Market Trends in Smartphone Design and Reliability Testing

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Abstract

Over the past decade, smartphones have become ubiquitous. Annual shipments have increased from 305 million units in 2010 to 1.37 billion units in 2019. This makes smartphones a highly relevant product group from a sustainability point of view. This paper firstly investigates market trends in smartphone design features over the past decade, both in terms of the evolution of technical specifications and design aspects that are relevant for material efficiency, particularly reparability and dismantlability. Secondly, reliability testing carried out by ICRT on 108 smartphone models are analysed. Both analysis combined provide a factual data base on which the development of the product group in present, past, and future, can be evaluated in the framework of a sustainable development.

1 Introduction

Over the past decade, smartphones have become ubiquitous. Annual global shipments have increased from 305 million units in 2010 to 1.37 billion units in 2019 [1]. This makes smartphones a highly relevant product group from a sustainability point of view. Reflecting this, the European Commission has launched a preparatory study to investigate the need and potential options for regularity measures under the Ecodesign Directive (2009/125/EC) in April of 2020.

A mounting number of studies investigates the environmental impact of smartphones, such as through life cycle assessment, and attempt to identify measures to mitigate environmental burdens. The consensus is that the majority of environmental impacts of smartphones is caused during the manufacturing stage, largely due to the energy intensive production processes associated with electronics [2].

Environmental impacts are influenced by many factors, a major aspect being hardware design. Therein, relevant questions are: How much RAM and flash memory are incorporated? Can the housing be opened for repairs? Is the battery user-replaceable? Is the smartphone protected from water and dust ingress? Does the device survive an accidental drop?

The first part of this paper analyses the evolution of technical specifications and major design trends that influence the environmental performance of smartphones over the past decade. Market data on the best-selling smartphones between 2010 and 2019 are complemented with specifications and design aspects to generate an array of diagrams that illustrate where this fast-evolving product group has moved towards.

In the second part of the paper, these design trends are linked to laboratory testing results from an international testing laboratory, investigating a range of reliability aspects such as ingress protection and resistance to mechanical abrasion and accidental drops.

Both analysis combined provide a factual data base on which the development of the product group in present, past, and future, can be evaluated in the framework of a sustainable development. The insights may be used to gain an understanding of the design of smartphones currently in use and in the urban mine. They may also serve to support the discussion around policy processes aiming to enhance the environmental performance of the product group smartphones.

This work is part of the H2020 project PROMPT, funded by the EU. The data and information described in this paper are partially based on a deliverable produced within the PROMPT project [3].

2 Methods

2.1 Market trends in smartphone design

The basis for the analysis of trends in smartphone design features is market data retrieved from Counterpoint Technology Market Research [4]. The data comprises sales volumes and market shares for the best-selling smartphone models in wider Europe (countries located in geographical Europe) for the years 2010 to 2019. The number of individual smartphone models and their share of the overall smartphone market varies for each year: 16 models are listed for 2010, 20 for 2011 and 2012, 22 for 2013, and 25 for the years 2014 to 2019, respectively. The total sales volume of

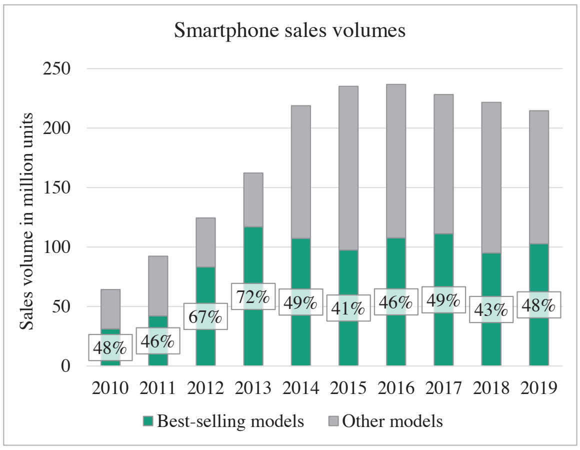

Figure 1: Sales volume of smartphones in wider Europe and market share of the smartphone models covered by the data from Counterpoint Technology Market Research [4]

smartphones and the market share covered by the listed models are illustrated in Figure 1.

The market data for listed smartphone models were complemented with technical specifications from a range of sources such as the GSM arena website [5]. To retrieve information on design and construction-related aspects of each phone model, a range of sources was consulted, including teardowns and repair instructions from iFixit [6].

2.2 Reliability testing of smartphones

Data was provided by the International Consumer Research & Testing (ICRT) within the framework of the Horizon 2020 PROMPT project for 108 smartphones from their 2018 testing programme [7]. The sample consists of low, middle and high-end devices. Several durability tests such as tumble tests, scratch tests (cover and camera) as well as rain (water spray) and water immersion (dive) tests were performed with all devices under test.

Durability against mechanical shocks (e.g. accidental drops) was tested with a tumbling barrel simulating a random fall from 80 cm height against a stone surface, as described in standard IEC 60068-2-31 [8]. For this test, devices are set in operational mode (e.g. active call), put into a tumbling drum for 50 and 100 drops and checked regularly. In case of damages during the test, the results are verified with a second and, if necessary, a third device.

Scratch hardness tests were performed to test how scratch-resistant displays and cameras are. The scratch resistance of the phones' displays and housing is commonly examined using a hardness test pencil (e.g. ERICHSEN, Model 318 S).

For the rain test, the devices were switched on and connected to a network. Following the standard IEC 60529 [9], a raining appliance provides an even rain distribution according to Ipx1 (7.2 l/h). The phones are placed horizontally on a turning table and are irrigated by the appliance for 5 minutes. The functions of the phone are checked directly after the test and several days after. When it comes to the immersion test, only those devices were tested that are certified to be ingress protected from water (at least IPX7) according to IEC 60529 [9]. Following this standard, the devices are submerged into a water tube at a defined maximum depth for 30 min. The correct functioning is checked directly after the test and several days later.

All tests results are reported on a five-point scale from 1 (poor) to 5 (very good).

3 Results and discussion

The results are presented in the following three subchapters, firstly on the evolution of technical specifications, secondly on the smartphone design features with relevancy to material efficiency, and thirdly on reliability testing results.

3.1 Market trends in technical specifications of smartphones

The development of technical specifications in the market is illustrated in a range of diagrams that comprise the market average among the best-selling smartphones for each year in addition to the minimum and maximum value to illustrate the variance of specifications in each year.

The average display size of smartphones, measured as the diagonal in inches, has roughly doubled over the past decade, from 3.2 in 2010 to 6 inches in 2019 (Figure 2). Among the best-selling smartphones in 2019, the largest display measured 6.7 and the smallest 4.7 inches.

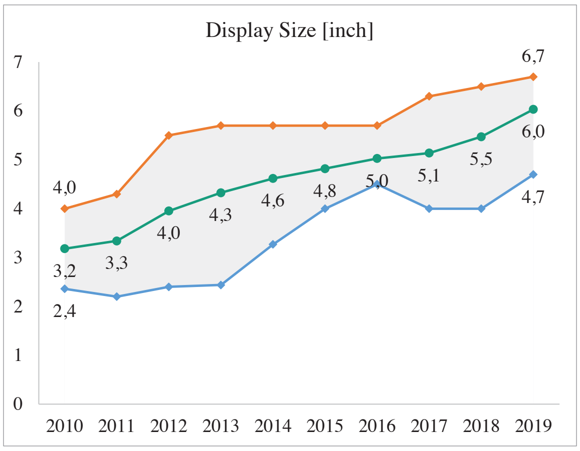

Figure 2: Increase in smartphone display size

The screen-to-body ratio signifies the area of the display relative to the front-facing area of the smartphone.

With increasing screen-to-body ratio, the bezels around the display becomes slimmer, with the display of some devices extending from one side to the other entirely.

The average screen-to-body ratio has been steadily increased over the last decade, from 46 % in 2010 to 81 % in 2019 (Figure 3). The extremes in 2019 among the best-selling smartphones were at 65 % and at 89 %.

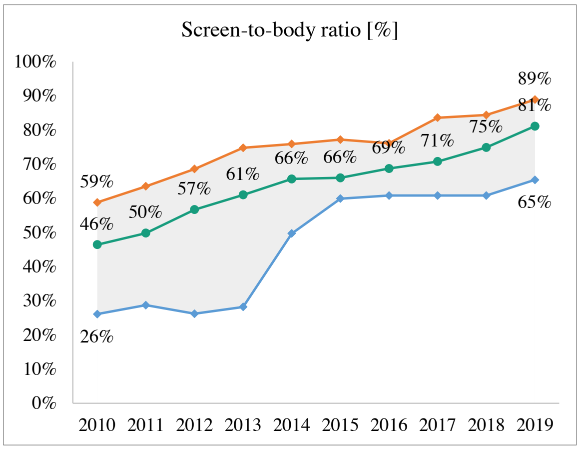

Figure 3: Increase in the screen-to-body ratio

Random access memory (RAM) is an essential component determining the performance of computing devices. The amount of RAM has been increased over time to match increasing performance requirements posed by operative systems and applications. Some smartphone models offer several configurations of RAM. In those cases, the largest available configuration was chosen for the analysis.

The average amount of RAM in the best-selling smartphones in Europe has increased sixteen-fold from 0.3 gigabytes (GB) in 2010 to 4.8 GB in 2019 (Figure 4). The phone model with the least amount of RAM features 2 GB, while the phone model with the highest configuration features 12 GB.

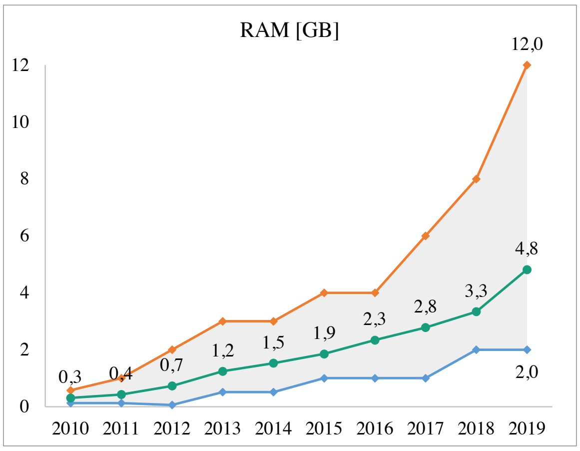

Figure 4: Increase in RAM in smartphones

Internal storage in smartphones is required to store the operating system, apps, and personal data such as photos and music. Commonly, flash memory integrated circuits are used for this purpose. The amount of storage space available has steadily increased over time to meet the need of users to store more and larger files. Some smartphone models offer several configurations of internal storage. In those cases, the largest available configuration was chosen for the analysis.

The average amount of internal storage in the best-selling smartphones has increased from 11 GB in 2010 to 248 GB in 2019. The phone model with the least amount of internal storage features 32 GB internal memory, while the model with the highest configuration features 1.000 GB or 1 terabyte (TB).

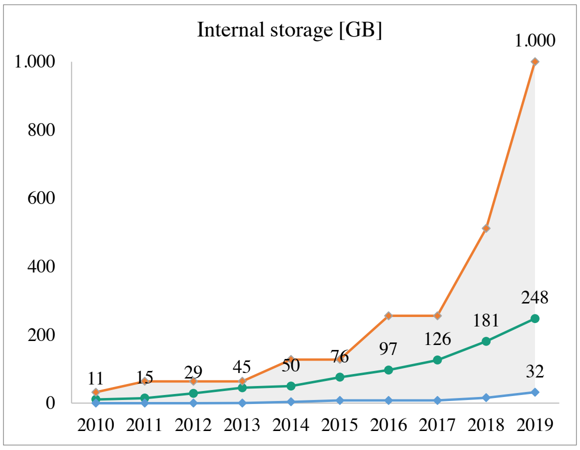

Figure 5: Increase in internal storage

Battery life is an essential parameter of personal mobile equipment. This, in addition to increasing computing power and display sizes, is a considerable driver to increase the battery capacity of smartphones.

The average battery capacity of smartphones, commonly specified in miliampere hours (a measure for electric charge), has increased from approximately 1.300 mAh to approximately 3.300 mAh within the last decade, effectively a 2.5-fold increase. Battery capacity is therefore the feature with the least growth within the last decade among assessed features.

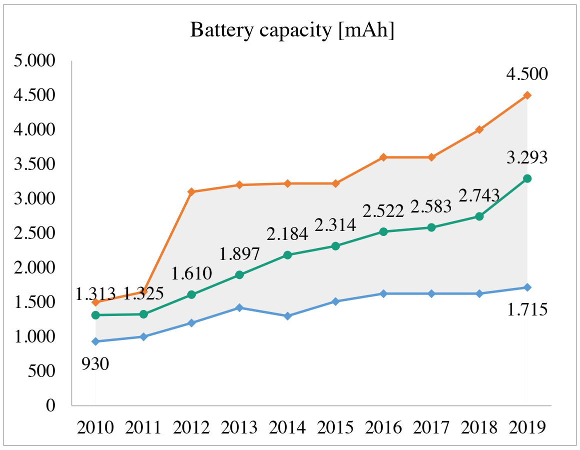

Figure 6: Increase in battery capacity

ISBN 978-3-8396-1659-8

3.2 Smartphone design features with relevance to material efficiency

One of the most controversial design trends in the product group smartphone in the past decade has been the shift from designs that allow users to easily remove and replace batteries to designs that integrate batteries into the device. This often goes along with sealed housing of the phones to enable elevated ingress protection (IP) from water and dust, commonly communicated by original equipment manufacturers (OEM) with an IP rating according to IEC 60529. Smartphone manufacturers have also increasingly moved from plastic housing to metal and glass housing, particularly in the high-end smartphone market. Glass has become particularly common in recent years, at least in part due to its favourable radio frequency characteristics and compatibility with wireless charging, the latter of which has also been a trend in recent years.

Figure 7 combines the market trend regarding all mentioned aspects. Among the most popular smartphones in Europe, the market share of devices with an embedded battery in the years 2010 to 2012 was between 18 and 33 %. The share of smartphones sold in Europe with an embedded battery then sharply increases every following year until reaching 100 % in the year 2019. This means that all of the 25 best-selling smartphones in Europe in 2019, covering around 48 % of the entire smartphone market in Europe, featured an embedded battery, not easily removable or replaceable without the use of tools and/or thermal energy.

The other design features illustrated in Figure 7, being glass back covers, IP ratings, and wireless charging, have co-developed over the past decade, all sharply increasing between the years 2015 and 2017/2018. There appears to be a reversal in the trend towards the year 2019. This can be explained by the relatively high market share gained by a group of mid-range phones from one of the market-leading OEMs that do not feature many of the designs shared by the phones in the high-end market, including glass back covers, IP ratings, and wireless charging.

Opening the housing is the first step in repair or dismantling, for instance for depollution before recycling. In the past decade, there have been two major design paradigms:

(1) the phone has a back cover that is to be separated in order to gain access to internal components, and

(2) the display unit is separated in order to gain access to internal components (“sandwich type”)

The first design commonly enables access to the battery immediately after removing the back cover. Further components are commonly only accessible after removal of a midframe. The display unit and logic boards are therefore commonly not immediately accessible. The second design paradigm provides access to the display unit as well as internal components, including PCBAs and battery, upon opening the sandwich-type housing.

The disassembly pathway for the best-selling smartphones in Europe has shifted in the last decade from predominantly featuring type (1) for approximately 90 % of phones entering the market between 2010 and 2012, while type (2) makes up approximately 50 % in the years 2015 to 2019. The year 2018 saw particularly high market share of phones based on the type (2) design.

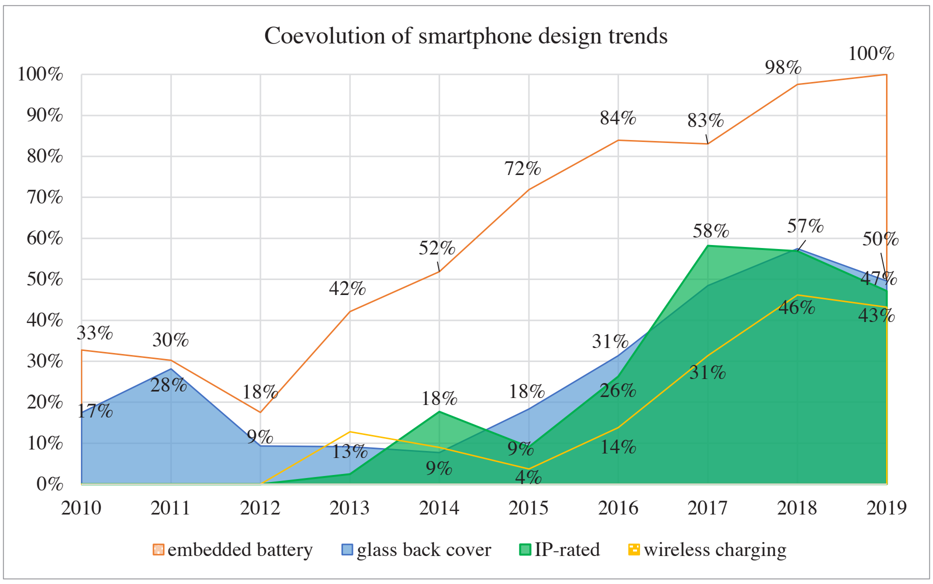

Figure 7: Development of the market share of smartphones featuring embedded batteries, glass housing, IP-rating and wireless charging over the last decade.

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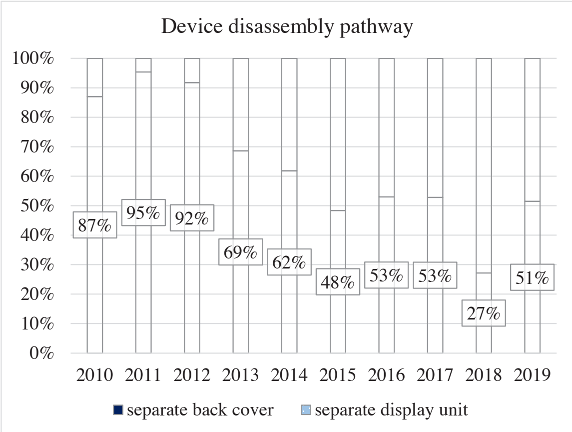

Figure 8: Market share of smartphones following different design paradigms affecting their disassembly pathway

Besides the disassembly pathway, the joining techniques applied to join the housing together are a considerable factor influencing the reparability and dismantlability of smartphones. Commonly used joining techniques for the housing are clips that require no tools to reversibly disconnect, snap-fits that do require tools for leverage, screws, adhesives, or a combination of screws and adhesives. Adhesives commonly require the application of thermal energy or chemical solvents to be dissolved.

The prevalence of joining techniques entering the European market among the best-selling smartphones is illustrated in Figure 9. While at the beginning of the decade, reversible joining techniques (clips, screws) were dominant; there was a shifts towards irreversible joining techniques over time. In 2019, close to 80 % of the most popular devices use adhesives to join the housing components. As mentioned previously, this may serve to enable designs that are more reliable in that ingress from water and dust can be prevented. On the other hand, the use of adhesives potentially complicates repairs that may be required to extend the lifetime of devices that have reached a limiting state, such as the failure of a component, a broken display, or a faded battery. The same can be assumed for recycling processes, in which operators need to quickly and safely remove batteries from electronic equipment.

Joining techniques were also analysed for batteries within smartphones, as these may also influence the process of battery replacement or depollution for recycling. While the market share of smartphones in which batteries were not fastened using adhesive was between 62 % and 85 % in the years 2010 to 2012, a trend towards using adhesives to fix the battery can be observed between the years 2013 and 2019 (Figure 10). In the year 2019, all batteries in the best-selling smartphones were fastened using adhesives. Of those, 52 % were fastened using pull tabs. Pull tabs are a specific design of double-sided adhesive tape that loses its adhesive properties when stretched. It has been argued that this design makes repair operations more user-friendly as opposed to adhesives that require thermal energy to be dissolved, however, a further evaluation is not in the scope of this paper.

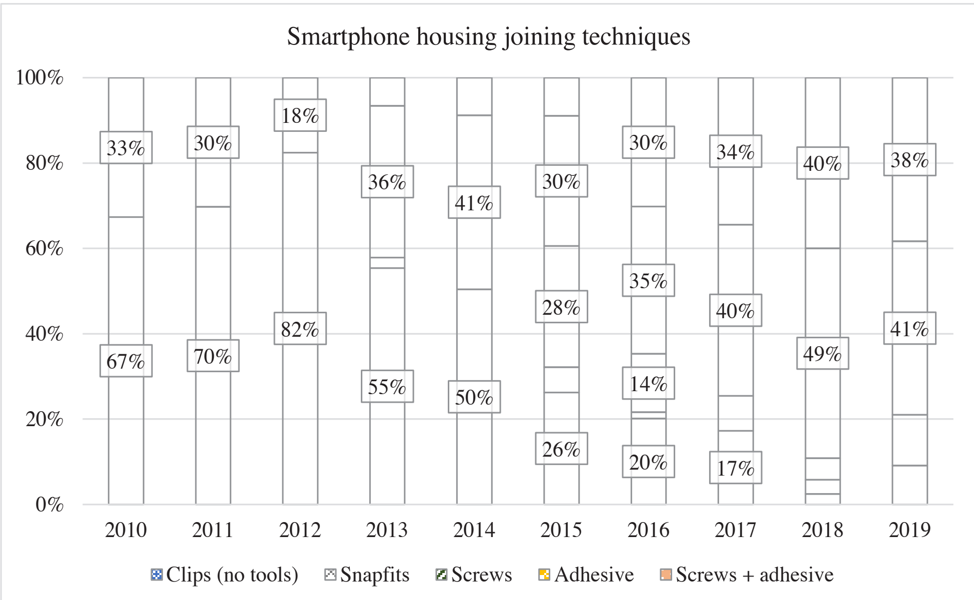

Figure 9: Evolution of smartphone housing techniques weighted by market share among the best-selling smartphones in Europe between 2010 and 2019.

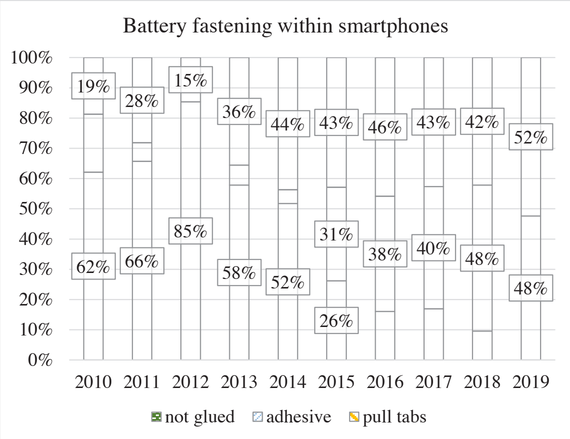

Figure 10: Evolution of joining techniques used to fasten batteries within smartphones

3.3 Smartphone reliability testing

Results of the tumble test (Figure 11) show that most of the devices had a good or very good test performance (82 %). 21 % of larger phones (> 6.2 in.) performed poorly after 100 drops from a height of 80 cm on a stone floor, as compared to 9 % of smaller phones (< 5.8 in.). "Poor" indicates that the phone is either no longer functioning or that display or housing are significantly damaged. However, these results do not necessarily proof that smaller devices are more likely to survive the tumble test, as other design features may also play a role (e.g. housing material).

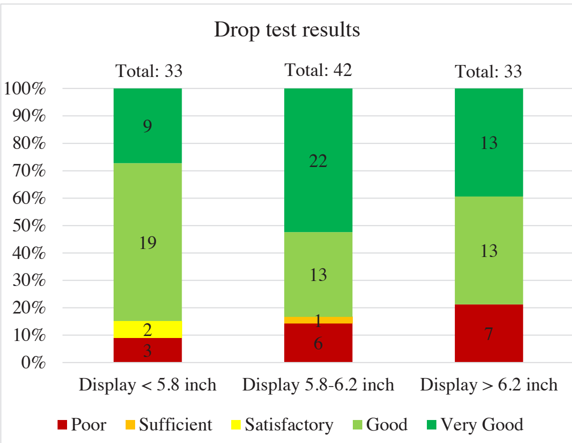

Figure 11: Results of drop tests (100 drops) for 108 phones, by size

When it comes to the cover scratch test (Figure 12), it can be observed that more expensive devices show a significantly better performance. While only 15 % of the devices below 240 EUR had a very good rating, the share was 95 % for the devices above 550 EUR.

The rain test was no problem for any of the devices and all of them performed good or very good, independent of price or battery removability (Figure 13).

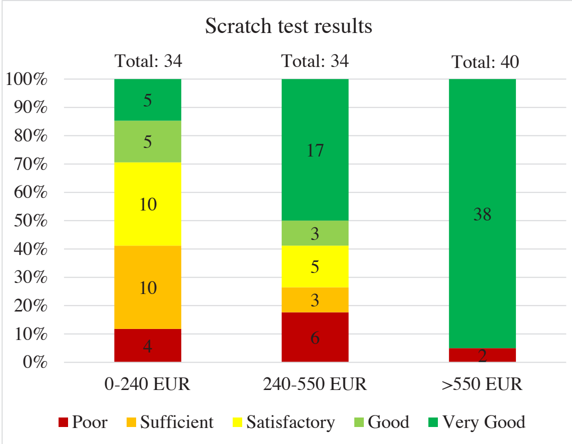

Figure 12: Results of cover scratch tests for 108 phones, by price range

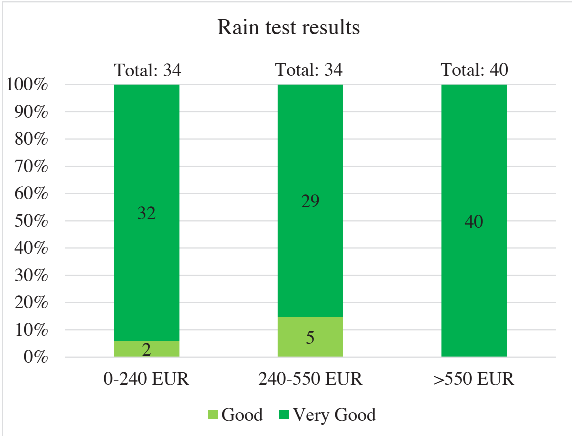

Figure 13: Results of rain tests for 108 phones, by price range

The immersion test was only applied to 32 of the 108 phones, since the others were not certified IPX7 according to EN 60529. All 32 phones featured embedded batteries and the large majority were in the higher price segment above 550 EUR. Only two phones performed poorly during the test, while the others showed either good or very good results (Figure 14).

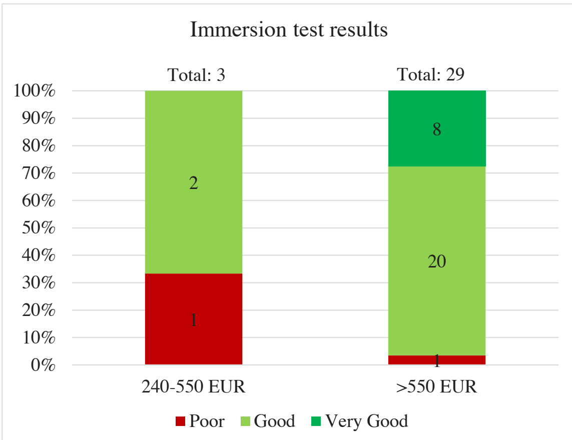

Figure 14: Results of immersion tests for 32 phones, by price range

4 Conclusions

In the first part of this paper, major market trends in technical specifications and material efficiency-related designs were analyzed based on market data covering the best-selling smartphones in Europe. Among technical specifications, the display size, screen-to-body ratio, and battery capacity have steadily increased over the past decade. It remains to be seen whether this increase will continue in the coming years. Assumedly, new designs, such as the emerging foldable phones, may disrupt or accelerate some of these trends. Foldable phones in particular may drastically increase the display size, and therefore also require higher battery capacity, featuring two-cell battery designs. At this point in time it is not yet clear whether foldable phones will remain a niche product or will be able to capture a relevant market share in the future. The amount of available RAM and flash memory appear to have been increasing almost exponentially over the past ten years. Questions remain to which degree Moore's law and advanced heterogenic packaging solutions can continue to support this trend, or whether a slowing down of the increase may be expected in this aspect as well.

For design trends impacting material efficiency, major shifts have taken place over the past decade. In 2019, none of the most popular phones had a user-replaceable battery, and the vast majority was sealed using adhesives. At the same time, the market share of devices with ingress protection rose sharply, to almost 50 % of the market in 2019. Therefore, it may be deducted that the market appears to favor more reliable over more reparable designs. One question in this regard is how well the electronics recycling sector will be able to handle the expected enormous numbers of end-of-life smartphones to be dismantled in the coming years featuring such designs.

Throughout the paper it has been made clear that the data only covers the best-selling devices in Europe, covering a share of the total smartphone market between 41 and 72 %, depending on the year. The "rest of the market" could not be covered due to absence of data, but it is assumed that a major share of devices not covered can be categorized as mid-range and low-end devices, that do not necessarily share all design features assessed in this work. For instance, plastic tends to be a cheaper material compared to metal or glass for the housing parts. Lower amounts of RAM and flash memory, as well as smaller battery capacity, may also be assumed. Similarly, IP-ratings and wireless charging may less frequently be encountered. No information on the accessibility of the battery in this market sector was retrieved for comparison. However, to provide an indication, from the 108 smartphones subjected reliability test by ICRT in their 2018 testing program, featuring devices from all market segments, only 5 featured a user-replaceable battery, while 103 featured embedded batteries.

The test data shows that nowadays most smartphones perform well during rain or scratch tests, irrespective of their price range. While most phones pass tumble drop tests well, larger phones tend to fail this test more frequently. The data further suggests that smartphones with embedded batteries do not perform significantly better than devices with replaceable batteries. The more expensive phones are more likely to pass the immersion test.

Smartphones will likely remain a ubiquitous communication tool for billions of people worldwide. The potential impacts of market trends need to be carefully considered by manufacturers, consumers, and policymakers, in order to steer towards a sustainable development.

5 Acknowledgements

This project has received funding from the European Union´s Horizon 2020 research and innovation programme under grant agreement no. 820331.

We want to thank ICRT for kindly providing data from their smartphone testing program, and Counterpoint Research for approval to publish part of their data.

6 Literature

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