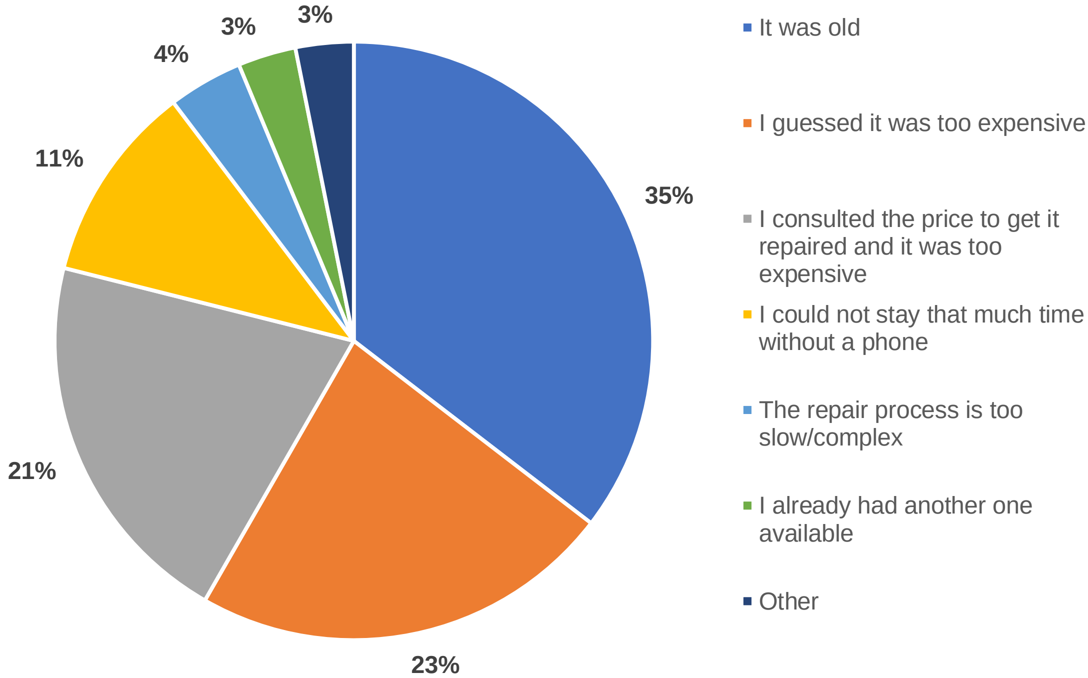

Figure 7. Reasons for replacing the smartphone before trying to repair it.

At this point, the respondents who did not tried to repair their smartphones were presented with an explanation of how modular phones like the Fairphone 2 were built and how they allowed owners to self-repair their devices. Then, they were asked whether they would have tried repairing their last smartphone had it been modular rather than immediately replacing it with a new one (Figure 8). Since we have learned to be sceptical about how optimistic people tend to behave when facing the longevity of their phones, these results should not be understood as a foreseeable reality were modular phones a design standard. However, they help us understand how design becomes a most important consideration for taking the steps to repair one's phone or not, and thus should be imperative that we demand this kind of features from our devices if we expect to achieve a more sustainable industry.

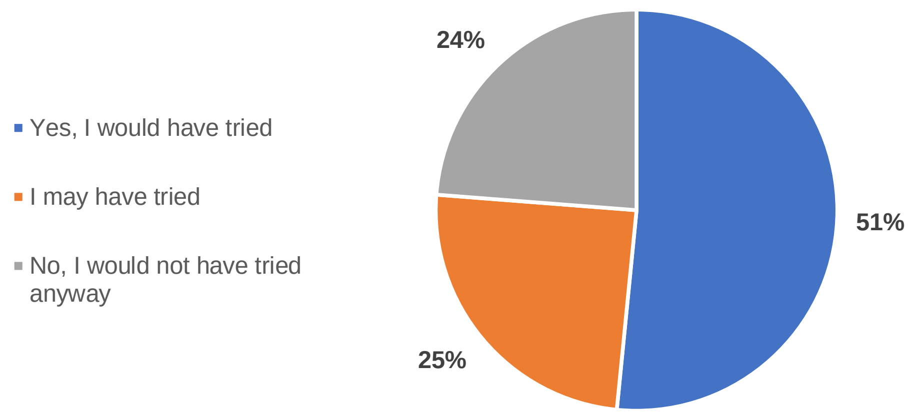

Figure 8. Answers to whether the respondents would have tried to repair their smartphone had it been modular.

All surveyed were asked if they had ever repaired their previous smartphone (Figure 9) and, to those who had, through which channel had they done it (Figure 10). Only 38% had ever repaired it at least once, and most of them had done it by taking it to a local store (46%), followed by the brand's official service (32%) and self-repair (19%).

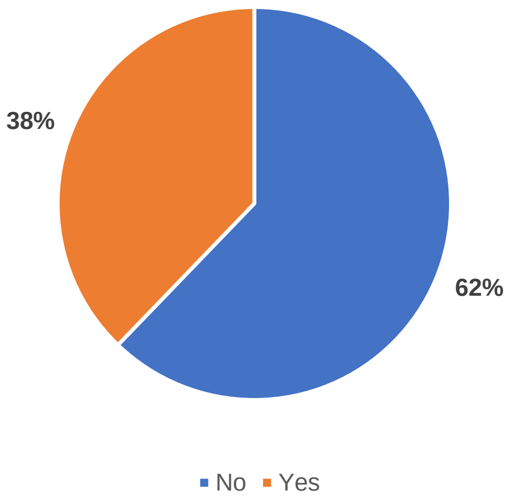

Figure 9. Percentage of respondents who had repaired their last smartphones at least once.

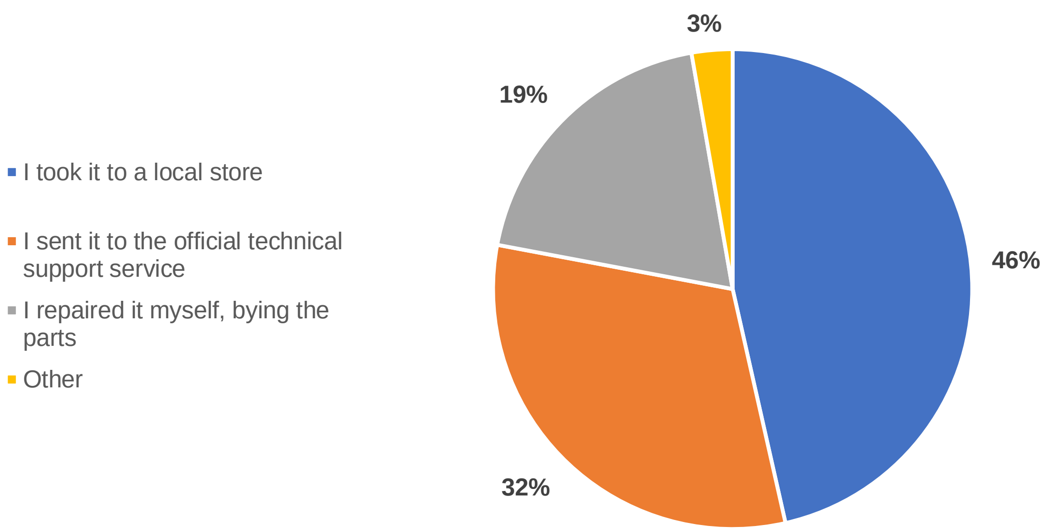

Figure 10. Means by which the respondents repaired their last smartphone.

For properly understanding which the most common technical issues of smartphones are, we asked the 672 respondents to recall at what time did every component malfunction. Table 2 shows how many of them faced this kind of faults and the time since purchase/obtention they occurred. Battery and display malfunctions were the most prominent, with 74% and 51% of the respondents having suffered them. According to the time of failure values given by the surveyed, battery is also the earlier component to fail (1.87 years), followed by display as well (2.07 years).

Table 2. Frequency for each component's malfunction and average time of malfunction.

Component	Average time of malfunction (years)	n
Display	2.068	346
Battery	1.869	497
USB port	2.208	245
Microphone	2.415	171
Jack port	2.517	151
Case	2.173	171
Camera	2.289	175
Other	2.146	192

As explained in the methodology section, a scale from 1 to 8 was provided to the respondents for classifying how severely damaged was each component they had reported faulty. We grouped these results in 2 categories: not severe and severe damage, with the first one covering all malfunctions of a damage degree from 1 to 4 and the second one from 5 to 8 (Figure 11).

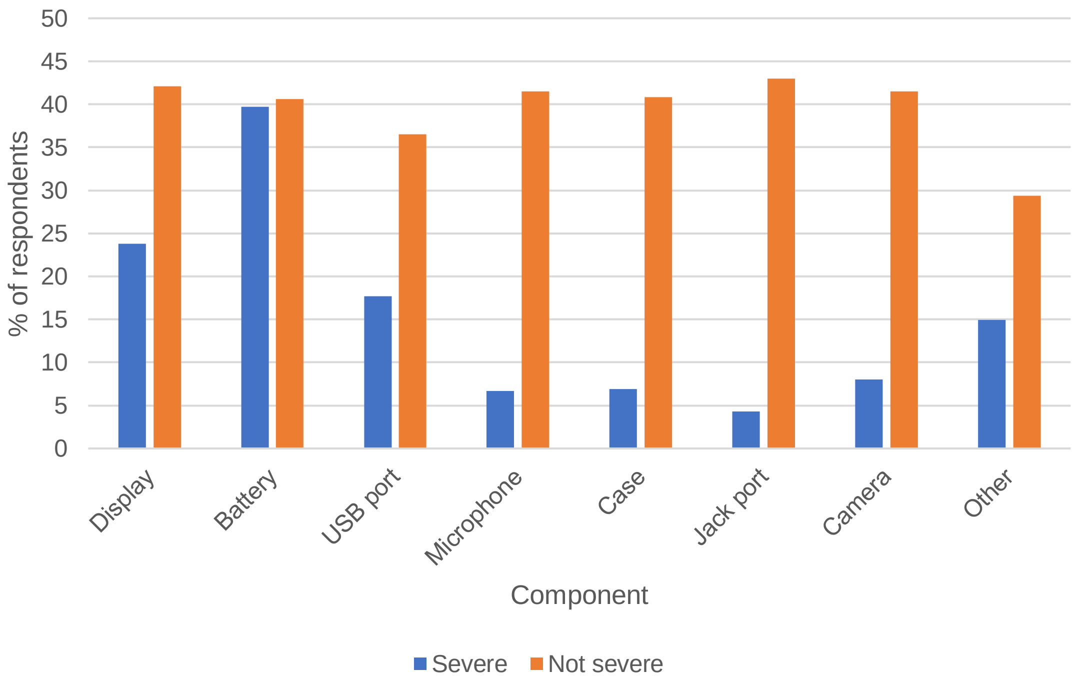

Figure 11. Percentage of respondents, from the ones claiming malfunction as the reason for replacing their smartphone, that claimed severe and not severe damage for each component.

It becomes clear that the number of minor or not severe malfunctions exceeds that of severe ones, so it could prove interesting to assert how many respondents replaced their phone without a single severe damage despite of claiming it to be the main cause of replacement. More specifically, we found that 152 of these 463 respondents (nearly 1/3 of them) did not suffer any severe damage before substituting their phones. This many people answering they replaced their phones without actually suffering any large issue could be related to how Jacoby et al. (1977) established that humans tend to justify the purchasing of new devices by exaggerating their current one's faults and issues. However, this should be treated carefully as it could be a deceptive result, since this damage-degree values were made of user perception and not from a technical specialist point of view. It could also be argued that a value of 5 out of 8 is located too above/below the line that divides a severe malfunction from a not severe one.

We tried to replicate the Sabbaghi and Behdad (2018) study's results by asking how much money the respondents were willing to pay for repairing their phones for the following years after its acquisition to collate it with each respondent's smartphone retail price. We examined the first year results - the top price they were willing to pay if the smartphone needed repairment during the first year of use - (Figure 12) and observed how indeed the more expensive the smartphone was, the more people were willing to pay for repairing it (Figure 13).

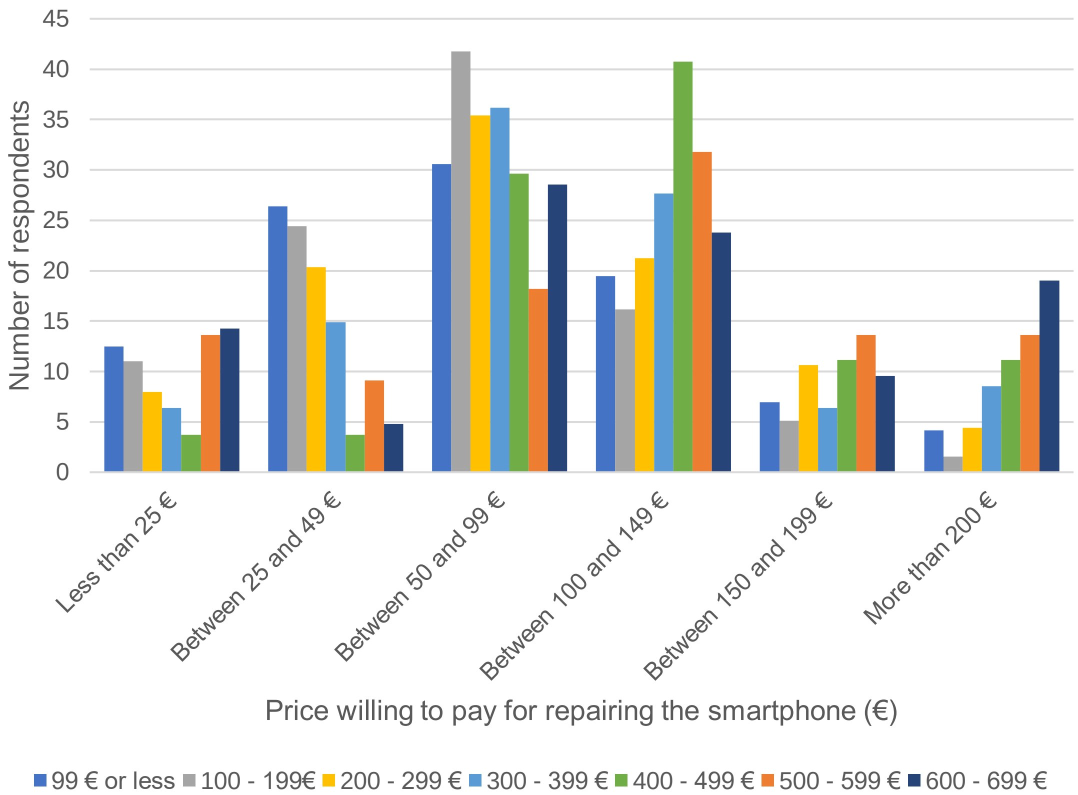

Figure 12. Price respondents are willing to pay for repairing their smartphone during the first year of use for different smartphone retail prices.

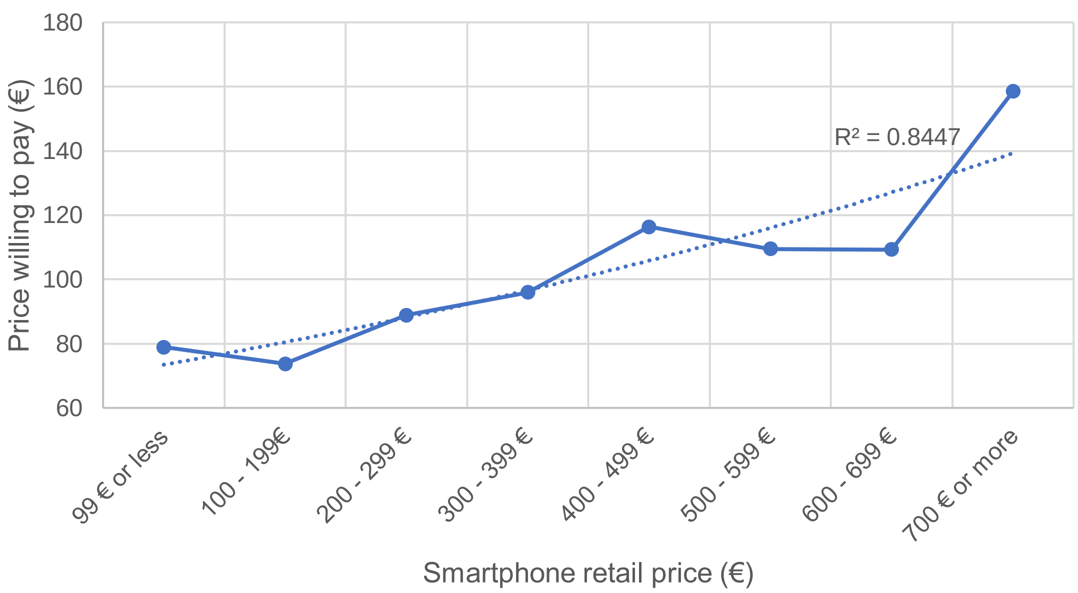

Figure 13. Average price willing to pay for repairing the smartphone during the first year of use according to the smartphone's retail price.

Finally, we displayed the average price willing to pay for all smartphone's retail prices and different years of use (Figure 14) and the percentage of respondents who would not repair for different years of use (Figure 15). The former showed how, as expected from our first year of use analysis and matching the results of Sabbaghi and Behdad (2018), people's willingness to repair decreases as time passes from the moment of purchase and the average price willing to pay relies on the original retail price for the smartphone. Interestingly, though, the results for the 5 years or more time of use are overall contradictory with the rest of the tendency. This may be because of some sentimental value or appreciation towards such reliable and long-lasting device; as Proske and Jaeger-Erben put it: "… the human-object relationships are not only keys to understanding obsolescence. They are also essential for strategies to prolong product lifetimes…" (Proske & Jaeger-Erben, 2019). The latter figure revealed how much people give up on repairing as time passes from the purchase. Another exception can be found here, as people seem to be less receptive to repairing a less than a year-old smartphone than a one year old one. This could be explained by how consumers don't expect for their devices to malfunction so soon and will punish them by discarding them in favour of another one.

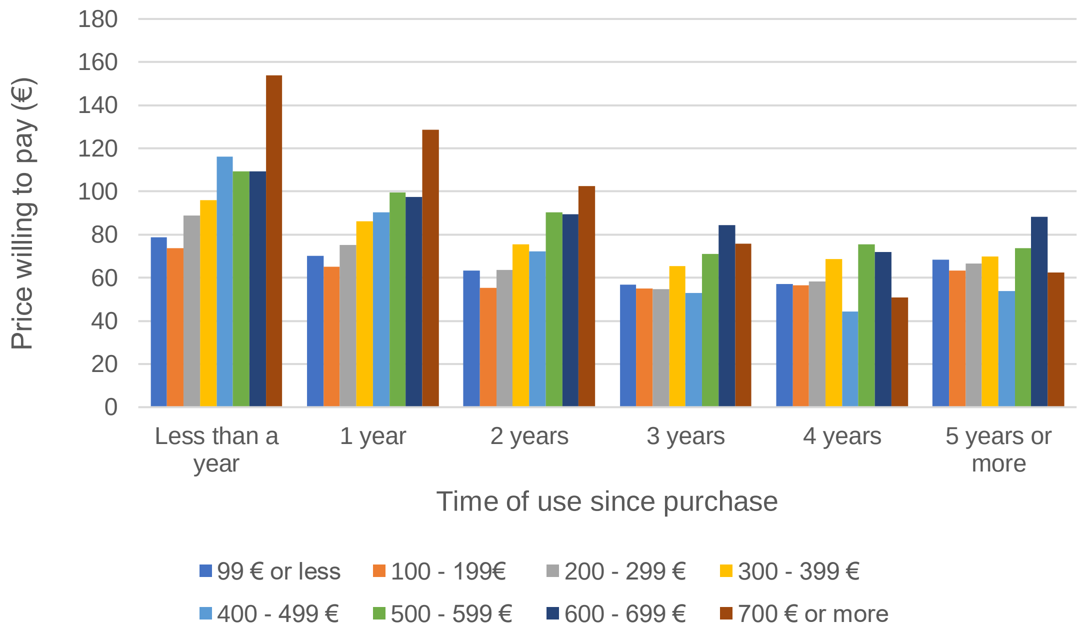

Figure 14. Average price willing to pay for repairing the smartphone according to the smartphone's retail price and time of use since purchase.

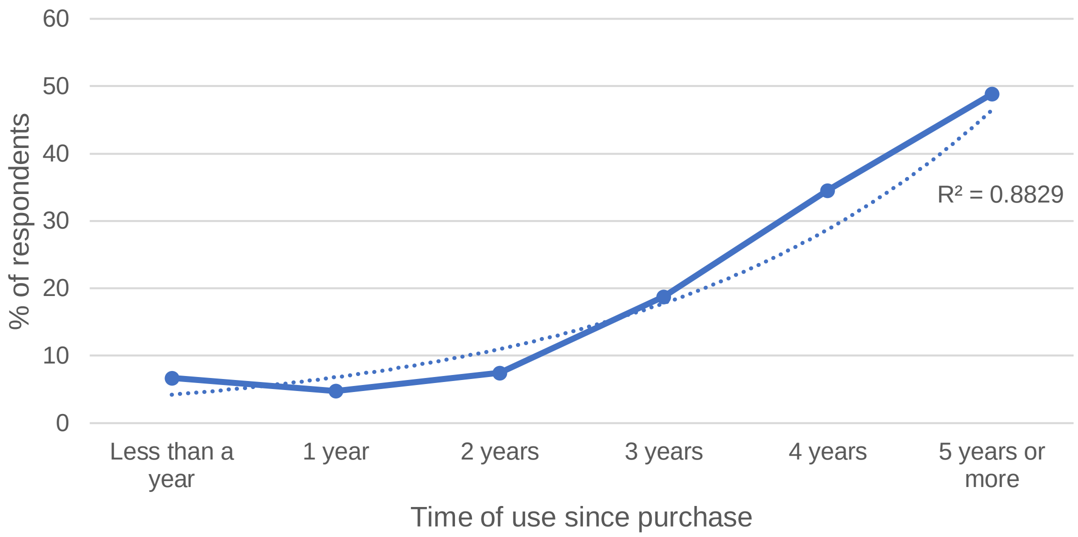

Figure 15. Percentage of respondents that would not repair at different times of use since purchase.

3.2. Scenarios

Our main goal when designing these scenarios was to comprehend how much, in a medium rather than short term frame, consumer's choices and habits regarding their smartphones damage the environment. Since this approach is about asserting an accumulated impact over time, we used an "accumulated individual carbon footprint" variable: the sum of GWPs (CO_2e emissions) over the years. Figure 16 shows different accumulated individual carbon footprints for various lifetime scenarios, from a 1-year lifetime to a 6-years one. This was estimated thanks to the Xperia Z5 GWP (57 kg CO_2e for a lifetime of 3 years), from which we were able to obtain the use-stage related GWP and normalise it as a GWP/year for applying it to different lifetimes than 3 years. This figure should be practical for understanding how damaging different replacing periods are on the long term. By the sixth year since the starting point, a consumer with a habit of replacing his/her smartphone every 2 years will have accumulated 49.8 kg CO_2 more than a consumer with a habit of replacing his/her one every 3 years, the exact GWP of a new one (excluding the use stage). The accumulated individual carbon footprint for the mean average of a smartphone's lifetime was also determined (Figure 17).

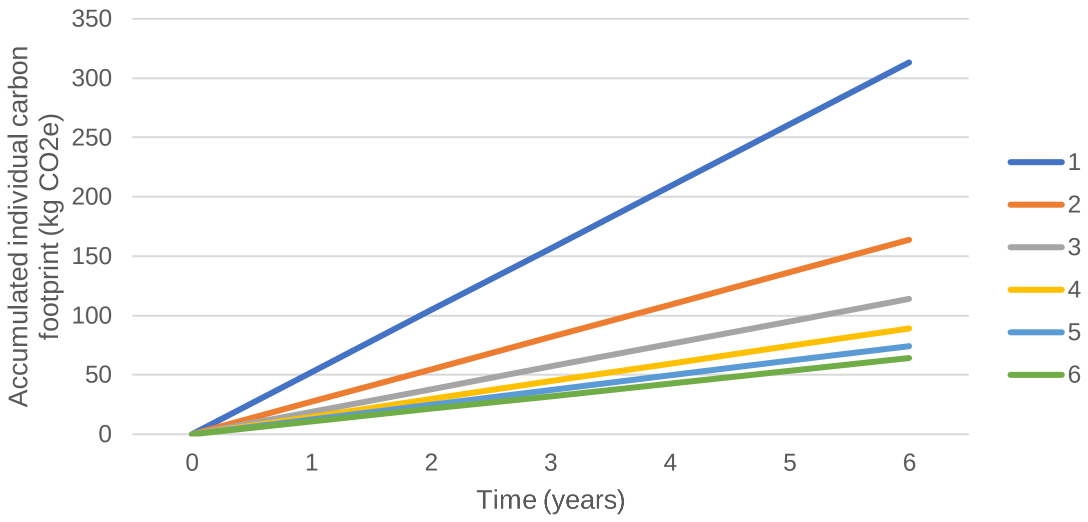

Figure 16. Accumulated individual carbon footprint for different smartphone lifetimes.

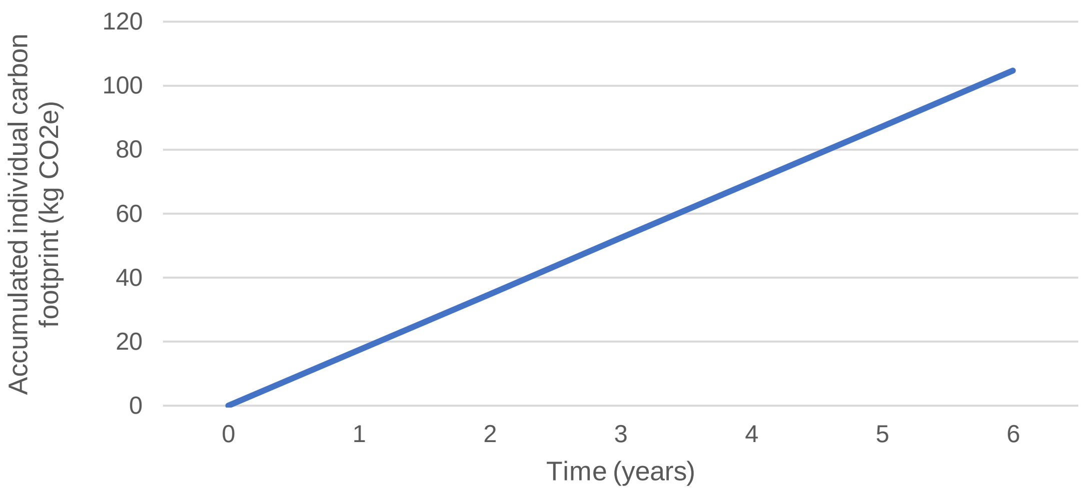

Figure 17.Accumulated individual carbon footprint for the average smartphone lifetime.

These scenarios show the significance of prolonging a smartphone's life, since just by extending it from 2 to 3 years, an emission of 8.3 kg CO_2e per year and user would be averted.

Four other scenarios were conceived for understanding the role of repairing in these terms of accumulated individual footprint. An average smartphone "extended lifetime" was determined for every component (Table 3) and two scenarios were designed for the display and battery component's repairment (which were selected since they are the most common and earlier component malfunctions observed): one for the replacement of the smartphone at the average time of malfunction of the respective component and another for the repairment (at the same time of malfunction) of the component and subsequent extended lifetime of the smartphone before it needs to be replaced (Figures 18 and 19). Though these scenarios, we intended to grasp how much a difference would it make if the average smartphone user with display or battery issues chose to repair it rather than replace the whole smartphone.

Table 3. Average smartphone's extended lifetime for repairing each component.

Component	Average extended lifetime (years)	n
Display	1.043	44
Battery	1.183	58
USB port	0.907	22
Microphone	1.480	5
Jack port	0.794	5
Case	1.390	5
Camera	1.224	5

Since each expected extended lifetime is determined using the statement of every consumer who repaired once each corresponding component (whatever the reason for the later replacement of the smartphone might be), we are taking into account every possible circumstance for replacing the phone from our sample.

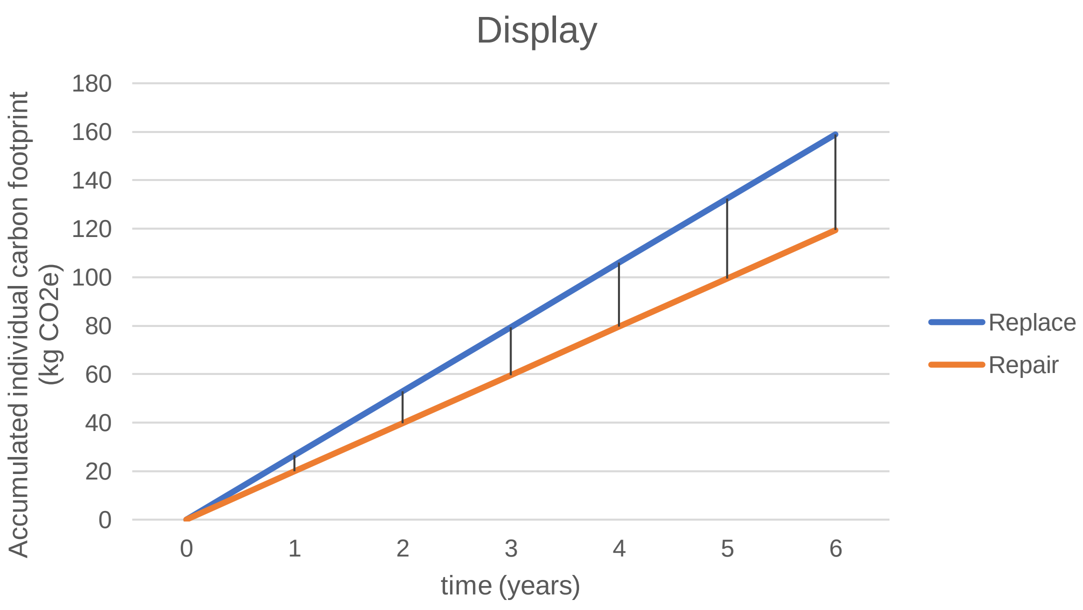

Figure 18. Accumulated individual carbon footprint for the display's replacement and repairment scenarios.

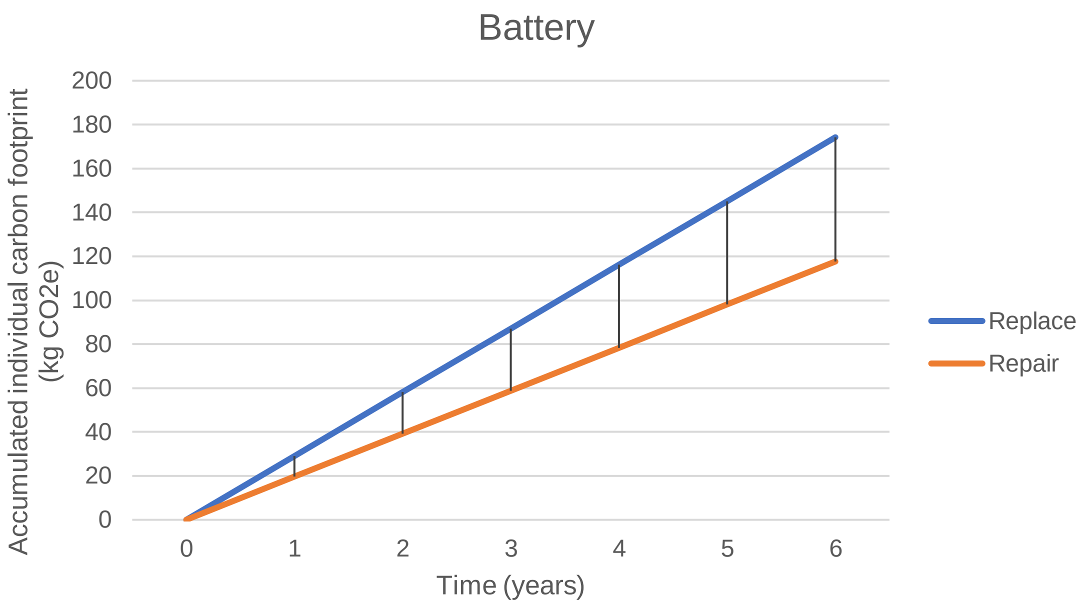

Figure 19. Accumulated individual carbon footprint for the display's replacement and repairment scenarios.

If the average consumer were to repair the display instead of replacing the phone at the average time of malfunction, 6.59 kg CO_2e per year would be spared, and he/she were to repair the battery, this would ascend to 9.43 kg CO_2e per year. Although it takes a lesser amount of GWP to produce and transport the battery than the display, the former average malfunctioning time is more than 2 months sooner the latter one. This implies that, in the battery's smartphone replacement scenario, the whole smartphone would be substituted 2 months earlier, and thus the whole GWP related to the entire life of the device would be concentrated in a lesser time, placing it above the display's replacement scenario GWP.

Finally, we aimed at estimating how many kg CO_2e would have been saved if every respondent that had proclaimed that he/she had replaced their phone because of a battery and/or display issue had instead repaired it/them. For every one of those respondents, we added to the lifetime of his/her phone the average extended life for the repairment of the faulty component they reported. When the malfunction of both components was the cause of replacement, we added the lesser average extended life of the battery repairment. Seventy-nine surveyed people were accounted on these circumstances. Comparing the GWP of the actual lifetimes of these smartphones to the one of the theorical lifetimes they could have had, a total of 588.25 kg CO_2e per year could have been avoided. If half a tonne of CO_2e per year can be saved through a different course of choices from 79 people (a 12% of our sample), are we aware how much more could be avoided at a population level only with a different kind of relationship with our devices?

4 Conclusions and future research

Along the discussion of this work we have seen how a change on new different kind of behaviours and habits can be a potential new path for diminishing the environmental impact of smartphones. This study has shown how easily, when faced with a component malfunction, consumers tend to replace their smartphone against the alternative of repairing them and what cost this has from a GWP perspective for the case of battery and/or display malfunctions. We have estimated an average lifetime for every component and an average extended lifetime for every phone repaired.

However, some improvements could be made to the model and scenarios in order to better comprehend reality, further explore different user circumstances, or expand it into another societies, such as:

- Analysing the GWP for the final transport of each component according to each smartphone brand and policy.
- Including replace/repair scenarios for every component.
- Including the extra lifetime of smartphones that find another use in developing countries.
- Evaluating at which point in a smartphone's life it is environmentally detrimental to repair the phone rather than replace it.
- Including the remaining impact categories of the environmental impact, as seen in the Xperia Z5 LCA.
- Considering pros/cons scenarios for a modular phone, since its gold coated connectors and additional board area increase environmental impact by 10% according to Proske et al. (2016).
- Learning more about the amount of time people coexist with malfunctions in order to postpone the need for repair or replace their phones or components.
- Developing a new measure of "extended life" from repairment that takes into account the age of the phone, since the oldest it is, the more likely it is to malfunction again in some way.

There is a huge margin of improvement for this study, but better-quality data and the gathering of data from a larger sample will be needed so as to provide a model closer to reality.

Understanding consumer's habits and perspectives should be a fundamental task for a sustainability agenda, for there lie many answers to environmental challenges. Competent legislation and manufacturer's responsible designing (whether they voluntarily agree to it or are compelled by the authorities) must exploit these opportunities in order to fulfil a global demand (and need) for a more sustainable world order.

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