PROMPT

Premature Obsolescence Multi-Stakeholder Product Testing Program

Project Duration:	**01/05/2019 - 30/04/2023**
Deliverable No.:	**2.5**
Deliverable Title:	**Environmental evaluation of current and future design rules**
Version Number:	**1**
Due Date for Deliverable:	**30/04/2020**
Actual Submission date:	**29/04/2020**
Lead Beneficiary:	**Fraunhofer**
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Deliverable Type:	R

R = Document, report

DEM = Demonstrator, pilot, prototype, plan designs

DEC = Websites, patent filing, press & media actions, videos, etc.

Dissemination Level: PU

PU = Public

CO = Confidential, only for members of the consortium, incl. the Commission Services

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Disclaimer

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

Content

1 Glossary

Abbreviation	Definition
CAGR	Compound Annual Growth Rate
CIS	Contact Image Sensor
CO_2	Carbon Dioxide
CRT	Cathode Ray Tube
EPS	Electronic Power Supply
EU	European Union
EUR	Euro
FBI	Federal Bureau of Investigation
FHE	Flexible Hybrid Electronics
GHG	Greenhouse Gas
GWP	Global Warming Potential
HD	High-Definition
IC	Integrated Circuit
ICT	Information and Communication Technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IoT	Internet of Things
IPTV	Internet Protocol Television
JRC	Joint Research Centre
LCA	Life Cycle Analysis
LCAI	Life Cycle Impact Assessment
LCD	Liquid-Crystal Display
LCI	Life Cycle Inventory
LIB	Lithium-Ion battery
LLCC	Least Life Cycle Cost
LTE	Long Term Evolution
MCI	Material Circularity Indicators
MEErP	Methodology for Energy-Related Products
MIL-STD	Military Standard
MP3	Moving Picture Expert Group 1.0 Layer 3
OEM	Original Equipment Manufacturer
OLED	Organic Light Emitting Diode
PCB	Printed Circuit Board
POP	Persistent Organic Pollutant
PROMPT	Premature Obsolescence Multi-stakeholder Product Testing Programme
PSU	Power Supply Unit
QLED	Quantum Dot Light Emitting Diode
RoHS	Restriction of Hazardous Substances
SDG	Sustainable Development Goals
SIM	Subscriber Identity Module
SoH	State of Health
TV	Television
UK	United Kingdom
US	United States
USB	Universal Serial Bus
VC	Vacuum Cleaner
VOD	Video On Demand
WEEE	Waste Electrical and Electronic Equipment
Wi-Fi	Wireless Fidelity

2 Executive summary

In the last 30 years, resource extraction has tripled and the consumption of metal ores, rare earth metals and critical raw materials keeps on rising (IRP 2019). This trend not only leads to ecological disturbances and the pollution of air, water and land, it has also a significant impact on global warming. Around 45% of emissions come from how products are made and used, and how food is produced (EMF 2019).

The production of electrical and electronic equipment (EEE) requires a significant amount of resources. Furthermore, complex challenges arise at the products' end of life (EC WEEE). European policy is tackling these challenges through a broad variety of regulations, measures and actions. A major focus of the second EU Circular Economy Action Plan is on aspects related to the design and production of goods, aiming to ensure that resources are kept in the EU economy for as long as possible (EC 2020).

The main objective of the PROMPT project is to develop an independent testing programme to assess the lifetime of selected EEE. For this purpose, it is important to analyse current and future design trends and to evaluate the possible impact of a lifetime extension from an environmental point of view.

This report has three main objectives. First, it identifies current and future design trends for selected product groups and discusses possible environmental impacts. Second, it shows a comparison of different existing life cycle analyses (LCA) to identify hot spots that are most relevant from an environmental point of view, with a focus on resource efficiency and possible lifetime extension. Third, it analyses environmental break-even points identified in the literature and discusses the advantages of possible lifetime extensions. The analysis is structured by the product groups covered in PROMPT, which are mobile phones (smartphones), televisions, washing machines and vacuum cleaners.

Mobile phones are considered to be fast-moving consumer electronics with a current average lifetime of 2-4 years. Recent smartphones tend to have larger screens, glass back covers and multiple cameras. Some companies recently released devices with foldable OLED displays. Battery lifetime is considered to be one of the main barriers when it comes to a long lifetime of the device. All analysed lifecycle assessments (LCA) show that the electronic components cause the main environmental impact. Since the main impact is related to product manufacturing, extending the use time has a high potential to reduce the overall environmental impact (Proske M. et al. 2016).

Television technology has undergone tremendous change in the past twenty years, moving mainly from CRT to LCD devices. Flexible OLED solutions are also gaining in popularity, but are still relatively expensive. On average, devices are used for 5-10 years. Most of the analysed LCA suggest that the main environmental impact is generated during the use phase and linked to electricity consumption. However, research suggests that a lifetime over 10 years can be beneficial from an environmental point of view. Although new televisions usually come with improved energy efficiency, it was shown that shorter-lived devices perform worse for all environmental indicators (Prakash S. et al. 2016).

Washing machines are investment goods or "workhorse" goods that are available in most of the households and used several times a week. The average lifetime of a washing machine is between 8-12 years in the EU. All analysed LCA suggest, that the use-phase is the dominant life cycle phase from an environmental point of view. However, different research showed that a lifetime extension beyond 12.5 years has a positive environmental impact on numerous environmental indicators (Tecchio P. et al. 2016) and that a long-life washing machine (20 years) has a lower environmental impact on all impact categories than an average washing machine (10 years) and a short-life washing machine (5 years). (Prakash S. et al. 2016).

Vacuum cleaners can be very diverse in design (canister, cordless, robot, etc.) and it can be observed that autonomous and battery-driven devices are gaining in popularity. While the average lifespan of canister vacuum cleaners is estimated at 6-10 years, battery-driven devices usually reach the end of their useful life much earlier (Viegand Maagøe A/S 2019). Most LCA suggest that the use-phase is the dominant life cycle stage from an environmental point of view, driven by electricity consumption. However, research has shown that the lifetime extension of conventional vacuum cleaners up to 800 hours motor lifetime can have environmental benefits (Bobba et al. 2015). Furthermore, battery-powered devices have a relatively high footprint in the production phase, for which reason a longer lifetime would also be beneficial from an environmental point of view.

3 Motivation and objectives

Global living standards increased significantly in the last decades and technological development has helped lifting many people out of poverty. However, this positive trend was also accompanied by an increased demand for natural resources. In the last 30 years, resource extraction has tripled (Figure 1) and the consumption of metal ores, rare earth metals and critical raw materials keeps on rising (IRP 2019). This trend not only leads to ecological disturbances, destruction of natural flora and fauna and the pollution of air, water and land, it has also a significant impact on global warming. A recent study (EMF 2019) shows that around 45% of emissions come from how products are made and used, and how food is produced (Figure 2).

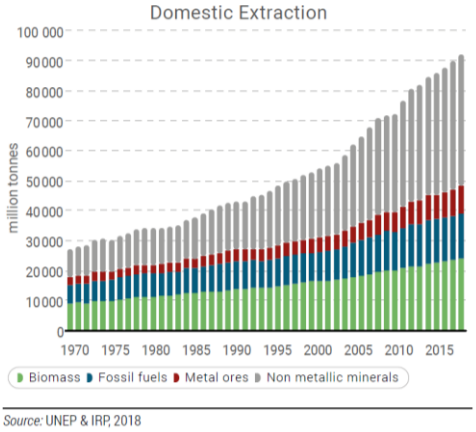

Figure 1: Global domestic extraction

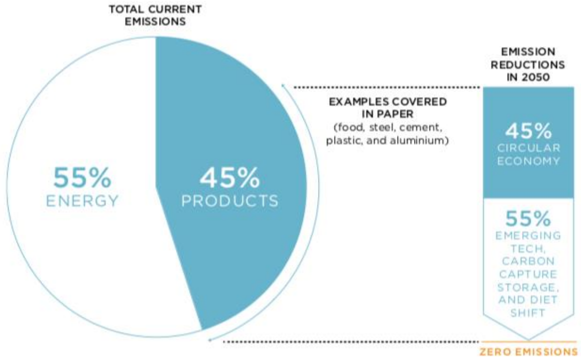

Figure 2: Share of total current emission from energy and products

The production of electrical and electronic equipment (EEE) not only requires a significant amount of resources, but also leads to the question what should be done with the equipment, once it reaches the end of its useful life. In Europe, the yearly waste stream related to electrical and electronic equipment (WEEE) is estimated at around 12 million tons (EC WEEE), growing at around 2% every year (EC 2020).

As one of the main building blocks of the European Green Deal, the European Commission adopted a new Circular Economy Action Plan, which strives to promote a more efficient use of resources, the transition towards a circular economy and the recreation of biodiversity. A major focus lies on the design and production of goods, aiming to ensure that resources are kept in the EU economy for as long as possible (EC 2020).

Since sustainability starts with design, one of the main objectives of the PROMPT project is to look at current and future design trends of electrical and electronic equipment and to evaluate their possible impact on the environment. Driven by ongoing trends towards miniaturisation and connected devices, a major focus lies on resource efficiency and in particular on a possible lifetime extension of devices through more robust and repairable design.

This report has three main objectives. First, in the context of the global market situation it identifies current and future design trends for selected product groups and discusses their environmental impact. Second, it shows a comparison of different existing life cycle analyses (LCA) in order to identify hot spots that are most relevant from an environmental point of view, with a focus on resource efficiency and possible lifetime extension. Third, it analyses environmental break-even points identified in literature and discusses the advantage of possible lifetime extension.

4 Current and future design trends

The product scope for the report are the product groups studied in PROMPT: mobile phones (with a focus on smartphones), televisions (TVs), washing machines and vacuum cleaners. Following the increased connectivity of these devices they will be analysed in the context of the smart home. The following subchapter provides definitions of these product groups.

4.1 Definitions of the product groups

4.1.1 Mobile Phone

Table 1: Key definitions for mobile phone

Reference	Scope	Definition
RAL-UZ 106 (2017) - Blue Angel Eco-Label for Mobile Phones (Blue Angel 2017)	Mobile phone	Portable, cordless phones that transmit telephone calls via mobile phone networks. The mobile phone is equipped with a module (SIM card) which allows the identification of the individual subscriber. In addition to the telephony function the mobile phone can provide several other functions, such as, for example, transmission of text messages, mobile use of Internet services, execution of programmes or recording and replay of video and audio signals. Mobile phones are also called cellular phone, cell phone, or smartphone - and many Germans call their mobile phone "handy".
UL Standard 110, Edition 2 - Standard for Sustainability for Mobile Phones (UL 2017)	Mobile phone	A wireless handheld device that is designed to send and receive transmissions through a cellular radiotelephone service including only the device itself and not packaging or accessories. Slates/tablets, as defined in the most recent applicable version of Energy Star specification, are excluded from this definition.
TÜV Rheinland, 2 PfG E 2073:07.2018, Criteria for the award of Green Product Mark Mobile Phones (TÜV Rheinland 2018)	Mobile phone	A wireless handheld device that is designed to send and receive transmissions through a cellular radiotelephone service including only the device itself and not packaging or accessories.
TCO Certified Smartphones 2.0 (TCO 2015)	Smartphone (display sizes ≥ 3" to ≤ 6")	A Smartphone is an electronic device used for long-range communication over a cellular network of specialized base stations known as cell sites. It must also have functionality similar to a wireless, portable computer that is primarily for battery mode usage and has a touch screen interface. Connection to mains via an external power supply is considered to be mainly for battery charging purposes and an onscreen virtual keyboard or a digital pen is in place of a physical keyboard.

4.1.2 Television

Table 2: Key definitions for television

Reference	Scope	Definition
Commission regulation laying down ecodesign requirements for electronic displays (EC 2019b)	Television	Electronic display designed primarily for the display and reception of audiovisual signals and which consists of an electronic display and one or more tuners/receivers.
	Electronic display	A display screen and associated electronics that, as its primary function, displays visual information from wired or wireless sources.
IEEE Standard for Environmental Assessment of Televisions (IEEE 2012)	Television	A commercially available electronic product designed primarily for the reception and display of audiovisual signals received from terrestrial, cable, satellite, Internet Protocol TV (IPTV), or other digital or analog sources. A TV consists of a tuner/receiver and a display encased in a single enclosure. The product usually relies upon a cathode-ray tube (CRT), liquid crystal display (LCD), plasma display, or other display technology.

4.1.3 Washing machine

Table 3: Key definitions for washing machine

Reference	Scope	Definition
Commission regulation laying down ecodesign requirements for household washing machines and household washer-dryers (EC 2019a)	Household washing machine	Automatic washing machine which cleans and rinses household laundry by using water, chemical, mechanical and thermal means, which also has a spin extraction function, and which is declared by the manufacturer in the Declaration of Conformity as complying with Directive 2014/35/EU of the European Parliament and of the Council or with Directive 2014/53/EU of the European Parliament and of the Council;
IEC 60456:2010 (IEC 2010)	Washing machine	Appliance for cleaning and rinsing of textiles using water which may also have a means of extracting excess water from the textiles.

4.1.4 Vacuum cleaner

Table 4: Key definitions for vacuum cleaner

Reference	Scope	Definition
Commission regulation laying down ecodesign requirements for vacuum cleaners (EC 2013)	Vacuum cleaner	An appliance that removes soil from a surface to be cleaned by means of an airflow created by underpressure developed within the unit.
	Robot vacuum cleaner	A battery operated vacuum cleaner that is capable of operating without human intervention within a defined perimeter, consisting of a mobile part and a docking station and/or other accessories to assist its operation.
	Hybrid vacuum cleaner	A vacuum cleaner that can be powered by both electric mains and batteries.
	Battery operated vacuum cleaner	A vacuum cleaner powered only by batteries.
	Cordless vacuum cleaner	A vacuum cleaner powered only by batteries, other than a handheld vacuum cleaner
	Handheld vacuum cleaner	A lightweight cordless vacuum cleaner with cleaning head, dirt storage and vacuum generator integrated in a compact housing, allowing the cleaner to held and operated whilst being held in one hand.

4.2 Overview of markets and end users

4.2.1 Overview of markets and trends

4.2.1.1 Mobile phones (smartphones)

The first smartphones already existed in the late 1990s, but it was with the introduction of the iPhone in 2007 that they gained significant market share (Statista 2020c). Figure 3 illustrates the number of smartphones sold to end users worldwide from 2007 to 2020. During the first years, a rapid growth in shipments could be observed and in 2014 sales multiplied tenfold as compared to 2007. Since 2015, sales have remained relatively constant at 1.5 bn annually. In 2019, with around 3.2bn users, 31% of the world's population owned a smartphone (Figure 4, (Newzoo 2019)). Around 600 million users are located in Europe (incl. Western and Eastern Europe).

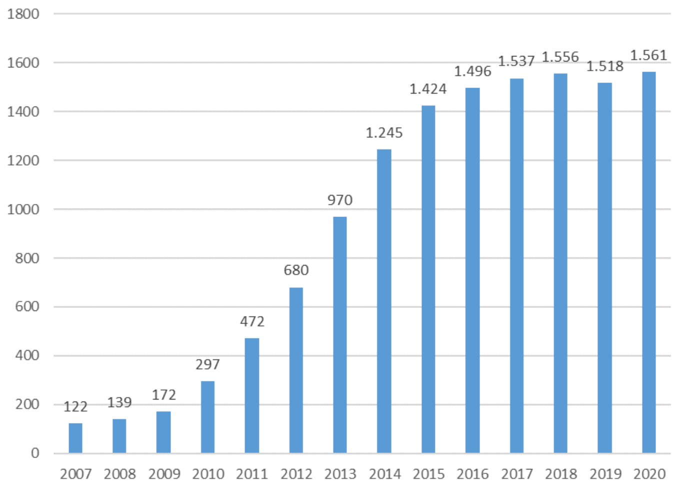

Figure 3: Number of smartphones sold to end users worldwide from 2007 to 2020

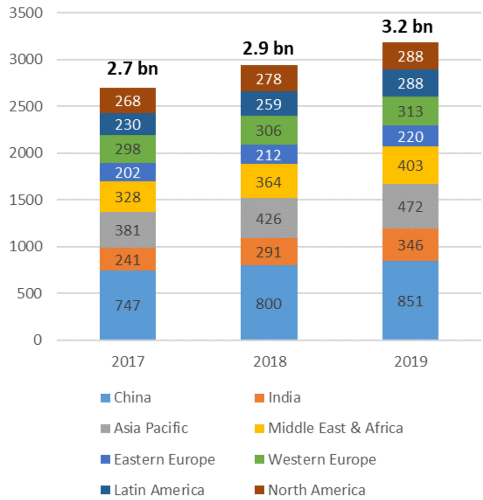

Figure 4: Smart phone user by region

The market of smartphones is relatively concentrated with three main brands (Samsung, Huawei and Apple) being responsible for more than 50% of total shipments by the end of 2019 (Figure 5, (Statista 2019b)).

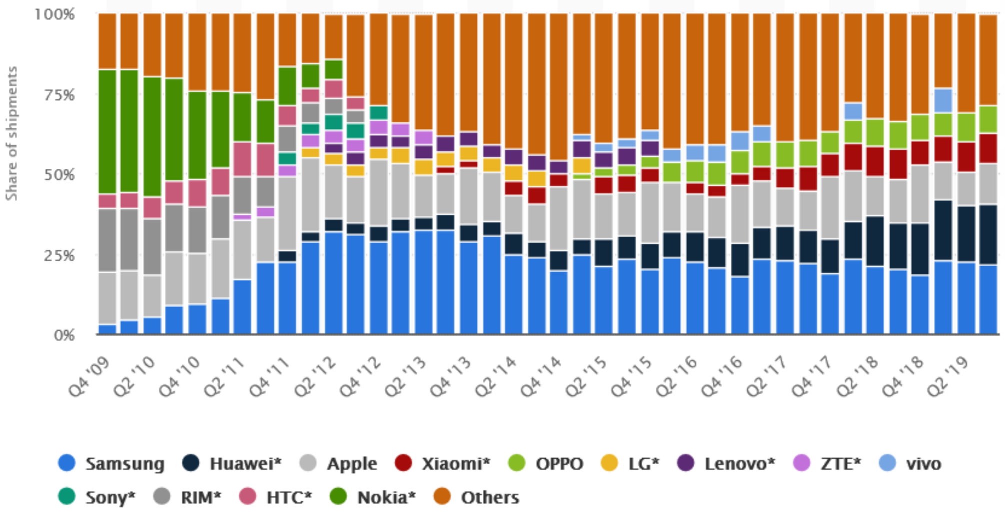

Figure 5: Global market share held by leading smartphone

When it comes to operating systems, the concentration is even higher with Android clearly dominating the market with more than 75% of market share within global sales to end users, followed by iOS (Figure 6, (Statista 2017b)).

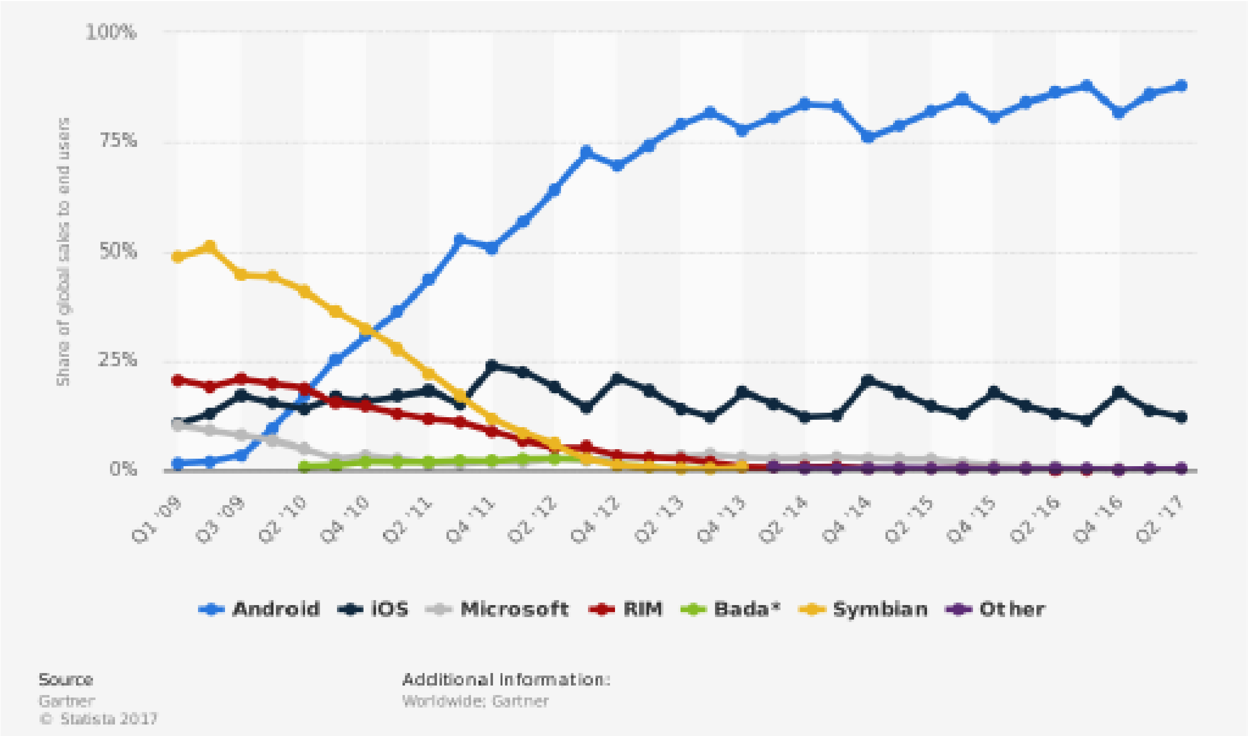

Figure 6: Global market share held by the leading smartphone operating systems in sales to end users

Figure 7 shows that average selling price of smartphones worldwide decreased by 40% from 440 USD in 2010 to 283 USD in 2016 (Statista 2017a). This trend is in particular linked to a larger variety of smartphones available on the market ranging from cheaper versions (USD <200) to flagship phones (USD >1000).

In general, smartphones are designed to have more and more functions and apps. Devices become thinner but eventually have bigger displays and less frames. Many devices have an integrated fingerprint sensor in the display and the first smart phones using the new, ultra-fast radio standard (5G) are on their way.

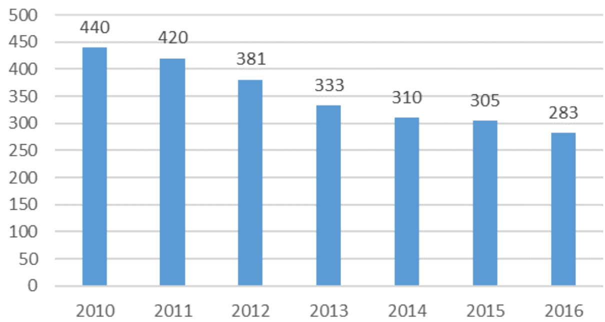

Figure 7: Average selling price of smartphones worldwide from 2010 to 2016 (in USD)

Today, it is not necessary to have a camera, a navigation system or a MP3-player, since smart phones integrate all of these functions. Due to the substitution of many single devices, material savings can be seen as a positive impact on the environment. On the other hand, smartphones have relatively short service lives due to a more complex, finer structure and the difficulty in repairing it.

The following subchapters summarise some of the main design trends currently observed on the market.

4.2.1.1.1 Design for disassembly

Over the past decade, there appears to have been a shift in terms of the design strategy with respect to the disassemblability of devices. While the ability of the user to easily access and replace the device battery was a given for most smartphone manufacturers and models in 2010, this design aspect has gradually disappeared in favour of designs that utilize adhesives to seal the exterior case in order to facilitate ingress protection from water and dust. This aspect is illustrated in Figure 8. Market data of the best-selling smartphones in Europe between the years 2010 and 2019 have been complemented with data on joining techniques applied to the devices external housing for this illustration. It is to be noted that the underlying market data cover up to 25 best-selling devices in each year. The data therefore covers between 41 % and 72 % of the overall European market and generally includes the high-end "flagship" models of the most popular manufacturers, in addition to particularly popular medium-range and low-end devices (market coverage for each year is denoted on top of the data columns in the diagram). The diagram clearly shows that joining techniques that are generally considered to be reversible (clips, snapfits, screws) have largely been displaced with adhesives in 2019. It can be assumed that this design trend may have negative implications for repair and recycling of smartphones, however, it may be beneficial for the robustness of phones at the same time (e.g. ingress protection).

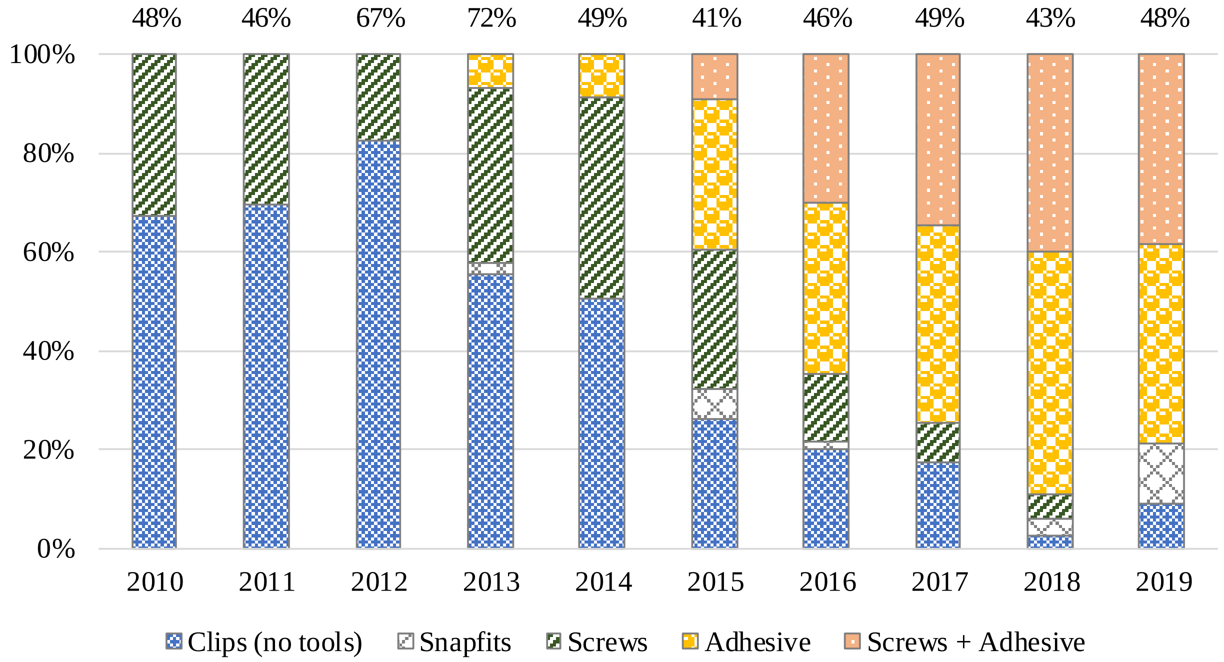

Figure 8: Evolution of smartphone case joining techniques applied to the best-selling smartphones in Europe (based on market data from Counterpoint Research; market coverage denoted on top of data columns).

Additional investigations into the evolution of the disassemblability of smartphones showed that batteries used to be easily removable from smartphones in 2010, while batteries in 2019 are mostly, if not exclusively, joined into smartphones using adhesives (Figure 9). Again, it can be assumed that this practice may have negative implications for repair and recycling of smartphones. However, it also may be beneficial for the robustness of phones as the batteries are firmly held in place and thereby possibly better protected from shocks and vibration. The diagram distinguishes between general adhesive (e.g. liquid adhesives; double-sided tape) and pull tabs, the latter of which are a type of double-sided tape that loses its adhesive properties when mechanically stretched, thereby facilitating the removal of batteries from phones without the use of thermal energy or chemical solvents.

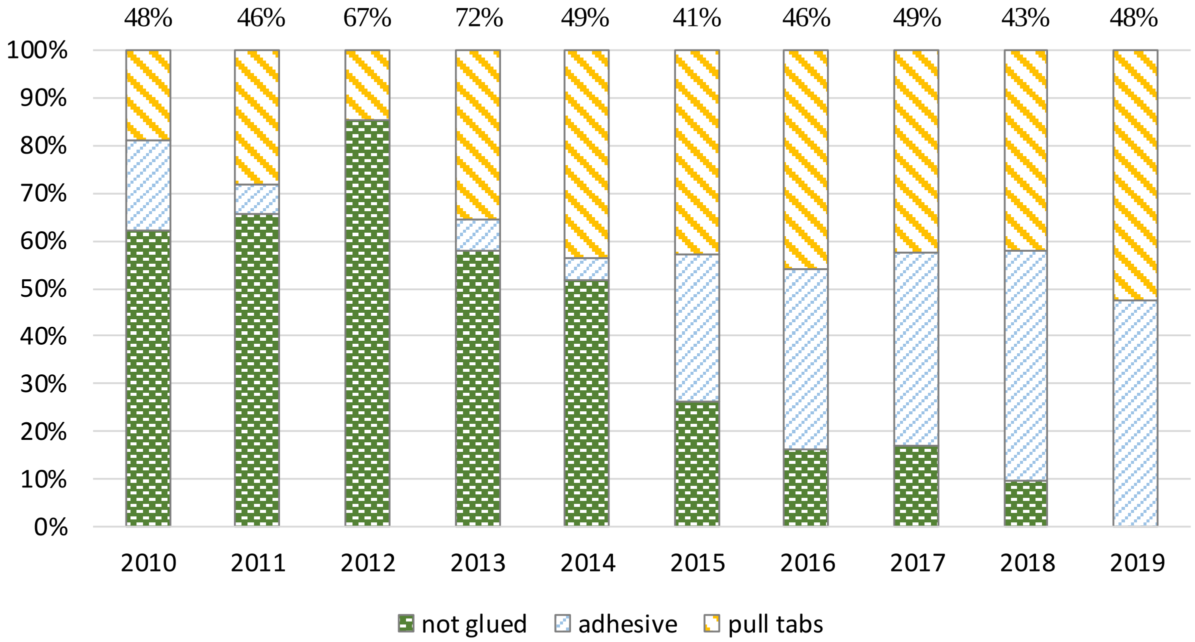

Figure 9: Trend towards the use of adhesives to fix the battery within smartphones among the best-selling smartphones in Europe (based on market data from Counterpoint Research; market coverage denoted on top of data columns).

Indeed, an apparent correlation can be observed when the market share of smartphones with embedded battery and phones with IP rating (water and dust ingress protection) are plotted over time (Figure 10). It can be assumed that the practice of embedding batteries in phones and sealing the external housing with adhesives enabled more phone models to successfully be rated for various levels of ingress protection (commonly IP67 or IP68).

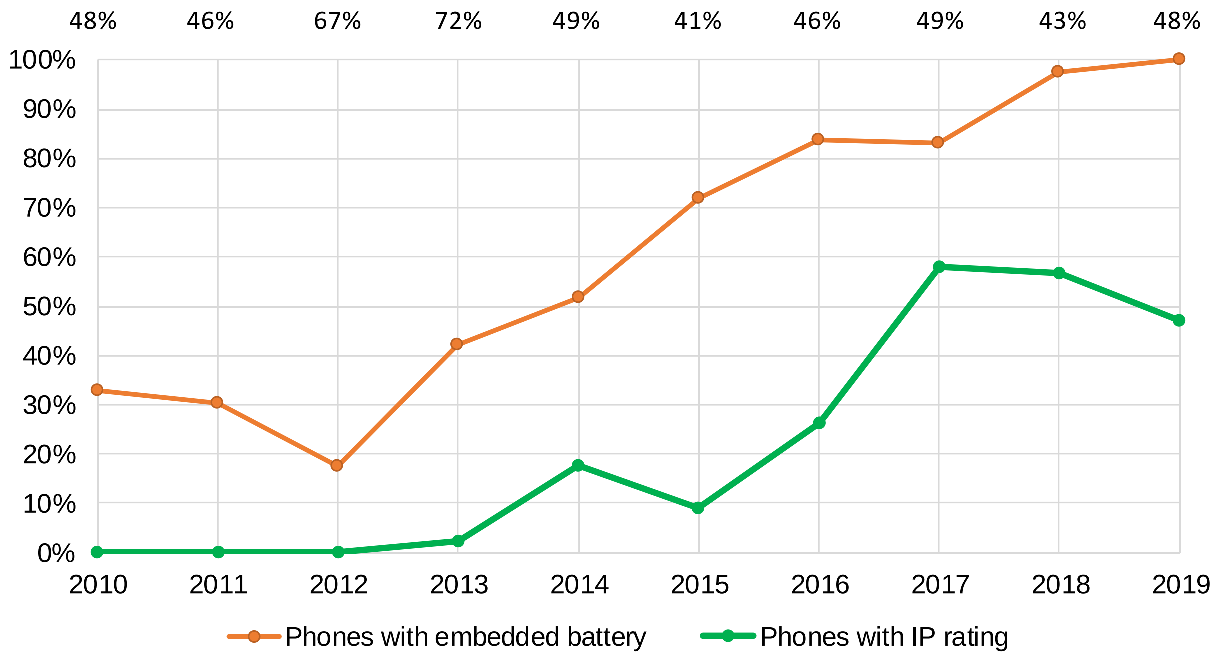

Figure 10: Market share of smartphones with embedded battery and smartphones with IP rating (based on market data from Counterpoint Research; market coverage denoted on top of the diagram).

4.2.1.1.2 Glass back

Since the iPhone 4, more and more smartphones not only have glass screens, but also glass on the back. The market penetration of smartphones with a glass back is expected to increase from 26 % in 2018 to 60% in 2020 (Counterpoint 2018). The main brand names are Gorilla, Sapphire and Dragontrail. Glass has several advantages: It is aesthetically appealing, relatively scratch-resistant, it ensures better signal reception (Wi-Fi, LTE, Bluetooth) and it can be used with wireless charging. The main disadvantage is the inherent fragility of the material. For this reason, it is usually chemically strengthened through an ion-exchange process, resulting in glass that is more resistant to damage. According to Corning, smartphones with Gorilla Glass 6 are able to survive at least 15 drops on a rough surfaces from a height of one metre (Corning 2018). However, repair statistics show that more than two thirds of all damaged smartphones have a display damage and every second damage also comes with a casing damage (clickrepair 2019), likely due to broken glass in both cases. Replacing screens or back covers comes at high costs for consumers. Apple charges up to USD 399 to replace the iPhone 11 glass back without AppleCare+ and USD 199 for the front screen (Apple 2020b). Samsung charges $99 for the back cover and $248 for a front screen repair for a Galaxy S10 device (Samsung 2020b).

Research into the market share of smartphones with glass back cover confirmed this trend between 2010 and 2017, after which the market share of devices with glass back cover appears to decline. One explanation to this trend may be that in 2018 and 2019, a number of mid-range devices with a plastic back cover rather than glass gained a high market share (glass being considered a “premium” material, mostly applied to flagship models).

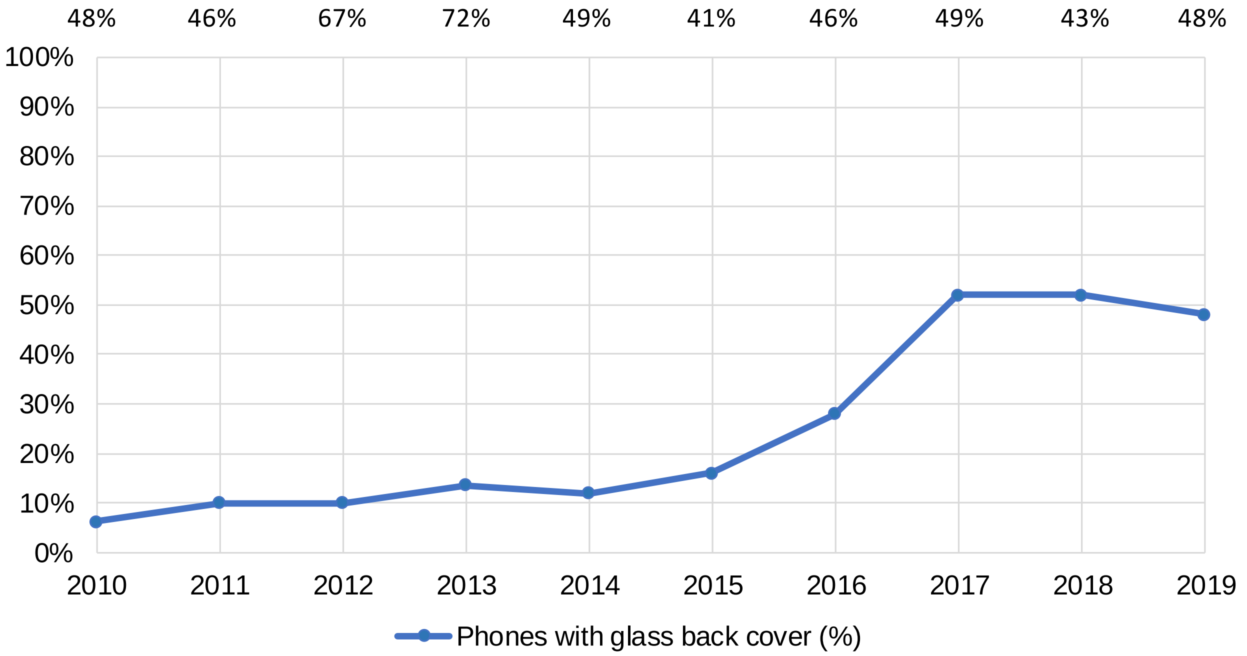

Figure 11: Market share of smartphones with a glass back cover (based on market data from Counterpoint Research; market coverage denoted on top of the diagram).

4.2.1.1.3 Foldables

The technology field of Flexible Hybrid Electronics (FHE) became an established term in the last years defining electronic systems that can bend, stretch and fold while preserving the operational integrity of traditional electronics architectures (Source: iNEMI 2019 Roadmap – Flexible Hybrid Electronics). FHE keep rapidly evolving in different application areas such as wearables, lighting systems and also display modules (e.g. with smartphones). The major smartphone producers have been using in particular OLED technology for displays and companies such as Samsung, Lenovo, Royale, LG or JOLED have demonstrated foldable OLED displays. As an example, the following Figures show the Motorola Razr and the Galaxy Z Flip, two clam-shell foldable smartphones, entered the market in 2020.

Figure 12: Motorola Razr (Motorola 2020)

Figure 13: Samsung Galaxy Z Flip (Samsung 2020a)

The durability of foldable screens has at this point not been comprehensively assessed in published literature. However, concerns exist regarding the longevity of the flexible panels, the hinges, and the material covering the screen to protect it from environmental impacts. Foldable devices usually come with two non-replaceable batteries and the displays are less scratch-resistant than most of the established non-foldable phones with a strengthened glass screen. Regarding the implications of foldable phones on reparability, iFixit recently called the Motorola Razr the “most complicated phone-based contraption we've ever taken apart” (iFixit 2020) and it received the low reparability score of 1/10. Similarly, the Galaxy Z Fold has received an iFixit reparability score of 2/10 (iFixit 2019). Furthermore, scratch tests of the displays performed on the internet show damages at relatively low levels, which does not happen to strengthened glass (Nelson 2020). First tests conducted by consumer organisations show that while the hinge withstands more than 30,000 opening / closing cycles, it performs less good during the drop tests (UFC QC 2020). Other models with weaker screens include Xiaomi with the Mi Note 10 Pro and Alcatel with the 1S 2020 model.

4.2.1.1.4 Mobile phone chargers

Today, charging cables are most of the time detachable from the external power supply (EPS) and most smartphones on the market use technologies based on USB specifications and standards. USB Type-C connectors are likely to replace older USB connectors within the next years for most Android OS smartphones (>75 % of the market). Whether proprietary solutions (e.g. Lightning by Apple) will remain on the market in the long run will mainly depend on regulation. The 2019 impact assessment study on common chargers of portable devices for DG GROW concluded that there is no clear-cut “optimal” solution (EC 2019d). However, the study also states that the most effective approach to improve consumer convenience would be to pursue common connectors in combination with interoperable EPS. This option could also be beneficial from a resource efficiency point of view, since it could increase interoperability between different devices and reduce the need to have multiple chargers. Interoperable chargers and charging cable form factors may further have the potential to eliminate the need to provide a separate charger with each new phone purchase.

Additionally, more and more phones are equipped with wireless charging and power share features, providing more charging options to consumers, and thereby reducing the mechanical strain put on the USB connector throughout the phones lifetime. On the other hand, it has been shown that the charging efficiency using wireless charging can be lower compared to wired charging by approximately 24% on average (Sánchez et al. 2018).

4.2.1.1.5 Audio jack

The 3.5mm headphone jack is one of the oldest and most widely used connectors. In 2016, Apple was the first to take the choice to remove it with the iPhone 7. Since then the trend has been going towards smartphones without a headphone jack. Instead, wired earphones are often shipped with a USB Type-C (Android) or Lightning (iOS) connector, but when those are being used, it is not possible to charge the phone and use the headphones at the same time. Wireless Bluetooth connected earbuds have gained in popularity, but come with an integrated battery and are very difficult to repair. In fact, AirPods received a 0/10 on the iFixit repair index, since they were impossible to repair without destruction.

4.2.1.1.6 Cameras

Although the global smartphone market has been stagnant in the last years, the trend for better image quality increased the demand for multi-camera, super-high-resolution, and larger optical formats. This resulted in increased growth in the market value of CMOS Image Sensors (CIS). According to Counterpoint Research, over US$11 billion worth of CIS were applied in smartphones (Counterpoint 2019). Latest flagship phones allow shooting 8K videos and up to 100x space zoom.

4.2.1.1.7 Battery durability

Lithium-ion battery (LIB) technology is currently predominant due to its favourable characteristics in terms of energy density, safety, and cost. Smartphone battery capacity has steadily increased over the years to enable powering the increases in performance and screen sizes. Battery life, typically measured in use time between charges, is a key characteristic for smartphone buyers. After a full charging process, the state of charge (SOC) of the battery steadily decreases with use from 100% down to 0% or until the phone is connected to a charger for the next charging process. However, the full charge capacity that the LIB can store and deliver to its host device inevitably decreases over time and with use, thereby steadily decreasing the battery life between charges. This is referred to as the battery's state of health (SOH), commonly denoted as the currently available fully charge capacity relative to the initial design capacity of the battery. While this capacity fade may go unnoticed by users at first, the battery will reach a low state of charge in shorter time periods and therefore require more frequent charging. At some point, depending on user behaviour and battery management firmware, the battery will no longer fulfil the phone's requirements or the user's expectations and needs to be replaced. From a material efficiency standpoint it is therefore preferable to extend the time period before this limiting state occurs as much as possible, within given technological and economic constraints. A high cycle life, denoting a relatively low capacity fade per charging cycle, is therefore a desirable characteristic of a smartphone battery.

The IEC standard EN 61960 is commonly referred to for standardized electrical and endurance testing of rechargeable batteries. Batteries are continuously charged and discharged in a laboratory environment under defined conditions (incl. charging rate, discharge rate, ambient temperature) to measure the cycle endurance. Further, the standard describes a method to gauge calendar ageing, in which cells are stored under defined conditions (SOC, ambient temperature) to observe capacity fade even when the battery is not cycled. Laboratory cycle tests carried out with batteries of a recent smartphone model (released in August 2019) indicated that they can endure 500 charge/discharge cycles while retaining 90% of their initial capacity (Clemm et al. 2020). In a scenario in which a user fully discharges and recharges their device daily, this translates into 16 months of use before the SOH drops to 90%. However, data collected from the field indicate that smartphone batteries are fully cycled on average only 230 times per year, on average, rather than 365 times (Clemm et al. 2016). In this scenario, the SOH drops to 90% after approximately 26 months of use. To contextualize this data, it should be noted laboratory testing is generally not able to capture factors that may accelerate battery degradation, particularly user behaviour that may not be ideal, such as charging under elevated temperatures or keeping batteries at a high voltage over extended periods of time (e.g. by regularly charging overnight).

Apple states on its website that batteries in their smartphones are "designed to retain up to 80% of its original capacity at 500 complete charge cycles" (Apple 2020a). In the case of tablets, notebooks and smart watches, this claim is increased to 1000 cycles and up to 80% SOH.

Users of smartphones are generally not able to verify the cycle life of their batteries, as most smartphone manufacturers do not employ smart battery management system integrated circuits that track and report the number of charge/discharge cycles or the current SOH (Clemm et al. 2019). Therefore, most smartphone users do not have insights into the state of health of their batteries, and therefore do not know whether the battery indeed performs as promised.

4.2.1.1.8 Military Standard (MIL-STD-810)

The MIL-STD-810 (DoD 2019) is a United States Military Standard which is approved for use by all Departments and Agencies of the Department of Defense (DoD), such as the United States Air Force, Army and Navy. The standard consists of three main parts: General program guidelines, laboratory test methods and world climatic regions. Part two contains 29 different test methods that range from less (e.g. rain, sand and dust, etc.) to more extreme conditions (e.g. pyro shocks, acidic atmosphere, etc.). While the document explicitly states that the standard can be tailored for commercial applications, it does not provide clear rules for its application. In fact the MIL-STD-810 is a flexible standard that allows companies to tailor test methods to fit the specific application. This means that it might be enough for a company to pass at least one of the 29 tests in order to be able to label its product MIL-STD-810. This flexibility of the standards and the fact that it is not verified by third companies or authorities can make the label misleading. For this reason consumers who require rugged products should verify which test methods and parameter limits were selected. As an example, the comparison of two phones labelled MIL-STD-810 shows differences in testing thoroughness.

Table 5: MIL-STD-810 tests passed by selected phones

Test	LG K50	Galaxy X Cover Pro
Low Pressure (Altitude)		2
High Temperature	1	4
Low Temperature	1	2
Temperature Shock	1	1
Rain		2
Humidity	1	1
Salt Fog		1
Sand and Dust		2
Immersion		1
Vibration	1	1
Shock	1	1
Temperature, Humidity, Vibration, and Altitude		1
Icing/Freezing Rain		1
Ballistic Shock		1
Total	**6**	**21**

4.2.1.2 Televisions

The main purpose of a television is to display and receive audiovisual signals. Television display technologies have evolved significantly in the last decades. Table 6 shows the most common display technologies.

Table 6: TV-Technologies

Technology	Description
CRT	The box of a CRT (Cathode Ray Tube) TV includes a screen and a projector gun. An image is created by shooting electrons through the gun onto a screen, exciting the particles on it. With the introduction of thinner and lighter LCD displays, CRT TVs lost in popularity.
LCD	LCDs (Liquid Crystal Display) are flat panels which can block light or allow it to pass. The panel consists of segments with each block filled with liquid crystals. Colour and transparency of these blocks can be adjusted by changing the electrical current. An external light source like a florescent bulb is needed to create an image, since LCD crystals cannot produce own light.
LED	LED (Light Emitting Diodes) displays are flat panel displays that use an array of light-emitting diodes as pixels for a video display.
OLED	OLED (Organic Light Emitting Diode) technologies use organic materials like carbon to create light when supplied directly by an electric current. OLED screens do not require a backlight and therefore can be very thin.
QLED	QLED uses quantum dot (Q) technology on an LED panel. A thin layer, called a quantum-dot filter, is put between the LED backlight and the LCD screen to purify the colour of the light coming from the LEDs to get a better and more saturated colour.

Global TV shipments reached around 250 million in 2017, as compared to around 200 million in 2008 (Figure 14). The CRT technology dominated the market in the end of the 20th century, but was gradually replaced by the LCD technology. In recent years, OLED and QLED displays started to play a larger role on the market. In 2016, Samsung was the dominant player in the market with more than 20% of global market share, followed by LG Electronics and TCL (Figure 15).

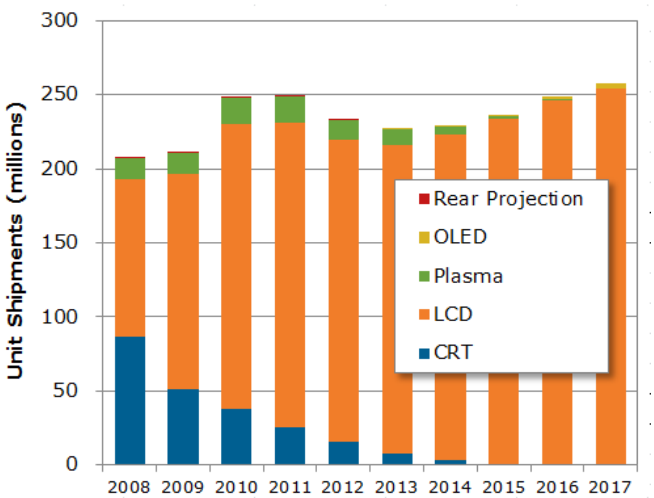

Figure 14: Global TV Shipment by technology (NPD DisplaySearch 2013)

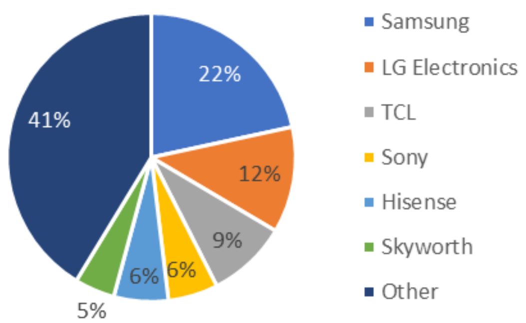

Figure 15: Global Market Share (2016, %, (Statista 2017c))

4.2.1.2.1 Towards connected, personalised and multi-functional devices

Television used to be the dominant media in households for decades, offering viewers a locally stationary and timely programmed experience. However, since the rise of high-speed internet and the proliferation of smart and mobile end devices such as notebooks, smartphones and tablets, the use pattern for television consumption has radically changed. Nowadays, it is possible to receive content mostly everywhere, all the time and on different devices. However, TV is not disappearing, but rather transforming into a new medium which is highly connected, personalised and multi-functional. New concepts such as tablet or motion control might replace remote controls in the future. The following graph summarizes ongoing trends in television:

	Today	Technology Enablers	Tomorrow
Sending Model	Broadcast	Internet	Narrowcast
Receiving Situation	Stationary TV	Mobile broadband LTE; tablets	Dynamic TV
Experience	Limited interface	Display technologies, motion control, sensors	Expanded interface
Comfort	Programmed TV	Intelligent algorithms, semantic web, filter	Personalised TV
Functionality	Functionality focused on entertainment, news	New content formats	Expanded functionalities, gaming, conferencing, shopping

Figure 16: Trends in television (Z Punkt 2011)

The way audiovisual entertainment is consumed has significantly changed in the last 20 years. Ever since increased bandwidth made video streaming possible, more and more video on demand (VOD) options became available. VOD systems can stream content by different means, either through traditional set-top boxes or through remote devices (e.g. computers, tablets, smartphones, etc.). VOD makes it also possible to download the content to a device to improve continued viewing and to enable offline access to the media.

Televisions also moved to VOD options with smart TV apps such as Amazon Prime video or Netflix, making unlimited streaming or temporary rentals and dematerialized purchases of video entertainment possible. Figure 17 shows an estimation for worldwide unit sales for Smart TVs in 2024, reaching 250 million devices (+26%) as compared to 2018. Comparing this trend to Figure 14 from another source suggests that most of the TVs put on the market are Smart TVs.

More and more TVs also offer so called “catch-up TV” for consumers to watch content through VOD after the original broadcast.

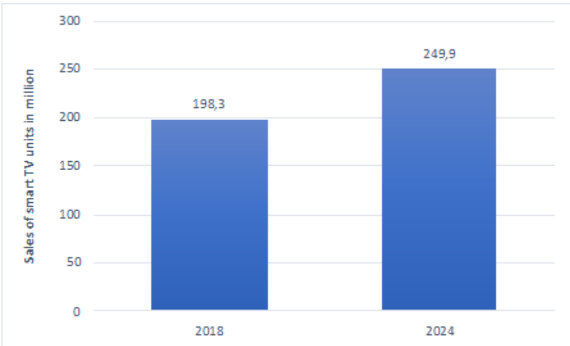

Figure 17: Smart TV unit sales worldwide 2018-2024 (Statista 2020a)

The TV of tomorrow is highly connected, which means that there will be no clear distinction between internet content and television channels broadcast anymore. The change from broadcast to schedule-free narrowcast on demand services means a highly personalised content experience for consumers. Streaming services such as Netflix, Amazon prime video, Disney+, YouTubeTV, etc. are competing for customers on a global level and offering personalised alternatives to classical TV channels. Mobile broadband also allows to access content on different devices and “on the go” which provides consumers with a different video experience, since the accessibility is not restricted to a fixed place in the household.

Television also became multi-functional. Many smart TVs have built-in cameras and microphones allowing for two-way conversations on a large screen and voice commands (e.g. to switch channels). They also allow for wireless gaming and 3D experience using special 3D glasses. Furthermore, in a connected home, the television can be used for apps, for online shopping or to control other connected devices.

Many televisions with integrated cameras also use facial recognition to make programming suggestions based on who is watching. While these highly personalised options can be convenient for consumers, they can come with considerable drawbacks when it comes to privacy. Not only does the two-way connection through integrated cameras and microphones allow OEMs to receive and track private information from consumers, but the FBI warned that they can also be used as gateways for hackers (FBI 2019).

4.2.1.2.2 Design for disassembly

LCD displays are currently dominating the market and there is a general trend towards larger and thinner screens with higher resolutions (4k, 8k) (gap intelligence 2019). Thinner displays usually have an impact on the ease of disassembly, since a compact design entails specific types of connectors (e.g. snap-fits or flat connectors). These might require specific tools for access. Furthermore, several manufacturers use adhesives to fix the back cover, making the opening of the product difficult with common tools. Smart TVs are also equipped with more complex electronics than older technologies, which makes them more difficult to repair for non-professionals. Using more and complex electronics also implies that more PCBs and ICs are integrated into the product (e.g. T-con board, main board, sound board, etc.) which puts a higher weight of the environmental impact on the manufacturing phase (Sanfelix et al. 2019).

Some new design trends also include televisions that are designed to be even thinner and to look like pictures, frames or to create the feeling to be invisible. As an example, with the SIGNATURE OLED TV R, LG introduced a rollable display which uses OLED’s flexibility. When inactive, the display is stored in a base that also acts as unfurling mechanism and a sound system. One advantage of OLEDs is the low operational temperature as compared to LEDs which generate a large amount of heat during operation, requiring heat sinks. The reason for this difference in thermal behaviour lies in the fact that LEDs are a chip point source with a much higher power density. The heat has only a small surface area to dissipate. OLED panels, on the other hand, operate at a lower power density and have a bigger surface area to dissipate heat (Pang et al. 2014). Not surprisingly this technology is rather challenging when it comes to repair.

4.2.1.3 Washing machines

Washing machines are considered to be "workhorses" (Cox et al. 2013) and their dimensions have not changed significantly in the last decades, mostly due to the requirement for a certain volume for the load of the laundry. However, there have been main design developments with respect to materials used and a general trend towards more electronics. Main designs include front loader and top loader (Table 7).

Table 7: Types of washing machines

Type	Description
Top-loader	A top loader is loaded and unloaded from above, and thanks to its design, the top loader is often more space-saving than a front loader.
Front-loader	The front loader is loaded and unloaded from the front. It usually can hold more laundry than a top loader and is more stable in the room.

Most of the EU households (92%) are equipped with a washing machine (Boyano A. et al. 2017).

Since the EU market is almost saturated, sales volumes have been increasing only slowly in the last years. Compared to 2019, sales are projected to increase from 24.9 million units to 26.4 million units in 2023 (+5.8%). New machines are mostly bought to replace old or broken ones.

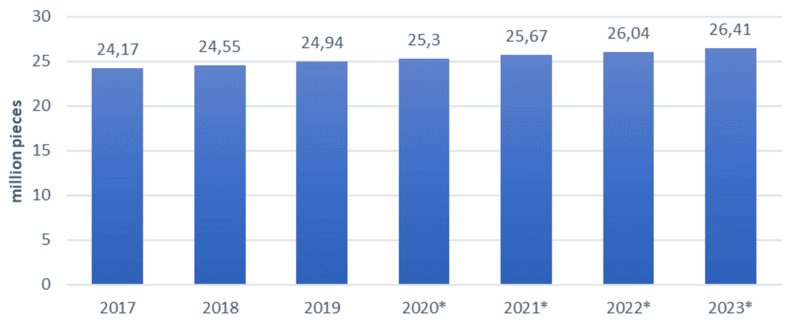

Figure 18: Number of washing machines sold in Europe (Statista 2019e)

According to Statista, prices have been slightly decreasing in the last years (Figure 19). The average price per unit dropped from 373 EUR in 2017 to 366 EUR in 2020 (-3%).

The overall market volume is estimated at 12,604 million EUR in 2020. Most of the revenue is generated in China.

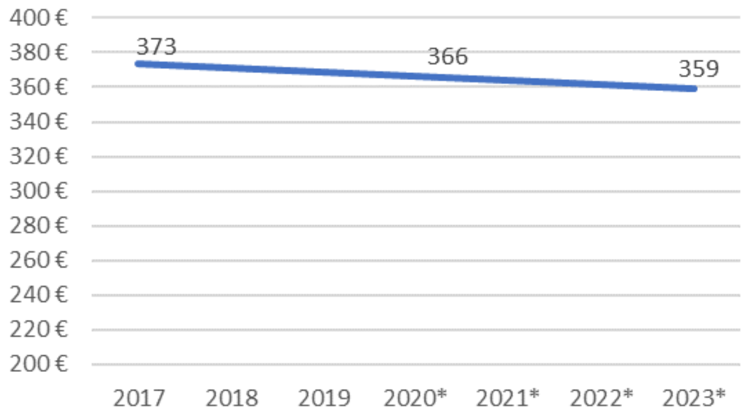

Figure 19: Average price of washing machines in Europe (*estimated values, (Statista 2019e))

The main brands dominating the washing machine landscape are Samsung Group (South Korea), LG Electronics Inc. (South Korea), Siemens AG (Germany), Haier Group Corporation (China), AB Electrolux Sweden), Whirlpool Corporation (U.S.), Robert Bosch GmbH (Germany), Miele and Cie. KG (Germany), Panasonic Corporation (Japan), and GE Appliances (U.S.)

Energy consumption is mainly related to heating up the water. In the last decades, major efficiency gains were achieved with respect to energy and water consumption (EC 2015b). Innovation has reduced water consumption by half, while increasing the load of laundry (VHK 2014). As of today, the major innovations are coming from intelligent and connected devices.

4.2.1.3.1 Intelligent washing machines

Intelligent washing machines detect the weight of the laundry and the degree of soiling and automatically dose the detergent and optimise the washing cycle. Flexibility regarding the adjustment of the rotational speed or the type of drum movement makes washing cycles with a small amount of clothing effective and allows to use relatively low temperatures. Automated programmes calculate and adapt the amount of water required and the cycle time in relation to the weight of the laundry. These programmes can save energy and water when the drum is not at its maximum load (GIFAM 2020).

Integrated steam processes can reduce water and energy consumption while optimizing the washing results. Some devices also offer a steam ironing programme. Several manufacturers have implemented spray systems that release water and the detergent through additional nozzles with the goal to loosen fibres and to improve detergent penetration. Some of the newer devices are equipped with an anti-vibration system to be quieter.

Driven by the global concerns on the environmental impact of mircoplastics, more and more washing machines are equipped with a built-in mircoplastic filter. France, as a first country, requires in its anti-waste law for a circular economy that as of 1st January 2025 new washing machines sold in France must be fitted with filters intended to prevent microscopic plastic fibres released from clothing from washing during washing (French Ministry for Ecological and Inclusive Transition 2020).

4.2.1.3.2 Connected washing machines

Using an App on mobile devices, users can turn smart washing machines on and off, select programmes and adjust timers remotely through an internet connection. Furthermore, a washing machine can be connected to the dryer and send relevant parameters from the last washing cycle, enabling the dryer to automatically select the appropriate settings for the drying process. Many manufacturers offer ranges of connected washing machines that provide new consumer features such as information on the consumption of water and electricity, assistance with remote repair diagnostics, maintenance advice, automatic laundry control, speed dryer communication of the washing program used, etc.

Yet, this intelligence comes at the cost of additional electronic integration, with sometimes limited reliability and safety.

Figure 14: Connected Washing machine (KDMARKETRESEARCH 2019)

4.2.1.4 Vacuum cleaners

While the residential sector dominates the market for vacuum cleaners (Figure 20), more professional and application specific devices are also used in the commercial (hospital, retail stores, hospitality, shopping malls, etc.) and industrial (manufacturing, food and beverage, pharmaceutical, construction, etc.) sector.

The main focus in this report lies on residential vacuum cleaners.

A broad variety of vacuum cleaner types exists, ranging from upright, to handheld, cylinder and robot vacuum cleaners.

Table 8 provides a brief description of the different types of vacuum cleaners on the market.

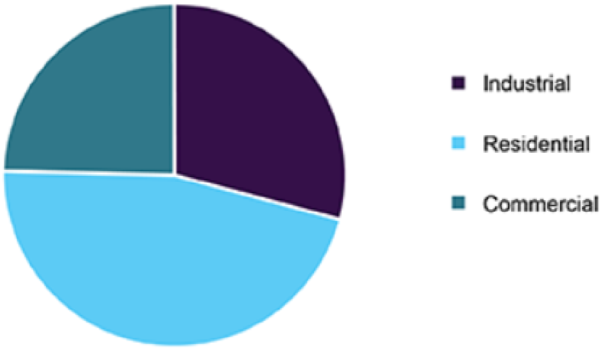

Figure 20: Europe vacuum cleaner market share in 2018, by application (%, (GVR 2019))

Table 8: Description of vacuum cleaner types

Vacuum cleaner type	Description
Canister / Cylinder	Canister vacuum cleaners dominate the European market. This design option has the motor and dust collector (bag or bagless) in a separate unit (canister/cylinder) which is mounted on wheels. The canister is connected to the vacuum head by a flexible hose.
Stick / Upright	Upright vacuum cleaners take the form of a cleaning head, onto which a handle and bag are attached. They usually are equipped with a rotating brush roll or beater bar that removes dirt through a combination of sweeping and vibration. Two main types of upright vacuum cleaners dominate the marked: dirty-air/direct fan and clean-air/fan-bypass.
Handheld	Hand-held vacuum cleaners are light and either powered from rechargeable batteries or mains power. They are usually used on occasion to clean up small spills.
Drum (wet & dry cleaners)	Drum vacuum cleaners are mostly used for industrial applications, but can also be found in households, mainly used outdoors. Usually, the canister consists of a large vertically positioned drum that can be stationary or on wheels. Wet or wet/dry vacuum cleaners are a special type of drum models that can be used to clean up wet or liquid spills.
Robot	Robot vacuum cleaners work autonomously and can launched by using an app or start on a timed schedule. They collect surface dust and debris into a dustbin and can navigate around obstacles (e.g. furniture) and come back to a docking station to recharge the battery. Some are able to empty the dust container into the docking station.

The EU market for vacuum cleaners is relatively saturated. The 2019 review study on vacuum cleaners (Viegand Maagøe A/S 2019) estimated that in EU households the average penetration rate of vacuum cleaners is 1.3. In 2018, around 40 million vacuum cleaners were sold in Europe. Sales are estimated to reach 43 million in 2025 and around 44 million in 2030, as shown in the following Table.

Table 9: Derived sales of different vacuum cleaner types from 1990 to 2030 in Europe

Sales in millions	1990	2000	2005	2010	2015	2018	2020	2025	2030
Cylinder domestic	14.81	16.92	25.01	25.28	25.07	23.43	22.06	17.88	12.07
Cylinder commercial	1.78	2.03	3.00	3.03	3.01	2.95	2.95	2.95	2.95
Upright Domestic	2.61	2.99	4.41	3.44	2.91	2.60	2.56	2.38	2.01
Upright Commercial	0.31	0.36	0.53	0.41	0.35	0.31	0.31	0.31	0.31
Handstick mains	0.30	0.34	0.50	0.91	1.25	1.66	1.87	2.38	3.22
Handstick cordless	0.51	0.59	0.87	1.56	4.24	7.39	9.11	13.51	18.10
Robot	0.00	0.00	0.00	0.79	1.45	2.00	2.45	3.58	4.83
Total	20.32	23.22	34.33	35.43	38.28	40.35	41.32	43.00	43.49

According to market data (GfK in above Table and GVR (GVR 2019)) small-sized, handheld, and battery-powered cleaning devices will drive market growth in the coming years. It is estimated that the global robotic vacuum cleaners market will expand at 11.2% CAGR between 2018 and 2026 (Credence Research 2018). Manufacturers are in particular looking at developing intelligent residential vacuum cleaners that allow customization, integrate AI workflow, and come with security features. Furthermore, they should satisfy the demand from consumers for eco-friendly and low-maintenance devices (GVR 2019).

The review study on vacuum cleaners (Viegand Maagøe A/S 2019) analysed retail prices for different vacuum cleaner types. Below table shows the overall sales weighted average in EU-28.

Table 10: Unit retail price in EUR vacuum cleaners, in 2018-prices for EU28

Unit prices, EUR	2005	2010	2013	2014	2015	2016	2018
Cylinder	133	119	110	112	121	119	120
Upright	210	184	169	177	196	171	168
Handstick mains	114	99	91	89	94	96	90
Sales weighted average of mains-operated vacuum cleaners	145	126	116	118	128	123	123
Commercial[27]	302	269	250	255	274	271	320
Handstick cordless	216	193	180	200	225	220	221
Robot	323	288	268	284	317	344	221

Vacuum cleaners with extended functions such as steam production or dry-wet selections are slowly penetrating the market. Cordless and bagless upright vacuum cleaner have the main advantage that they are small, light and portable. Robotic vacuum cleaners gain in popularity due to their ability to perform autonomously due to integrated navigation technologies which can be operated through voice control (e.g. via Alexa and Google Home) or remotely using an app on mobile devices. According to a market research report, robotic vacuum cleaners make up around 20% of the worldwide vacuum cleaners market (Credence Research 2018). Some robotic vacuum cleaners can take video pictures and send them to the smartphone. While these features can be convenient for some consumers, the increased connectivity can also come with security risks (CNET 2020).

4.2.1.4.1 Wireless and robotic vacuum cleaners

One of the main design impacts of the trend towards wireless and robotic vacuum cleaners is the need for batteries. Not only do battery-powered devices require frequent charging, but a drop of battery capacity over time can also limit the overall useful lifetime of the product. Over the last 5 years, significant progress in performance, battery capacity and lifetime for cordless vacuum cleaners could be observed (Viegand Maagøe A/S 2019). Nevertheless, tests conducted by Stiftung Warentest show that most of the handheld battery driven devices can only run for around 15-20 min under maximum performance and recharging the batteries can take from two to six hours (Stiftung Warentest 2016).

Recent studies show that conventional vacuum cleaners (e.g. canister) tend to have a longer useful lifetime than their robotic and wireless counterparts. While the useful lifetime of conventional vacuum cleaners is around 6-10 years (Stiftung Warentest 2018) the one of robots can go as low as 3 years (FNAC DARTY 2018). Robotic vacuum cleaners usually also require a remote controlling device (e.g. smartphone, tablet, etc.) and therefore create software related dependencies between different devices. These autonomous and connected devices usually use also more and more complex electronic components (e.g. PCBs, sensors, etc.), which can have a higher environmental impact during the manufacturing phase, linked to the use of more semi-conductors, and limited repair capability.

On the other hand, bagless and robotic devices also have advantages from an environmental point of view. Bagless devices can be emptied and reused without the need of one-way dust bags, resulting in using less consumables and waste generation. Furthermore, hoses of canister vacuum cleaners are considered to be wear parts and can be one of the main reason for product failure (Viegand Maagøe A/S 2019).

4.2.1.5 The Connected Home

The term “Connected Home” refers to a networked home enabling “the interconnection and interoperability of multiple devices, services and apps, ranging from communications and entertainment to healthcare, security and home automation” (Gartner).

Multiple devices are interconnected through different home networking technologies (Wi-Fi, Bluetooth, Ethernet, etc.) and members of a household can control and monitor these devices in real-time using an app on their end device (smartphone, tablet, laptop, etc.). This can be done either inside the house within the home network or remotely using an internet connection. Users can not only control the devices in real-time, but also create time schedules, e.g. programme a wash cycle, start the vacuum robot at a certain time, etc. Often, connected home appliances are also “smart”, since they are able to observe patterns, interpret data, or use artificial intelligence in order to adjust their operation according to past information and user preferences. The market of connected and smart appliances consists of the following main applications: Smart Appliances, Security, Control and Connectivity (provides infrastructure for the connection of Smart Home IoT), Home Entertainment, Comfort and Lighting and Energy Management.

The number of IoT connected devices is estimated to reach 50 bn in 2030 (Statista 2020b). Applications can include door locks, thermostats, cameras, lights and household appliances such as washing machines or robot vacuum cleaners.

Global revenues of the smart home market amounted to 80.6 bn EUR in 2020 and are expected to show an annual growth rate (CAGR 2020-2024) of 15%, resulting in a market volume of 140.7 bn EUR by 2024. Most of the revenue is generated in the United States. Growth is mainly driven by smart appliances, security applications and the control and connectivity segment (Figure 21).

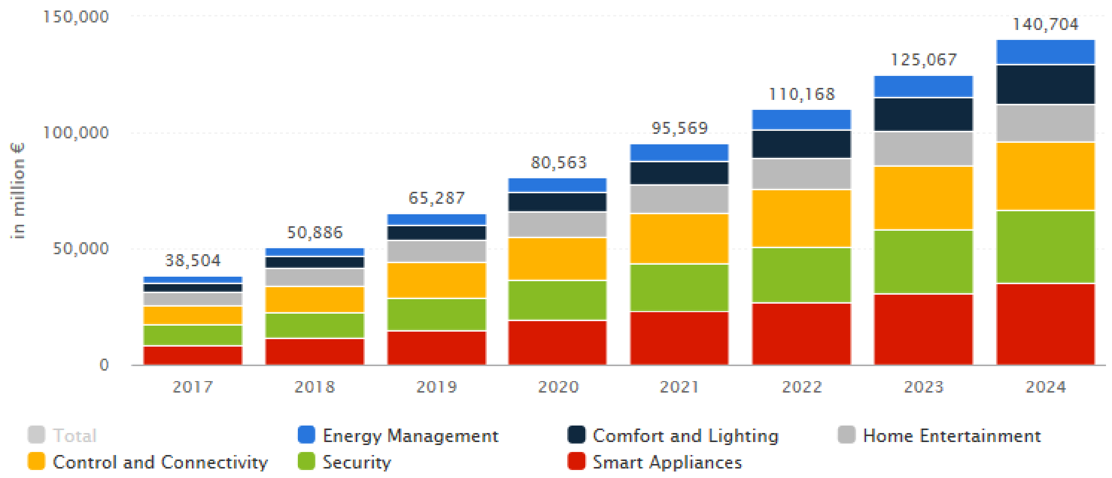

Figure 21: Global revenues from the global smart home market (Statista 2019c)

4.2.2 End users' perspective

This chapter has the main objective to analyse user behaviour for the different product groups.

4.2.2.1 Mobile phones (smartphones)

Mobile phones went through very quick innovation cycles in the last decade and consumers tend to change their smartphone nowadays on average every three years. Table 11 shows the results of recent studies on the average lifetime of smartphones in different European countries.

Table 11: Average useful life of a smartphone in different countries

Average useful life in years	Country	Year	Source
4.3	Belgium	2019	(FNAC DARTY 2019)
3	France	2019	(FNAC DARTY 2019)
2.3	Switzerland	2017	(Statista 2019d)
2.5	Germany	2016	(Proske et al. 2016)

In the year 2000, before smartphones gained in popularity, the average (median) useful lifetime of mobile phones was around 5 years in Germany and 4.8 years in the Netherlands (Bakker et al. 2014).

Since their market introduction, smartphones became more and more popular among all age groups. Figure 22 shows the results of a survey conducted in 2017 in the US. It can be observed that smartphone penetration increased among all age groups between 2015 and 2017 and that they are particularly popular with younger adults. However, the share of elderly adults owning a smartphone has also been rising steadily.

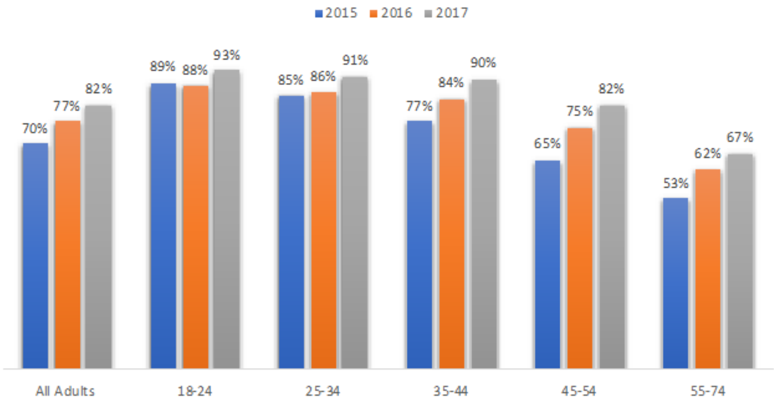

Figure 22: Smartphone penetration by age group (Deloitte 2017)

Figure 23 shows results of a global survey on the amount of time spent daily on a smartphone in 2017. As of that time, almost half of the respondents spent five or more hours on their smartphones every day. More than 25% spent even more than seven hours every day on their device.

When purchasing a new smartphone, some features are more important than others for consumers. Figure 24 shows the results of a survey conducted in 2015 in Germany highlighting the most important purchasing criteria. The interviewed persons were 14 years and older. The most important criteria cited were a long battery life (almost 70%) and good internet and Wi-Fi access. For 40% of respondents a high-quality finish was a major purchase criteria.

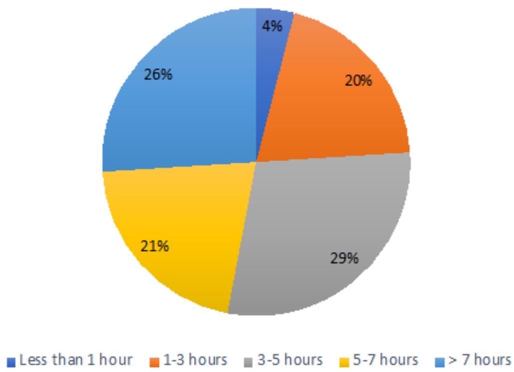

Figure 23: Average hours spent on smartphone/day (Statista 2020e)

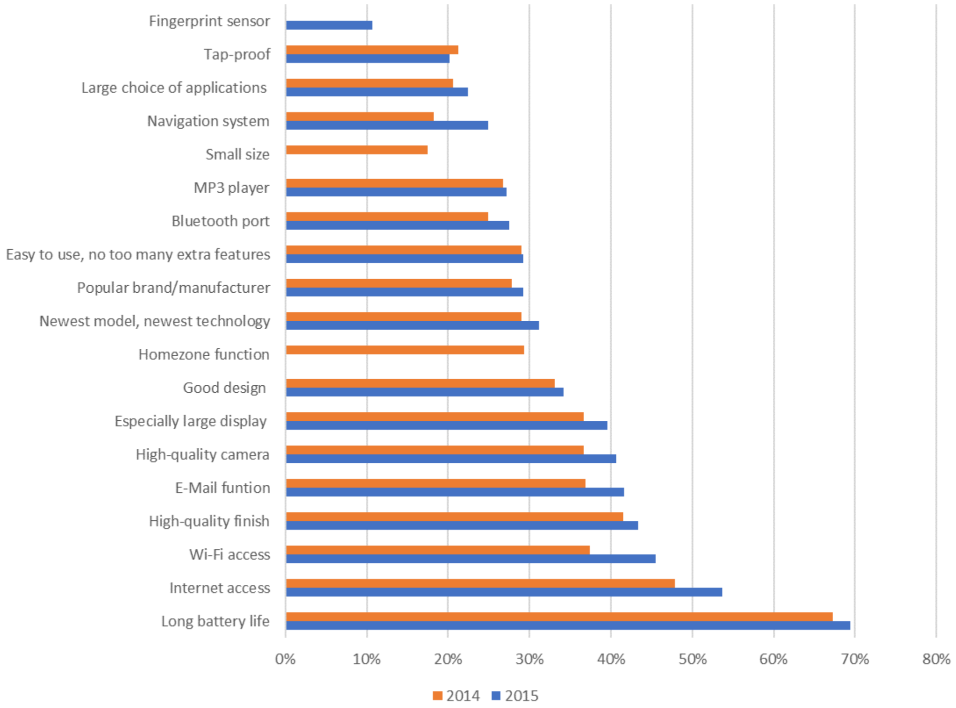

Figure 24: Most important criteria for buying a new mobile phone or smartphone in Germany (Statista 2015)

4.2.2.2 Televisions

The lifespan of a television was around 10 years in the Netherlands in the year 2000 (Bakker et al. 2014). Another study, conducted by (Osmani et al. 2014) showed that the TV replacement cycle has decreased globally from 8.4 to 6.9 years, compared to the 10-15 year average when the main technology replacement went from CRT to LCD technology. A study conducted for the German Environmental Agency, showed that the average lifespan of televisions was around 10 years in Germany (Prakash S. et al. 2016). A recent JRC report suggests that currently the lifetime of televisions in the EU usually ranges from 5 to 10 years (Sanfelix et al. 2019). This range is also supported by the recent statistics from FNAC-DARTY, showing that the average useful life of televisions was 7.4 years in France and 8 years in Belgium (FNAC DARTY 2019).

Main drivers for the replacement of televisions are declining prices, increased screen sizes and the desire for the latest technologies. The most important driver seems to be the wish for larger screens and to change the technology towards flat panel TVs (Osmani et al. 2014). In general, consumers welcome the relatively new features, e.g. internet connection and video streaming integrated in smart TVs, but these are usually not the main reason for replacing an old device. TVs are generally discarded when they are outdated or broken. As long as the device is still functioning, it is usually kept in the household or sold for second use.

According to Eurostat, 11% of Europeans watched internet streamed television or other video content on smart TVs in 2016 (Figure 25). Only few used a smart TV to browse internet (4%) or for other apps (3%). The popularity of streaming TV or watching other video content on a smart TV was highest among ICT professionals (23%).

A comparison of the different EU states shows that the use of smart TVs for internet streamed TV or other video content was most popular in the Netherlands and the UK (22%), followed by Sweden (21%), Denmark (20%) and Finland (17%).

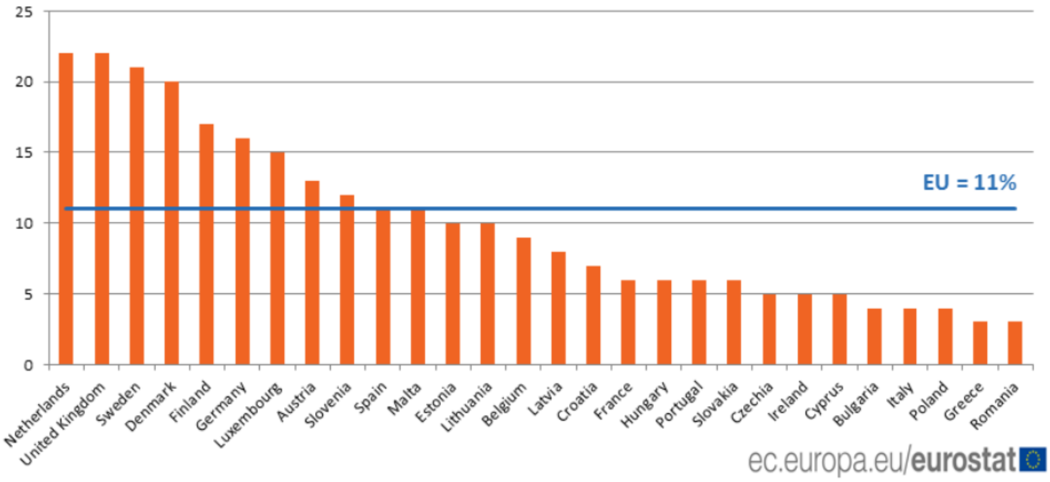

Figure 25: People who used a smart TV to watch internet streamed TV or other video content in 2016 (% of all individuals, (Eurostat 2018))

Figure 26 shows the average time spent watching television daily in European countries in 2016 and 2017. The highest number is recorded for Romania (5.3h) and the lowest for the French speaking part of Switzerland with around 2h. On average, Europeans watched television for 3.85h per day in 2017.

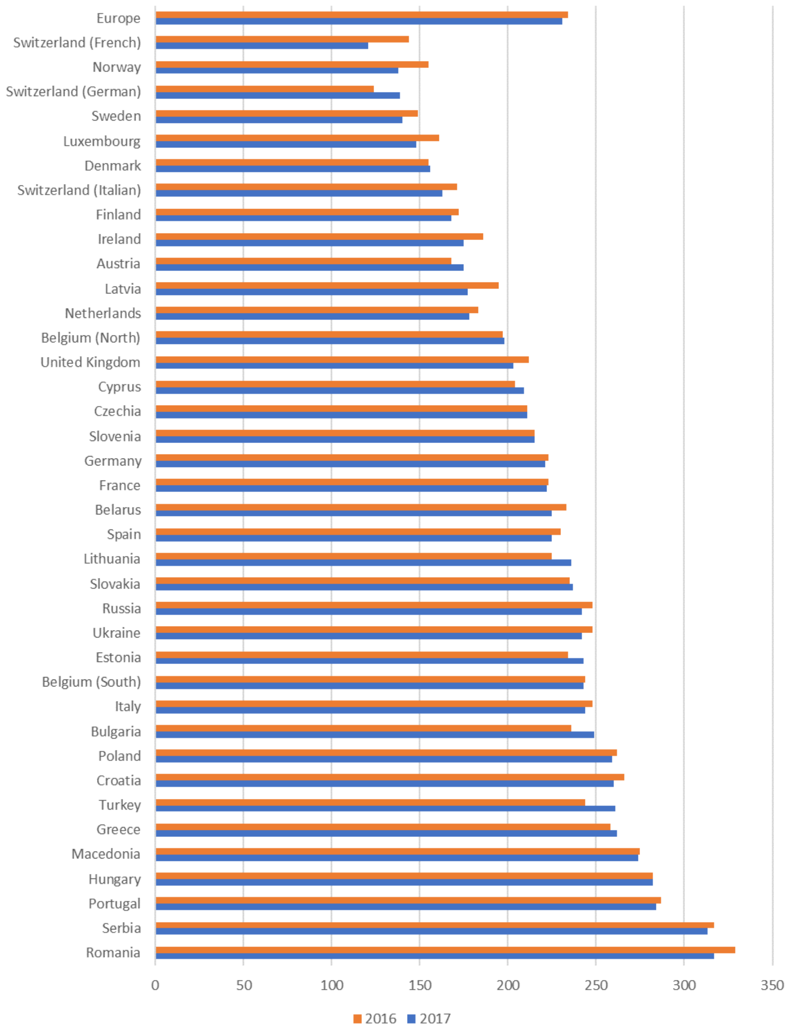

Figure 26: Average time (min) spent watching television daily in European countries in 2016 and 2017 (Statista 2019a)

4.2.2.3 Washing machines

Washing machines are not only part of almost every household, they are also essential in the commercial sector, such as in restaurants or hotels. In 2015 the global share of household washing machines amounted to around 55 % (Figure 27).

In Germany, the average first use of large household washing machines has declined slightly from 12.7 years in 2004 to 11.9 years in 2012 (Prakash S. et al. 2016). According to latest data from FNAC-DARTY, the average lifetime of a washing machine is around 8.1 years in France and 8.6 years in Belgium (FNAC DARTY 2019).

A Euromonitor International survey among worldwide households, conducted in 2015, shows the most important preferences when buying an automatic washing machine (Figure 28). According to the survey, the major choice criteria for consumers were energy and water efficiency, followed by features that increase convenience, such as time-saving and size-saving factors. Design and appearance features and other more technological advances seem to be less important.

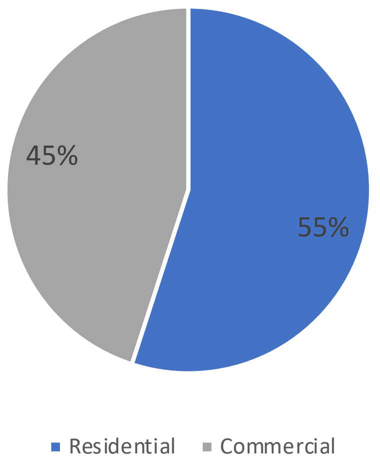

Figure 27: Global washing machine market by end-use, 2015 (GRV 2016)

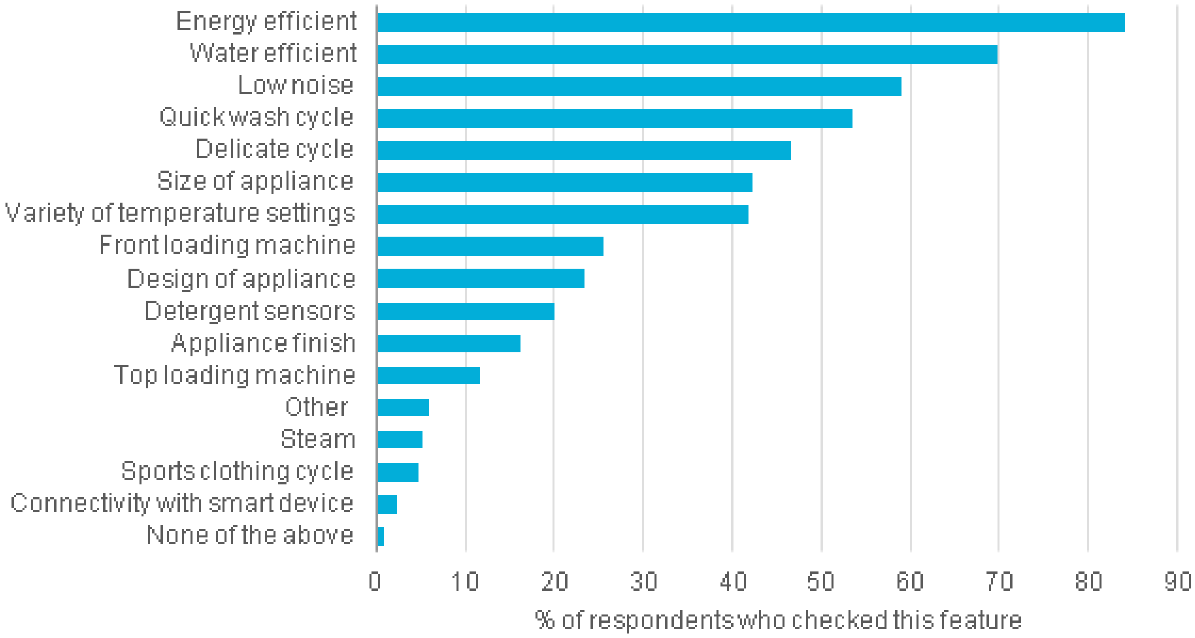

Figure 28: Main criteria when choosing a new washing machine (Euromonitor 2015)

Washing machines are used very frequently. An internet based consumer survey among more than 700 German households showed that 98.4% of the households use their washing machine at least once a week (Prakash S. et al. 2016). More than two thirds of the participants use it several times a week (Figure 29). A study conducted in 2015 in France revealed that French households use their machine on average 3.5 times per week, mostly on the weekend (TNS 2015).

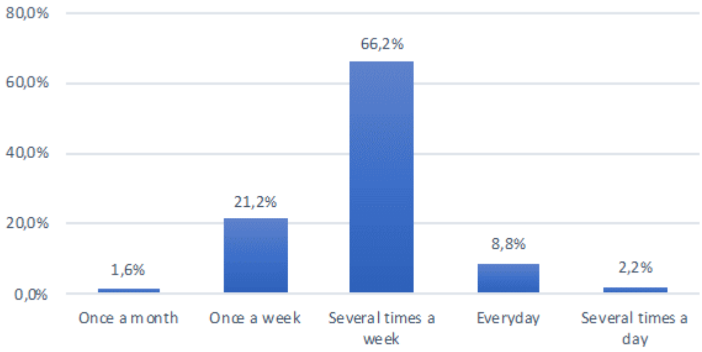

Figure 29: Frequency of use of washing machines in Germany

In 69% of the cases where washing machines are replaced, the underlying reason is a technical defect (Hennies, L. and R. Stamminger 2016). This number is supported by statistics provided by FNAC-DARTY, where in 71% of the cases the reason for the purchase of a new washing machine is a technical defect (FNAC DARTY 2019).

4.2.2.4 Vacuum cleaners

The review study on vacuum cleaners prepared for the European Commission (Viegand Maagøe A/S 2019) estimates the average lifespan of canister vacuum cleaners at 8 years (with 2 years of standard variation) and for cordless and robot vacuum cleaners at 6 years (with 3 years of standard variation). According to latest data from FNAC-DARTY, the average lifetime of a canister vacuum cleaner is around 6.7 years in France and 6.9 years in Belgium. These values are higher than for handheld vacuum cleaners, where the average life time is around 5.6 years in France and 5.8 years in Belgium (FNAC DARTY 2019). In their 2018 version of the “baromètre du SAV” FNAC-DARTY estimated the average lifetime of robot vacuums at 3 years (FNAC DARTY 2018). The main reason for a reduced lifetime of handheld and robot vacuum cleaners is usually the limited battery lifetime.

The use pattern is different for the different types of vacuum cleaners. The review study on vacuum cleaners estimates that mains-operated household vacuum cleaners are used on average for 73 minutes for one cleaning cycle and that there are on average 50 cleaning cycles per year (Viegand Maagøe A/S 2019).

Handheld vacuum cleaners are usually used for a shorter duration than canister vacuum cleaners. Robot vacuum cleaners work autonomously and the number of cleaning cycles can be higher than for non-autonomous alternatives, since no personal time has to be invested by the user. Table 12 shows estimated use patterns for cordless and robot vacuum cleaners per year (Viegand Maagøe A/S 2019).

Table 12: Use pattern for VC

	Cordless VC (h)	Robot VC (h)
Cleaning	63	104
Charging	671	211
Charged & docked	8026	8445

When it comes to purchasing decisions, only 6% of European buyers purchased their vacuum cleaner for energy efficiency reasons (Visser et al. 2018). The remaining 94% of buyers said that their buying decision was mainly based on reliability, durability, key features, the brand and value for money, independently of energy efficiency information (Figure 30). This findings support additional requirements for more information concerning reliability and durability at the point of sales.

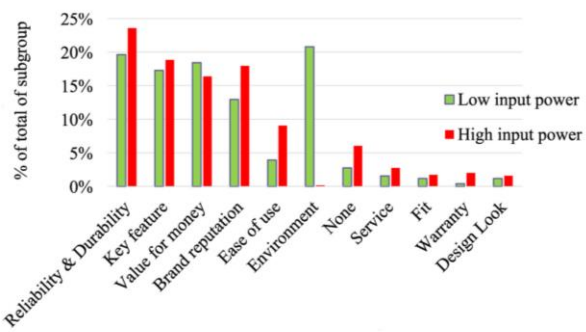

Figure 30: Reason to buy a specific model (N=951)

Maintenance plays an important role when it comes to vacuum cleaners. Full dust bags put additional pressure on the motor and need to be emptied or changed by the user. Moreover, filters only can fulfil their function when they are cleaned and/or exchanged on a regular basis.

4.2.2.5 The Connected Home

The popularity of connected devices and smart homes is rising quickly. Almost 80% of Europeans find the idea of living in a smart home appealing and the number of smart homes in the EU is estimated to increase almost tenfold from 8.5 million homes in 2016 to 80.6 million homes in 2021 (Applia 2019). A survey conducted in Germany in 2018 finds that the main reasons for users to switch to smart home appliances is additional comfort, security and the reduction of heating and electricity costs (Statista 2018). Another survey among UK citizens suggests that confidence, interoperability and comfort are the main drivers for adoption of connected home devices, while main barriers are higher costs, privacy concerns and a lack of technological knowledge (techUK 2019).

The trend of connected and smart home applications is mainly driven by younger adults between 25-34 years, which constitute around one third of all users. The popularity of connected and smart home devices decreases with age and only 7% of the end users are above 55 years old (Figure 31). This global trend can also be confirmed on national levels. When asked about their beliefs of how useful connected devices will be, more than 80% of young UK citizens believe that connected devices would make their life slightly or a lot easier (Figure 32).

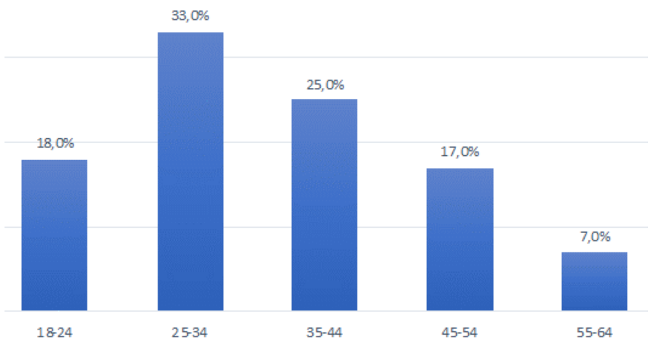

Figure 31: Smart Home users, by age (Statista 2020d)

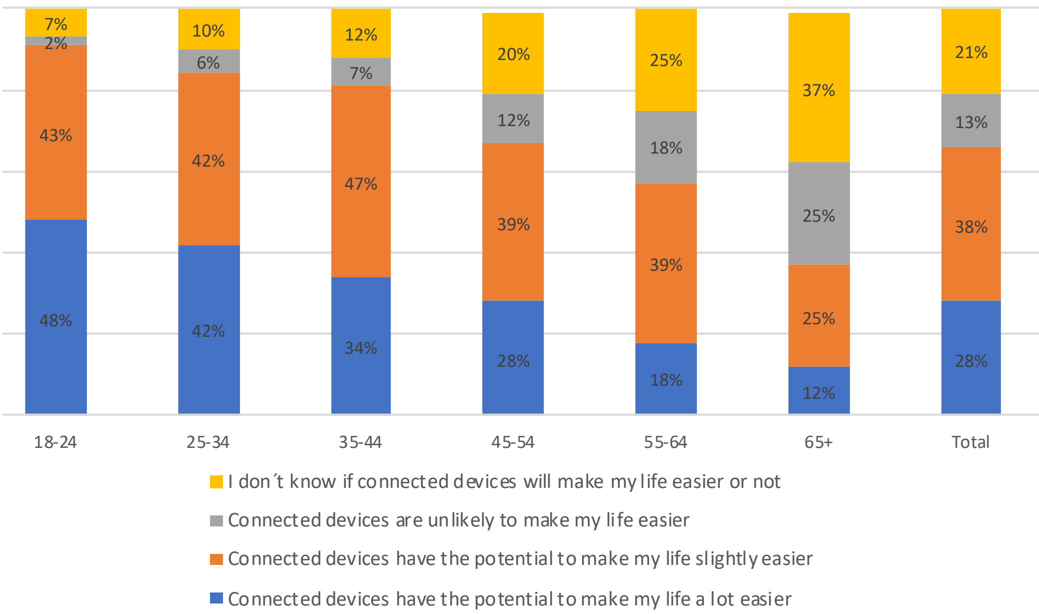

Figure 32: Beliefs about the usefulness of connected devices (Deloitte 2016)

While smart appliances generate most of the global smart home revenues, their presence in homes is still relatively low (2% in 2017, expected to rise to 8% in 2023). On a global level, it can be observed, that most of the connected and smart devices present in homes are linked to the market segments “Control and Connectivity”, followed by “Comfort and Lighting” and “Home Entertainment” (Figure 31).

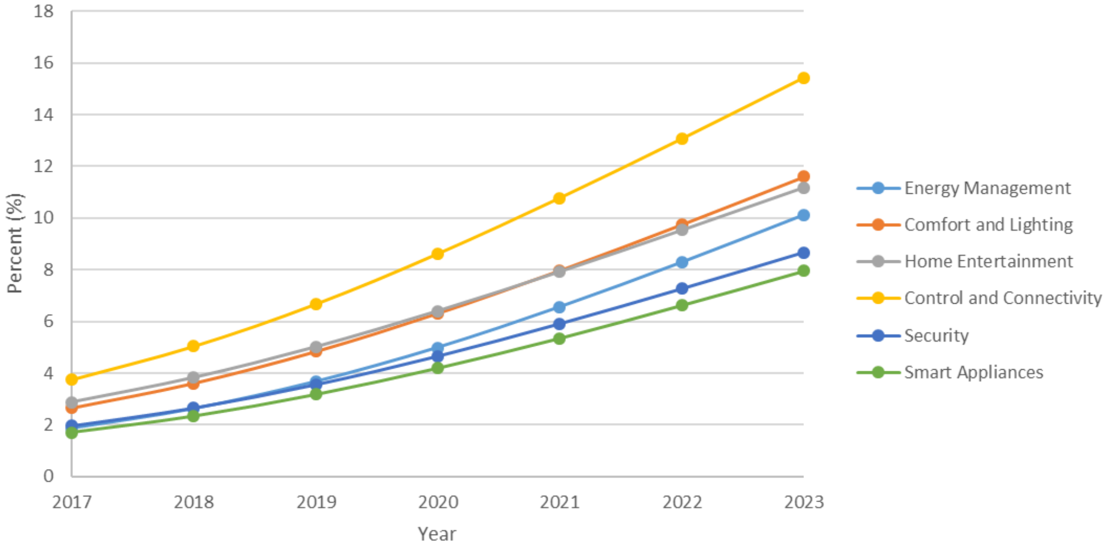

Figure 28: Household penetration in the smart home market (Statista 2020d)

Control and connectivity devices provide the required infrastructure for the connection of Smart Home devices. When consumers in the UK were asked which appliances they would most likely replace with connected devices, lamps and lighting were named first with thermostats (Figure 33). Vacuum cleaner and washing machine are not cited in the list.

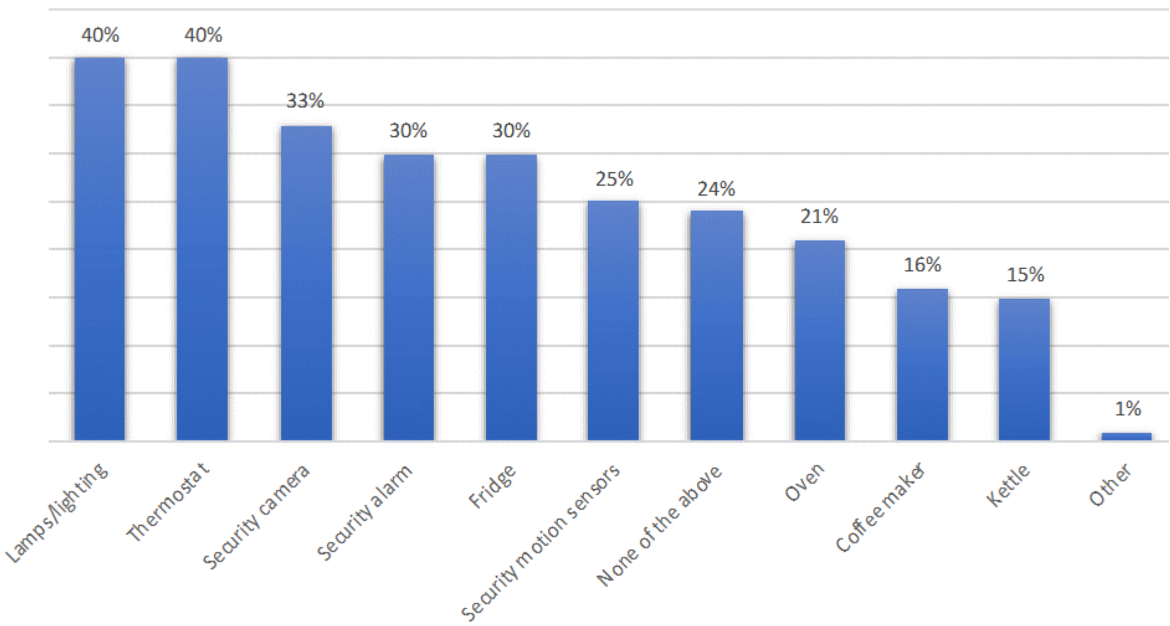

Figure 33: Appliances consumers are most likely to replace with a connected device (Deloitte 2016)

5 Lifecycle environmental aspects

The main objective of this chapter is to highlight environmental hotspots for different product groups. The chapter is divided in three main parts. The first part provides a short introduction into the concept of life cycle analysis (LCA) and the simplified LCA methodology developed to conduct Ecodesign preparatory studies for the European Commission, called the Methodology for Energy-Related Products (MEErP, (COWI 2011)). These two approaches were selected since they have been widely applied in the past, providing a solid basis of quantified results.

The second part shows a summary of the EcoReport outputs of different preparatory studies for chosen product groups. This information is complemented by results of other LCA using a different methodology in order to complement the analysis of the hotspots.

Last, but not least the information from the LCA analysis is summarised showing the main environmental hotspots for the different product groups. This outcome shows where the main focus should lie when it comes to considering lifetime extensions.

5.1 Life cycle analysis (LCA)

5.1.1 Brief methodological introduction

Life cycle analysis (LCA) is an increasingly important methodology for environmental policy. It is a tool used to assess the environmental impact of a product throughout its entire life cycle. This includes different life phases of the product starting with extraction and processing of raw materials, manufacturing of the components and the product, distribution, use, recycling, and final disposal of the product. According to standards ISO 14040 (ISO 14040:2006) and ISO 14044 (ISO 14044:2006), an LCA is carried out in four distinct phases. The following Figure illustrates the approach.

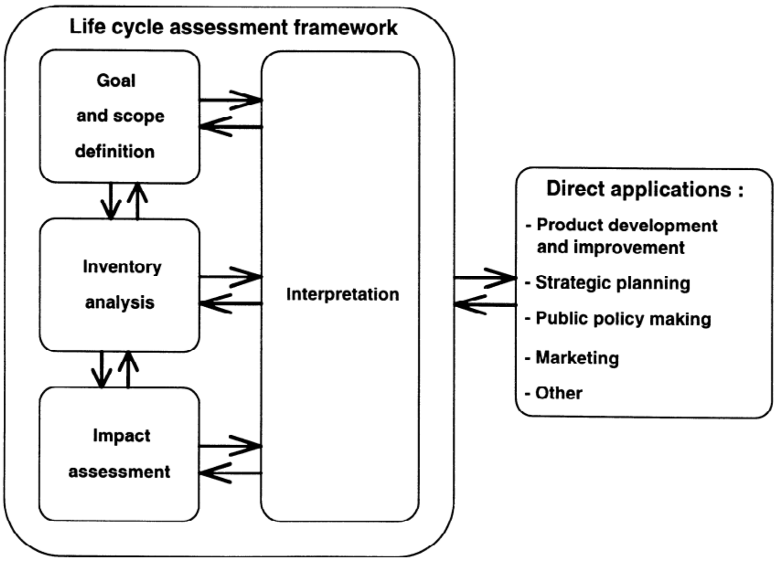

Figure 34: Phases of an LCA (ISO 14040: 2006)

In the beginning of each LCA the goal and the scope of the analysis has to be defined including technical details on:

- The functional unit (i.e. a quantified description of the function of a product that acts as the reference for all performed calculations for the impact assessment);
- The system boundaries (i.e. defining which unit processes to be included in the analysis)
- Assumptions and limitations;
- Data quality requirements (source, completeness, geography, time, etc.);
- Allocation procedures (needed when dealing with several products);
- Type of critical review (if any)
- Impact categories (e.g. global warming potential, toxicity, eutrophication, etc.)

In the next step a life cycle inventory (LCI) is performed, containing data collection and allocations procedures in order to quantify relevant inputs and outputs such as use of resources, releases to air, water and land, etc. The inventory is the main input for the impact assessment.

The life cycle impact assessment (LCIA) is the third phase of the overall analysis and evaluates the significance of potential environmental impacts. It includes elements such as:

- Classification (i.e. assignment of inventory data to impact categories)
- Characterization (i.e. modelling of inventory data with impact categories)
- Weighting and/or grouping (optional)

The final phase is the life cycle interpretation phase is in which all results are summarised and discussed in order to feed into conclusions and recommendations supporting specific decisions. It should be consistent with the defined goal and scope.

5.1.2 Critique and limitations of LCA

LCA has been widely used within the last decades and international standards were developed in order to reach a consensus on how to perform environmental assessment of products. Nevertheless, the method has its limitations and is often criticised, mostly because subjective assumptions and assessments have to be made during the different phases. Several caveats are presented in below table (Michalski 2015):

Table 13: Overview over problems related to different LCA phases

Phase	Possible problems
Goal and scope definition	Definition of the functional unit Selection of the system boundaries Necessary assumptions
Inventory analysis	Selection of relevant inputs and outputs Allocation procedures Local technological considerations
Impact assessment	Selection of categories and methodologies Local differences Evolvement over time
Interpretation	Valuation Weighting
All	Data availability and quality

Because of these possible drawbacks the international standard ISO 14040:2006 highlights the importance of transparency throughout all the different phases.

5.2 The Methodology for Energy-Related Products (MEErP)

5.2.1 Brief methodological introduction

The EU Ecodesign Directive (Directive 2009/125/EC) is a product-oriented policy tool that has the objective of setting up product specific requirements to improve the environmental performance throughout the product's entire life cycle based on design intervention. Article 15 of the Directive foresees that implementing measures, where the product specific requirements are set-up need to be based on:

- the consideration of the entire life cycle of a product and all significant environmental aspects and
- have to include an assessment of impacts on the consumers and manufacturers.

These aspects are evaluated in independent product preparatory studies using a common methodology, the so called Methodology for Energy-Related Products (MEErP).

The MEErP is divided into two main parts: data retrieval and initial analysis (Task 1-4) and modelling (Task 5-7). The MEErP includes the EcoReport tool, which allows to perform a simplified LCA for the preparatory studies. The EcoReport is an Excel file using the bill of materials, energy and other resources used during a product's life, as well as key parameters for manufacturing, distribution and end-of-life as input parameters. The tool then automatically generates environmental impacts for the indicators required for the four stages of a product's life as output parameters. These outputs are afterwards used to evaluate which design interventions are the most promising in order to improve the environmental performance of the product over its lifecycle. Furthermore, an economic evaluation is undertaken by calculating the Life Cycle Costs (LCC) of the different design options. As a final outcome the tool presents the design options with respect to costs and benefits, determines the combined impact of clusters of options that give the Least Life Cycle Costs (LLCC), the Best Available Technology (BAT) and the Best Not yet Available Technology (BNAT).

5.2.2 Critique and limitations of the MEErP and the EcoReport

The MEErP was used for more than 40 ecodesign preparatory studies and for Ecodesign of energy related products and some critics highlighted that while energy efficiency was well covered by the methodology, resource efficiency aspects could be improved. In 2013, a study assessed the possibility of enhancing material efficiency aspects of the MEErP (BIO Intelligence Service 2013) and tested features on recyclability benefit rates, recycling content, lifetime and a critical raw material index.

Regarding the assessment of material efficiency, the choice of materials within the EcoReport is considered to be very limited. Additionally, material efficiency measures often do not pay off within the given MEErP when applying the least life cycle cost (LLCC) approach, since savings are mainly achieved through lifetime extension. Furthermore, negative externalities are not thoroughly priced in.

Although the MEErP includes "MEErP equivalent costs", the assumed costs are very low, rarely applied in preparatory studies and are not automatically calculated in the EcoReport. The impact of critical materials, high-tech metals, bio-based materials and (only to a limited degree) recycled materials cannot be reflected by the current data sets in the EcoReport. Although new data sets can be entered by the practitioner, the development of new data sets can hardly be done within preparatory studies, due to time constrains, and would deviate from the aim to use the same database between the preparatory studies. These problems are mostly due to the limitation and the age of the EcoReport and not the methodology itself.

Despite these limitations, the existing preparatory studies of the European Commission are probably the best source to have a horizontal comparison between the different product groups, since they use one unique methodology and calculation tool, the EcoReport.

5.3 Comparison of LCA results for different product groups

This chapter has the main objective to provide an overview over existing LCA results for a variety of white goods and consumer electronics and to identify hot spots for the different product groups. It aims to show the contribution of the different life-cycle phases (production, distribution, use and end-of-life) of selected products to global warming. The comparison of other environmental issues was made difficult by the fact that no other indicator has been consistently used across product groups. For this purpose, more than 30 LCA studies were reviewed. The focus was laid on the following product groups:

Table 14: Product groups for which LCA were analysed

Consumer Electronics / IT	Large White Goods	Small White Goods
• Smartphone • Tablet PC • Smartwatch • Notebook • Television • Printer	• Vacuum Cleaner • Washing Machine • Dishwasher • Fridge	• Kettle • Coffee Machine

The reviewed studies come from a broad variety of sources (academic papers, company publications, ecodesign preparatory studies, etc.) and the underlying LCA methodologies vary significantly ranging from simplified LCA (e.g. MEErP used in Ecodesign preparatory studies) to LCA following standards ISO 14040 and 14044.

Chapter 5.1 described possible problems that can arise at the different phases of an LCA. Because of different functional units, system boundaries and other assumptions, the comparison of absolute values (e.g. GWP [kg CO2-eq.]) between the product categories and products can be misleading. For this purpose, only relative numbers for the different impact categories are presented in Table 15, highlighting the environmental impacts in terms of GWP.

It can be observed in below table that smartphones, tablets, smartwatches and notebooks have their highest environmental impact (in terms of GWP) during the production phase (>70%). These are consumer electronics that have usually relatively short lifetimes (2-5 years). The reason for the dominance of the production phase lies in the very energy and resource intensive production of semiconductors (ICs and memory placed on the PCB). Contrary to other energy related products, the energy consumption in use is limited, only accounting for the recharging of the battery over a shorter period of time.

For the other product groups most of the time the use-phase dominates, driven by energy use or other consumables (water, cartridges, coffee pads, etc.). The distribution and the end-of-life phases usually play a relatively minor role for all products. Negative values in the EoL phase indicate that the environmental credits are larger than the burdens.

Table 15: Comparison of different LCA results with respect to GWP (in %)

Product Group	Product Reference	Prod.	Use	Distr.	EOL	Source
Smartphones	Fairphone 2	82%	14%	7%	-3%	(Proske M. et al. 2016)
	Apple iPhone 8	80%	16%	3%	1%	(Apple 2017)
	Apple iPhone XR	76%	19%	4%	1%	(Apple 2018d)
	Google Pixel 3XL	71%	22%	6%	1%	(Google 2018)
	Sony Z5	78%	13%	10%	-1%	(Ercan et al. 2016)
Tablet PC	iPad—6th generation (32 GB)	82%	13%	4%	1%	(Apple 2018c)
	iPad - 7th gen	79%	14%	6%	1%	(Apple 2019c)
Smartwatch	AppleWatch Series 4	71%	18%	10%	1%	(Apple 2018b)
	AppleWatch Series 5	77%	13%	9%	1%	(Apple 2019b)
Notebook	Apple MacBook 12 inch	83%	12%	4%	1%	(Apple 2018a)
	Apple MacBook 16 inch	75%	19%	5%	1%	(Apple 2019a)
	Lenovo ThinkPad E580	70%	21%	9%	0%	(Lenovo 2017)
	Dell Latitute 7300	75%	24%	9%	-8%	(Dell 2019)
Television	32" LCD-TV	14%	84%	2%	0%	(Stobbe L. 2007b)
	42" PDP-TV	13%	86%	1%	0%	
	Samsung Flat Panel QM55N	29%	69%	1%	1%	(Samsung 2019)
	Plasma Television Device	24%	78%	1%	-4%	(Hischier and Baudin 2010)
	HD LED TV (LG 43LW310C)	14%	85%	0%	1%	(LG 2016)
Vacuum Cleaner	Reference Canister VC	26%	77%	2%	-5%	(Gallego-Schmid et al. 2016)
	Reference Canister VC	18%	81%	0%	1%	(Bobba et al. 2015)
	Reference Canister VC	9%	88%	0%	3%	(Blepp M et al. 2013)
	Reference Hand VC	8%	89%	0%	3%	
	Reference Battery VC	28%	62%	0%	9%	
	Reference Canister VC	28%	67%	10%	-4%	(Viegand Maagøe A/S 2019)
	Reference Cordless VC	33%	63%	7%	-4%	
	Reference Robot VC	48%	47%	6%	-1%	
Washing Machines	Reference horizontal-axis WM	25%	79%	0%	-4%	(Rüdenauer et al. 2005)
	Reference horizontal-axis WM	42%	74%	2%	-18%	(Yuan Z. et al. 2015)
	Base Case WM	19%	81%	3%	-2%	(Boyano A. et al. 2017)
Dishwasher	Standard Dishwasher (A)	9%	91%	0%	0%	(Gensch C-O. et al. 2013)
	Standard Dishwasher (A+++))	13%	87%	0%	0%	
Fridge	Base Case household fridge	18%	82%	6%	-6%	(VHK and ARMINES 2016)
	Base Case household fridge	12%	89%	0%	-2%	(Rüdenauer et al. 2005)
Printer	EP-Copier mono	34%	61%	3%	2%	(Stobbe L. 2007a)
	EP-Copier color	39%	54%	3%	3%	
	EP-Printer mono	15%	82%	1%	1%	
	EP-Printer color	18%	79%	2%	2%	
	IJ-Printer color	60%	28%	6%	6%	
	IJ-Printer color	57%	32%	5%	5%	
	Color Laser Office Printer	14%	86%	0%	0%	(Lexmark 2016)
	Deskjed D1360 Inkjet Printer	24%	73%	2%	1%	(Grzesik K. and Terefeńko T. 2012)
Kettle	Electric Kettle	7%	92%	1%	1%	(Marcinkowski and Zych 2017)
Coffee Machine	Nespresso	40%	47%	8%	5%	(Quantis 2013)
	French Press	10%	88%	0%	2%	(Brommer et al. 2011)
	Filter drip coffee maker	14%	78%	0%	8%	
	Fully automatic coffee	6%	90%	0%	4%	
	Pad filter machine with credit	10%	86%	0%	4%	
	Capsule (PP+Alu) with credit	25%	64%	0%	12%	
	Capsule (100% Alu) with credit	25%	69%	0%	7%	

5.4 Identification of environmental break-even points

This chapter has the main objective to summarise findings from recent studies on the optimal lifetime of different product groups and to show whether optimal environmental break-even points exist. A break-even point in time is reached when the overall environmental impact (manufacturing, use phase, end of life) of purchasing a new device is lower than the environmental impact of extending the use time of an existing device. Letting a device have a longer use phase avoids specific impacts during manufacturing, such as mineral extraction and energy use and end-of-life, such as recycling, incinerating and landfilling. If the main environmental impact is coming from the manufacturing phase, the focus should lie on durability and maintenance. In this case, the policy advice would be to replace the old device as late as possible. On the other hand, replacing an old device with a new, more efficient one can lower the impacts of the use phase. Depending on the level of benefit, the policy advice would be to replace the device at a certain point in time. In this case, the focus would lie on the development of more energy efficient technologies. The following figure illustrates the idea of an environmental break-even point.

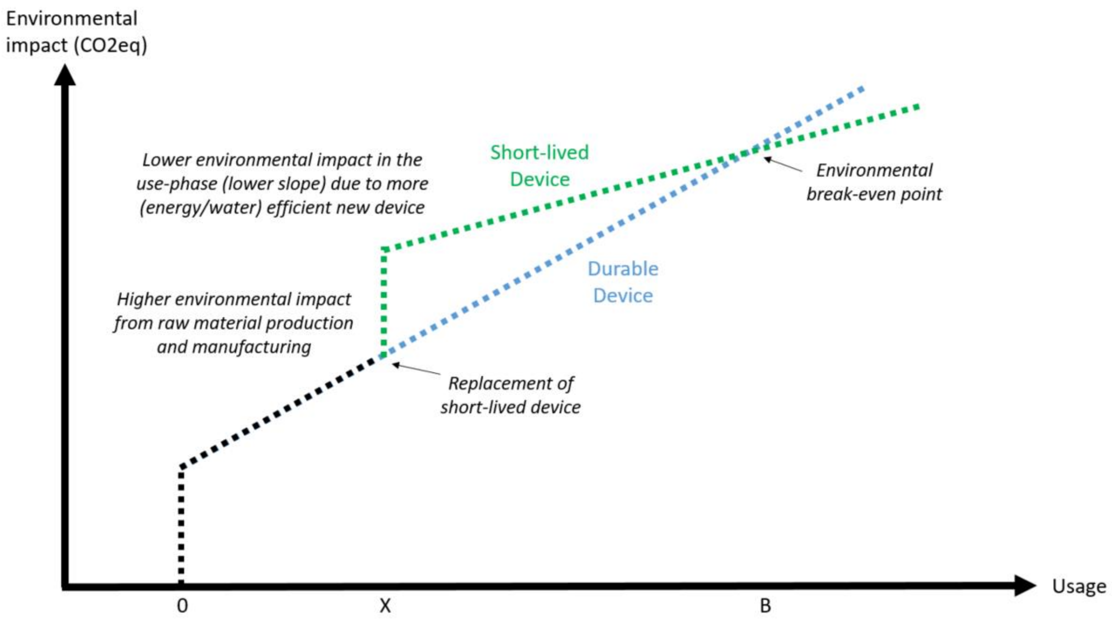

Figure 35: Illustration of an environmental break-even point (Source: own illustration)

The energy efficiency of household appliances and consumer electronics has significantly improved since the introduction of the Ecodesign Directive and Energy Labelling.

One of the consequences of this evolution is that the relative importance of the production phase has been rising in the product LCA and material efficiency has now become a major focus of European policy action. This can be in particular seen in the first Circular Economy Action Plan which explicitly called to “emphasise circular economy aspects in future product design requirements under the Ecodesign Directive” (EC 2015a). This aspect is further strengthened in the second Circular Economy Action plan which aims for a sustainable product policy initiative and highlights electronics and ICT as priority sector with high potential for circularity (EC 2020).

However, it is not only the improvement of the energy efficiency that shifts the environmental focus more towards the production phase, but also new design trends that move towards a smart and connected home (e.g. connected washing machines and fridges) and more battery driven devices (e.g. battery vacuum cleaner, wearables, etc.), as shown in Chapter 4. The use of more semiconductors (e.g. ICs and memory placed on the PCB) comes with an increased environmental impact of the production phase. For this purpose, material efficiency aspects are becoming increasingly important and lifetime extension should become a priority for all product groups. The following subchapters discuss possible break-even points for each product group in the scope of PROMPT.

5.4.1 Mobile phones (smartphones)

All analysed lifecycle assessments of mobile phones show that the electronic components in phones cause the main environmental impact. Since the main impact is related to the product manufacturing, prolonging the use time (number of years) has a high potential to reduce the overall environmental impact. This can be reached through more robust design, better reparability, longer battery lives and modularity of certain components. A modular design usually comes with a slightly higher impact on manufacturing when compared to a non-modular device. This is due to additional board-to-board connectors, sub-housing of the modules and more PCB area for the connectors.

However, this additional environmental impact during the manufacturing phase can be compensated through an extended lifetime which modularity enables. The following analysis from the Fairphone 2 LCA shows the potential of a modular and therefore repairable/upgradable design as compared to a non-repairable baseline scenario. The repair scenario has a positive effect on the whole life cycle and reduces the GWP by 28 %. Furthermore, with increasing processing capacity and more powerful batteries the energy consumption of new phones is increasing.

For these reasons, from a GWP point of view, there is no optimal point to change a smartphone and its lifetime should be maximised.

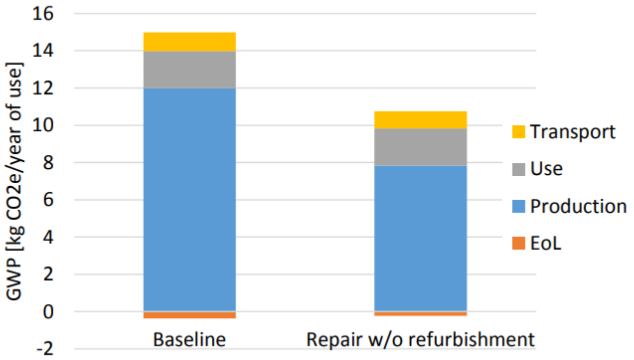

Figure 36: Results per year of use - baseline and repair scenario (Proske M. et al. 2016)

5.4.2 Televisions

Table 15 shows that most LCA find that the main environmental impact of televisions is generated during the use phase and mainly linked to electricity consumption over the lifetime. The energy efficiency of televisions has improved significantly in the last decades (see Figure 37).

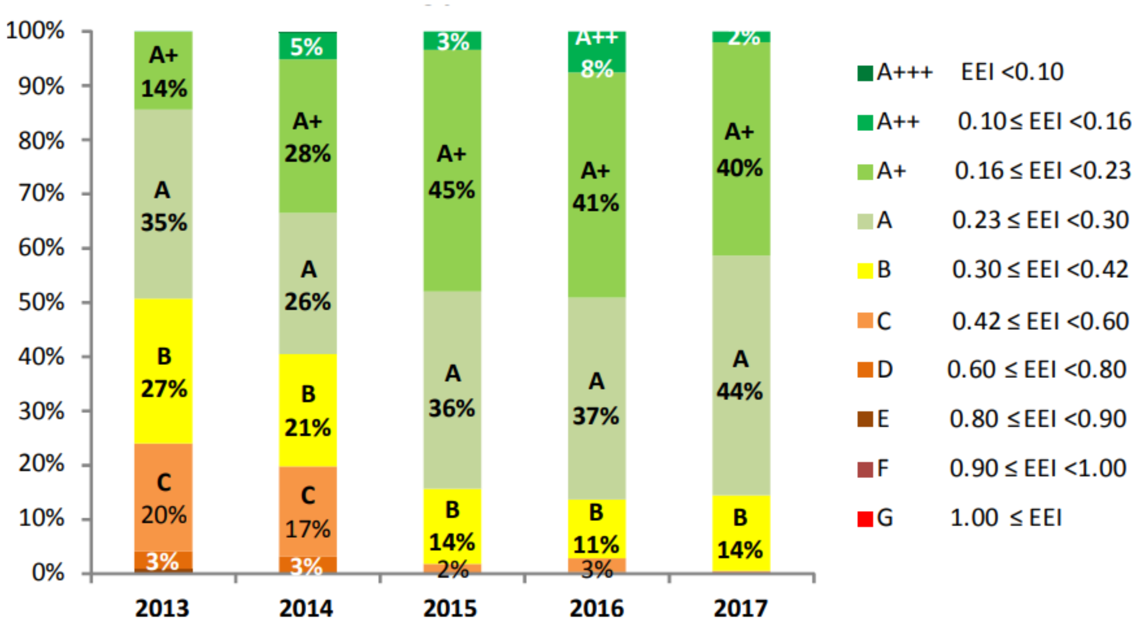

Figure 37: EU television unit sales by EU Energy Label classes 2013-2017 (EC 2019c)

However, since display technologies have been evolving quickly, changing from CRT to LCD with more ICs and larger PCB areas, material efficiency criteria are becoming more and more important.

A study conducted for the German Environmental Agency showed in an ecological comparative analysis results of environmental impacts for short lived and long lived televisions. For the long life appliance one single appliance was considered with a replacement of the hard drive and the power-supply board. In the case of the short-lived appliance, the TV was replaced instead. Although the new television comes with improved energy efficiency, below Figure shows that the shorter-lived television performs worse for all environmental indicators (Prakash S. et al. 2016).

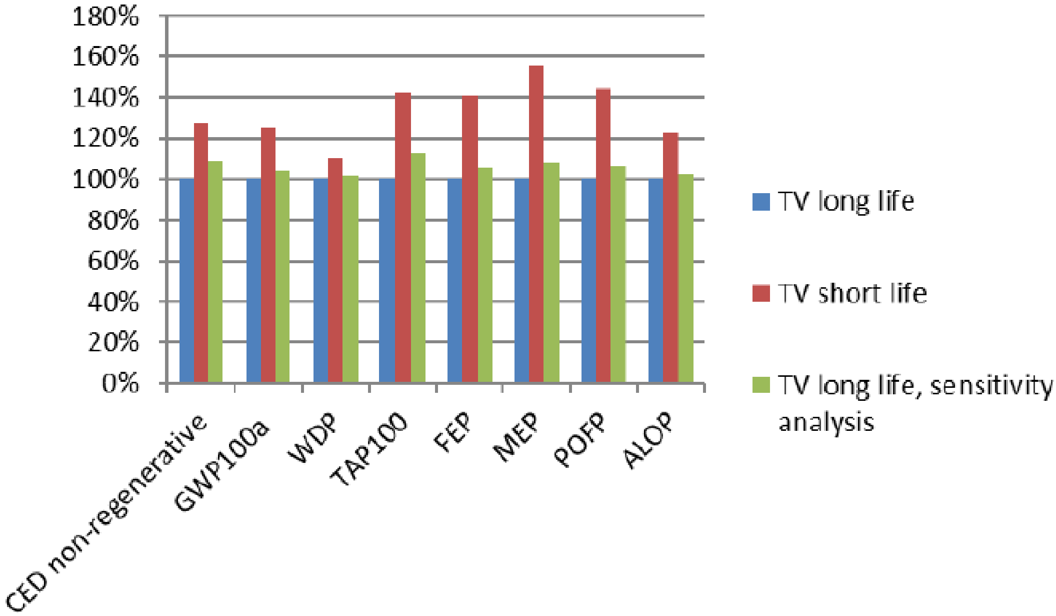

Figure 38: Environmental impacts of a short- and long-life television (> 10 years)

When looking to a more detailed analysis on the part level, results of an LCA conducted by the JRC show that PCBs are the major contributor to the environmental impacts of the manufacturing stage (93% for GWP). Repairing a product always implies additional environmental impacts due to the replacement of the faulty part, which can be compensated as long as the product is used longer up to the point in which repair becomes less beneficial than replacing a device. This means that the lifetime of the television has to be extended for a longer period of time if the parts repaired have a high environmental. The JRC study shows that in the case of the T-con board and main PCB, the television should be used at least 3-4 years longer than an average device to make repair beneficial from an environmental point of view. For other parts, such as speakers that have smaller environmental impacts, the repair would be environmentally beneficial even with a marginal increase of the time of use. The following table summarizes the findings (Sanfelix et al. 2019):

Table 16: Calculated lifetimes when the GWP impact of Repair and Replacement Scenarios are equals (x stands for „the lifetime after repair“)

Part repaired	Year of failure	x (years)	Break-even time (years)
Main PCB	4	9.4	13.4
T-con board	4	10.2	14.2
Speakers	4	6	10

This analysis on the reparability of television also implies that specific parts such as the main PCB or the T-con board that have a high environmental impact should be initially designed in a reliable way that allows for a long lifetime.

As has been shown in Chapter 4, the average useful lifetime of televisions in the EU usually ranges from 5 to 10 years. However, numerous studies suggest, that extending the useful lifetime beyond 10 years would be beneficial from an environmental point of view.

5.4.3 Washing machines

Washing machines are investment goods or “workhorse” goods which are used by households several times a week. The analysed lifecycle assessments of washing machines in Table 15 suggest, that the use-phase is the dominant life cycle phase from an environmental point of view. This is primarily related to energy and water use. Energy efficiency of washing machines has improved significantly in the last decades, but the remaining improvement potential is decreasing. The following analysis of the efficiency classes of washing machines between 2004 and 2014 shows the trend towards more energy efficient devices:

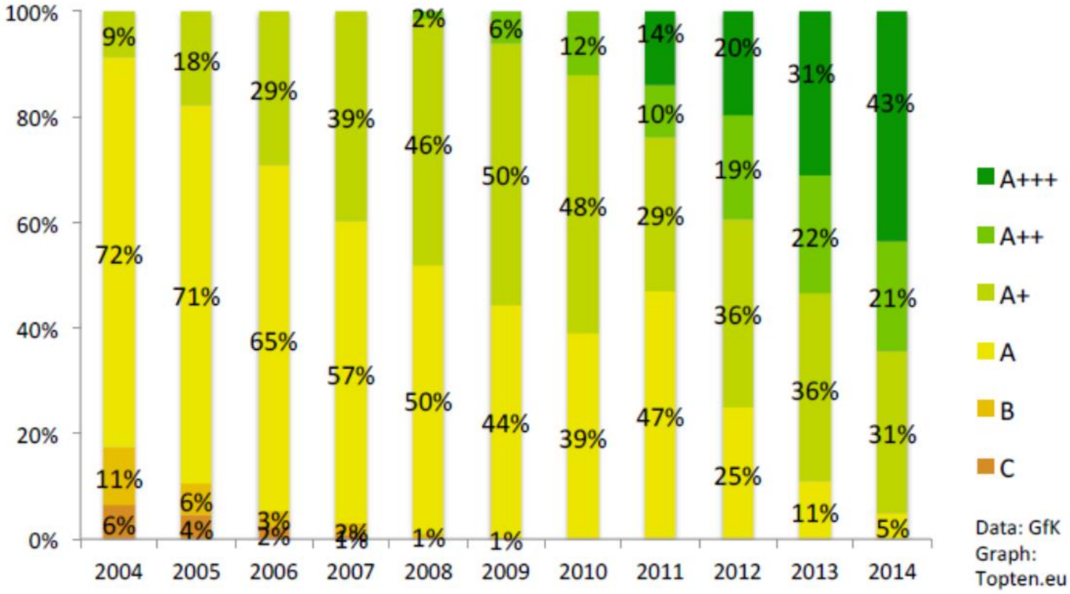

Figure 39: Efficiency classes of washing machines sales (EC 2015c)

Studies in different countries show that in around two third of the cases the main reason for replacing a washing machine is a technical defect ((Hennies, L. and R. Stamminger 2016), (FNAC DARTY 2019), etc.).

While the main environmental impact of washing machines lies in the use-phase, research shows that an extension of the lifetime of a washing machine beyond an average lifetime expectancy of 12.5 years has a positive environmental impact on freshwater eutrophication, climate change (measured as GWP) and abiotic depletion of elements (Tecchio P. et al. 2016). As far as global warming potential is concerned, extending the lifetime of the washing machine is environmentally beneficial as long as the alternative product does not consume at least 15% less electricity during the use phase. For other impact categories, such as the abiotic depletion potential impact that is largely influenced by the use of materials during the manufacturing phase, extending the lifetime of washing machines was shown to be always beneficial, independently of the energy efficiency of the replacement products.

These tendencies are supported by a study conducted for the German Environmental Agency (Prakash S. et al. 2016), finding that a long-life washing machine (20 years) has a lower environmental impact on all impact categories than an average washing machine (10 years) and a short-life washing machine (5 years). The impacts are presented in below Figure.

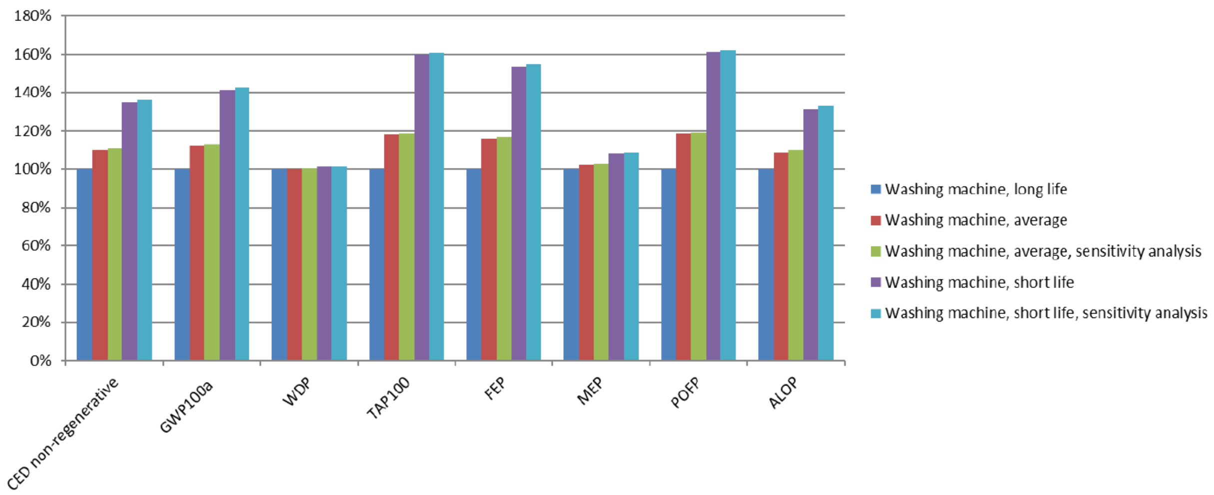

Figure 40: Impact assessment for short-life, average life and long-life washing machine (> 20 years)

Despite an increase in energy efficiency of the new appliances and higher production costs of longer-life washing machines, the shorter-life devices perform worse for all environmental indicators. According to this study, over a period of 20 years, a long-life washing machine causes around 1,100 kg less CO2eq emissions than the short-life device.

Most of the failures are nowadays stemming from electronics (control/engine/programmes), even before mechanical wear parts such as shock absorbers and bearings, the door, carbon brushes or pumps (Tecchio P. et al. 2016).

Current design trends towards more connected and integrated devices indicate that the share of failures related to electronics might increase in the future. This is why reliability and reparability of connected devices are key to good environmental performance of new products.

It was shown in Chapter 4 that the average lifetime of a washing machine is usually ranging between 8-12 years in the EU. Several studies suggest, that extending this lifetime up to 20 years could be beneficial from an environmental point of view. Although new ecodesign measures for washing machines, such as the availability of spare parts for at least 10 years, point in the right direction, a more robust initial design extending the first use of a device, without needing repair, could be even more beneficial.

5.4.4 **Vacuum Cleaners**

Like washing machines, vacuum cleaners are present in most of the households and used at least once a week (see Chapter 4). The analysed life cycle assessments of vacuum cleaners in Table 15 suggest, that most of the time the use-phase is the dominant life cycle stage from an environmental point of view. This is primarily related to electricity use. As for washing machines, the energy efficiency of vacuum cleaners has improved significantly in the last years. In this respect, Ecodesign and Energy Labelling Regulations have been very effective in reducing the average power from ca. 2200W before the 2014 measures, to 900W or less since 2017 (Viegand Maagøe A/S 2019). The following analysis of the efficiency classes of vacuum cleaners in 2015 and 2016 shows that most of the devices were in the energy label classification A of the previous Energy Label, which was annulled by the General Court of the European Union in November 2018 (Dyson Case).

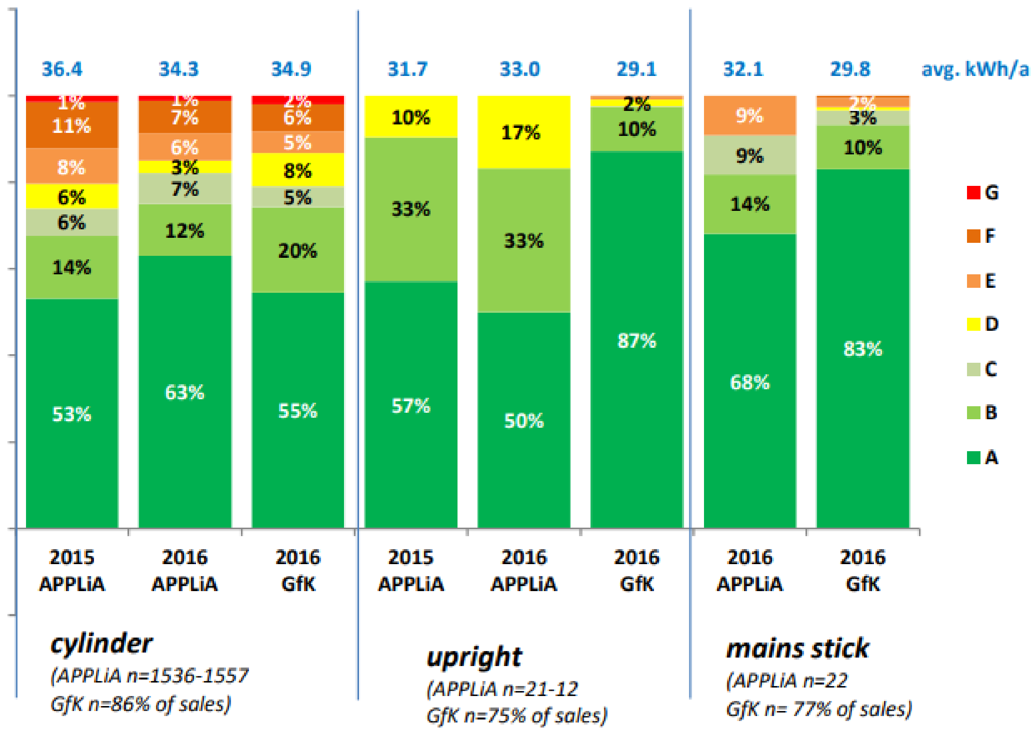

Figure 41: Energy Class Vacuum Cleaners 2015-2016 (Viegand Maagøe A/S 2019)

Current ecodesign requirements already include some durability measures for vacuum cleaners, such as minimum durability of the hose (40,000 oscillations under strain) and minimum operational lifetime of the operational motor lifetime (greater than or equal to 500 hours). However, recent studies show that there seems to be an opportunity for increasing the durability of the motor to 550 hours without much extra cost, e.g. by increasing the size of the carbon brushes while optimising the thermal and mechanical design of the universal motor. The extra cost, in consumer prices is estimated at around 2 EUR (Viegand Maagøe A/S 2019).

A study on the durability assessment of vacuum cleaners (Bobba et al. 2015) performed an environmental assessment applying a 'Durability Index' (Ardente F. and Mathieux F. 2012). The 'Durability Index' is calculated by comparing a base-case scenario and a durable scenario. One of the main hypothesis in this evaluation was a variation of the lifetime from 500 hours (base-case scenario) up to 800 hours (durable scenario). The analysis showed that the environmental benefits depend on the energy efficiency of the potential replacement device and the considered impact category. Yet, even higher benefits of the durable scenario could be shown for those impact categories more influenced by the manufacturing phase. When it comes to GWP, increasing the lifetime of the vacuum cleaner by 100 h (corresponding to around 2 years) saves around 1.5 % of GWP compared to its replacement with a 15 % more efficient product. Furthermore, the same lifetime extension can create higher benefits (up to 20%) for other impact categories (e.g. ADP). The analysis also shows that higher environmental benefits can be obtained for larger lifetime extensions. As an example, compared to the replacement of a vacuum cleaner with a new 15% more efficient device, a lifetime extension of 300 hours can reduce the GWP impact by 5 % (Bobba et al. 2015).

Sales of cordless vacuum cleaners and robot vacuums are rising (Chapter 4). These products are equipped with a battery which increases the environmental impact of the production phase and also has a significant impact at the end of life phase, since batteries need to be removed safely before further treatment (e.g. shredding & recycling).

Besides containing PCBs, robotic vacuum cleaners are also equipped with a broad variety of sensors (e.g. IR sensors, mechanical bumper sensors, drop sensors, piezo-electric sensors, etc.). These product categories also tend to have a shorter lifetime than canister vacuum cleaners, in particular because of their dependence on batteries. LCA of robotic vacuum cleaners confirm that the environmental impact is high the production phase. According to a recent study (Viegand Maagøe A/S 2019), the production phase (material & manufacturing) is responsible for 48% of the emission of CO2-eq and contributes with the highest share to most of the other impact categories, such as acidification, POPs or heavy metals.

In summary, recent research suggests that improved energy efficiency of conventional (canister) vacuum cleaners and the quick rise of cordless and robot devices moves material efficiency aspects to the front when it comes to the environmental evaluation of vacuum cleaners. It has been shown that the lifetime extension of conventional vacuum cleaners up to 800 hours motor lifetime can come with environmental benefits. Furthermore, battery powered devices have a relatively high footprint in the production phase, for which reason a longer lifetime could also be beneficial for these devices from an environmental point of view.

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