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Guidance for the Assessment of Material Efficiency: Application to smartphones – v 2

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Summary:

Improving the material efficiency of products has the potential of bringing added value to the environment and to the economy, by saving resources and avoiding production of waste. However, improved design of products needs to be assisted by appropriate assessment methods.

In this context, the Joint Research Centre Directorate B, Circular Economy & Industrial Leadership unit (JRC B.5), has prepared a methodological guide for the assessment of material efficiency of products (GAME). The methodology is based on the analysis of technical and functional aspects of products, as well as on the definition of life cycle assessment scenarios targeting environmental and economic impacts, aiming at two practical targets:

- To identify key material efficiency aspects of products;
- To propose tangible improvement measures.

This report describe the application of the methodology to the assessment of material efficiency aspects for smartphones, with the aim of compiling a list of possible actions for improving their performance with respect aspects as durability, reparability, upgradability, use of materials and recyclability.

The report is structured in the following chapters:

1. Product group definition and characterisation (including: scoping, legislation and testing methods of interest, relevant information on market, user behaviour and products);
2. Identification of hot-spots for material efficiency (based on product-specific information and life cycle considerations);
3. Technical analysis and assessment of material efficiency aspects (e.g. durability, reparability, use and recycling of materials);
4. Definition of possible improvement measures.

This is the draft version of the final report, which you are asked to comment by 2 June 2019. Depending on your interest in and familiarity with the subjects covered in the report, you may provide input either to all or some parts and questions of the report, by using the provided commenting form.

DISCLAIMER: The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

Table of Contents

SUMMARY

LIST OF ACRONYMS

1G	First Generation
2G	Second Generation
3G	Third Generation
3GPP	3rd Generation Partnership Project
3TG	Tungsten, Tantalum, Tin, and Gold
4G	Fourth Generation
5G	Fifth Generation
AC	Alternating Current
AMOLED	Active Matrix OLED
AMPS	Advanced Mobile Phone System
ASM	Artisanal small-scale mining
BBP	Butyl benzyl phthalate
BFR	Brominated flame retardants
BS	Base Station
BoM	Bill of Materials
C&L	Classification & Labelling
CBD	Chronic Beryllium Disease
CDMA	Code division multiple access
CEPN	Clean Electronics Production Network
CF	Carbon Footprint
CFC	Chlorofluorocarbons
CLP	Classification, Labelling and Packaging
CoC	Code of Conduct
CMR	Carcinogenic, Mutagenic or toxic for Reproduction
CPU	Central Processing Unit
CRM	Critical Raw Materials
DBP	Dibutyl phthalate
DC	Direct Current
DEHP	Bis(2-ethylhexyl) phthalate
DIBP	Diisobutyl phthalate
DINP	di-isononyl phthalate
DIY	Do It Yourself
DNOP	di-n-octyl phthalate
DRC	Democratic Republic of Congo
EC	European Commission
ECHA	European Chemical Agency

EDGE	Enhanced Data rates for GSM Evolution
EEE	Electrical and Electronic Equipment
ELV	End-of-Life Vehicles
EoL	End of Life
EPR	Extended Product Responsibility
EPS	External Power Supplies
	Evolved Packet System
ErP	Energy-related Product
ESD	Electrostatic Discharges
EU	European Union
EUTRAN	evolved UMTS terrestrial radio access network
E-UTRA	evolved UMTS terrestrial radio access
GAME	Guide for the Assessment of Material Efficiency
GB	Gigabyte
GGSN	Gateway GPRS Support Node
GHG	Greenhouse gas
GPP	Green Public Procurement
GPRS	General Packet Radio Service
GPS	Global Positioning System
GPSD	General Product Safety Directive
GPU	Graphics Processing Unit
GSH	Globally Harmonised System
GSM	Global Systems for Mobile Communications
GWP	Global Warming Potential
HBCDD	Hexabromocyclododecane
HC	Hydrocarbons
HCFC	Hydrochlorofluorocarbons
HD	High Definition
HDSPA	High-Speed Downlink Packet Access
HFC	Hydrofluorocarbons
IC	Integrated Circuit
ICT	Information and Communications Technology
IEC	International Electrotechnical Commission
IPXX	Ingress Protection XX
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCD	Liquid Cristal Display

169	LCI	Life Cycle Inventory
170	LED	Light Emitting Diode
171	LP	Low Power
172	LPDDR	Low-Power Double Data Rate
173	LTE	Long Term Evolution
174	MIMO	Multi Input Multi Output
175	MoU	Memorandum of Understanding
176	MP	Mega Pixels
177	NFC	Near Field Communication
178	NGO	Non-Governmental Organisation
179	NIB	Neodymium
180	NMT	Nordic Mobile Telephone
181	OEM	Original Equipment Manufacturer
182	OS	Operating System
183	PA	Power Amplifiers
184	PBB	Polybrominated biphenyls
185	PBDE	Polybrominated diphenyl ethers
186	PBT	Persistent, Bio-accumulative and Toxic
187	PC	Personal Computer
188	PCB	Polychlorinated biphenyls
189	PCT	Polychlorinated terphenyls
190		Projected Capacitive Touch
191	PRO	Producer Responsibility Organisation
192	PVC	Poly Vinyl chloride
193	RAM	Random-Access Memory
194	RAPEX	Rapid Alert System for non-food dangerous products
195	REAPRO	Resource Efficiency Assessment of Energy-related PROducts
196	REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
197	RCI	Responsible Cobalt Initiative
198	RED	Radio Equipment Directive
199	REE	Rare Earth Elements
200	RNC	Radio Network Controller
201	ROHS	Restriction of Hazardous Substances Directive
202	SD	Storage Device
203	SGSN	Serving GPRS Support Node
204	SIM	Subscriber Identity Module
205	SMD	Surface Mount Device

SoC	State of Charge
	System on a Chip
SVHC	Substance of Very High Concern
TACS	Total Access Communication System
TBBPA	Tetrabromobisphenol A
TCPP	Phosphoric acid tris (2-chloro-1-methylethyl) ester
TDCPP	tris (1,3-dichloro-2-propyl) phosphate
TDMA	Time Division Multiple Access
TD-CDMA	Time Division Synchronous Code Division Multiple Access
TD-SCDMA	Time Division Synchronous Code Division Multiple Access
TWG	Technical Working Group
UMTS	Universal Mobile Telephone System
UN	United Nations
UPA	Universal Power Adaptor
USB	Universal Serial Bus
vPvB	very Persistent and very Bio-accumulative
WEEE	Waste Electrical and Electronic Equipment
WiFi	Wireless Fidelity
WMSC	Wideband CDMA Mobile Switching Centre
W-CDMA	Wideband CDMA Mobile Switching Centre

INTRODUCTION

The Communications from the Commission COM(2015) 614 "Closing the loop – An EU action plan for the Circular Economy" and COM(2016) 773 "Ecodesign Working Plan 2016-2019" point out the increased importance of improving the resource efficiency of products in order to promote a transition towards a more circular economy in the EU. This can be for instance supported through a series of measures aiming to make products more durable, easier to repair, reuse or recycle.

Improving the material efficiency of products has the potential of bringing added value to the environment and to the economy, by saving resources and avoiding production of waste. However, improved design of products needs to be assisted by appropriate assessment methods. The importance of assessment and verification procedures is also confirmed by the recent creation of the CEN/CENELEC JTC10 "Energy-related products – Material Efficiency Aspects for eco-design", which is working on the development of general standards on material efficiency aspects for Energy-related Products (ErP).

In this context, the Commission has launched a research study focused on the assessment of material efficiency aspects for smartphones, and aimed at compiling a list of possible actions for improving their performance with respect to circular economy aspects such as durability, reparability and upgradability, use of materials and recyclability. The study, entrusted by DG ENV to the Joint Research Centre Directorate B, Circular Economy & Industrial Leadership unit (JRC B.5), will follow the Guidance for the Assessment of Material Efficiency (GAME), which is described in the present document while applied to the analysis of smartphones.

GAME has been prepared by JRC B.5 to support the assessment of material efficiency of products and the definition of possible improvement measures in those areas. The methodology is targeted at achieving two practical aims:

1. Identification of key material efficiency aspects of products;
2. Proposal of tangible improvement measures.

GAME is based on the analysis of technical and functional aspects of products, as well as on the definition of life cycle scenarios of assessment targeting environmental and economic impacts. The methodology builds on in-house knowledge about Life Cycle Assessment (LCA) (Cordella et al. 2015; Cordella and Hidalgo 2016), material efficiency analysis (Alfieri et al. 2018a; Cordella et al. 2018a; Cordella et al. 2019a) and product policy analysis and implementation (Cordella et al. 2018b, 2019b), as well as on former methodological work carried out in the JRC (Ardente and Mathieux 2014).

Final results of the study, which has a research orientation, could feed into work on actions covered under the Circular Economy Action Plan and related to product policy[1] and the Ecodesign task force for ICT products[2].

This draft report is structured in the following chapters:

1. Product group definition (scoping, legislation and testing methods of interest);
2. Market characterisation;
3. Information on user behaviour;
4. Analysis of technical and system aspects;

[1] COM(2015) 614
[2] COM(2016) 773

5. Definition of a framework for the life cycle assessment of material efficiency hotspots (Note: analysis to be completed for the final report);
6. Definition of improvement measures;
7. Questions for stakeholders;
8. Preliminary conclusions.

A Technical Working Group (TWG) of experts, consisting of manufacturers, retailers, repairers, recyclers, academia, environmental and consumer NGOs, as well as experts working in relevant authorities of Member States, has been formed to provide input to the study. Two written consultations have been planned to get technical input and feedback from stakeholders:

- The first consultation took place from 23 April 2018 until 21 May 2018.
- The second consultation is taking place from 6 May 2019 until 2 June 2019.

A series of boxes have been inserted along the document in order to point out specific questions of interest for the study team. We would much appreciate if you could send your feedback, on these questions and any other comments you may have, to JRC-B5-E4C@ec.europa.eu by using the provided commenting form. Depending on your interest and familiarity with the subjects covered in the report, you may provide input either to all or some parts of the report.

Information about the progress of the study and the final report will be made available on a dedicate website (http://susproc.jrc.ec.europa.eu/E4C/index.html).

1 PRODUCT GROUP DEFINITION

The present study focuses on the assessment of material efficiency aspects associated to the design of smartphones. The first step is to define the scope of the analysis, including the identification of legislative references and existing testing methods.

Once the product group is defined, background information has to be gathered about:

- Market and use of the product (e.g. information about prices of new and second hand products, costs of repair/refurbishment, functional lifetime, consumers expectations, market failures, circular business models).
- Technical design and related product systems (e.g. functions, parts and technologies, main causes of failure, Bill of Materials and End of Life, hazardous components).

This will be used in the study for the definition of product design option(s) which can be considered representative for average performance conditions, and for the further assessment of material efficiency aspects.

1.1 Scoping

1.1.1 Key definitions

Some general definitions were found in a few voluntary labelling and certification schemes, as described in the table below. As apparent, no standard definition is used internationally for this fast developing product group.

Table 1: Definitions provided in different labelling and certification schemes

Reference	Scope	Definition
RAL-UZ 106 (2017) - Blue Angel Eco-Label for Mobile Phones	Mobile phones	Mobile phones, i.e. 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"[3].

[3] The former definition, used in 2013 version of RAL-UZ 106 was "Mobile phones include "Handys" (as the Germans call mobile phones) and smart phones using the LTE (often also called 4G), HSDPA (3G+), UMTS (3G) or GSM standard (2G). The devices shall be primarily designed for making phone calls, text messaging and/or the mobile use of internet services. The size of the visible display is used to distinguish mobile phones from mobile computers (e.g. tablet PCs). Thus, devices with a maximum visible display size of 100 cm^2 are considered as mobile phones, provided that they meet the above requirements"

TCO Certified Smartphones 2.0	Smart-phones (display sizes ≥ 3" to ≤ 6")	The intended use of a Smartphone is portable computing and mobile communication. 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.
UL Standard 110, Edition 2 - Standard for Sustainability for Mobile Phones (2017)	Mobile phones	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.

1.1.2 Product classification

Some characteristics which can be used to classify smartphones are reported in Table 2 (OCU 2018a).

Table 2: Examples of key characteristics which can be used to classify smartphones (OCU 2018a)

Part	Characteristics
Display	> 5.5" (Phablets) 5-5.5" (Medium-size smartphones) < 5" (Small-size smartphones)
Operating System (OS)	iOS (Apple) vs. Android
Memory	> 11-17 GB (iOS), > 8-13 GB (Android), external micro SD
Battery	2000-5000 mAh (theoretical vs. real)[4]
Camera	5-23 MP (back), 1-16 MP (front) Hardware (e.g. 1 vs. 2 back cameras) and software 4K, full HD, HD (video)

1.1.3 Scope of the study

For the purposes of this study, a smartphone is described as follows:

[4] Main sources of energy consumption: display, web browsing, watching videos, GPS

- A smartphone is a handheld electronic device designed for mobile communication (making phone calls, text messaging), internet connection and other uses (e.g. multimedia, gaming).
- It can be used for long-range communication over a cellular network of specialized base stations known as cell sites[5].
- It is functionally similar to wireless, portable computers (e.g. tablet PCs), since

  - designed for battery mode usage, and connection to mains via an external power supply is mainly for battery charging purposes,

  - presenting an operating system[6], WiFi connectivity, web browsing capability, and ability to accept original and third-party applications (Apps),
- It has a display size between 4 and 6.5 inches, a high-resolution touch screen interface in place of a physical keyboard, a fissure for a Subscriber Identity Module (SIM), and usually a camera.

In particular, the following functions and technical specifications seem to be important for consumers:

- Size of the screen, camera, quality aspects as reliability and screen resolution (Kantar World Panel 2017),
- Longevity of battery, internet access, and high specification camera (Benton et al. 2015).
- Availability of operating system updates, which do not decrease the operating speed of the device (also known as "software obsolescence").

Basic mobile phones, feature phones[7] and smart-watch phones are not considered in the scope of this study.

1.2 Legislative context and testing methods

This section describes legislative aspects that can influence material efficiency of the product (e.g. repair and/or upgrade, use of materials). Testing methods and standards which are used worldwide to assess and verify material efficiency of the product are also presented.

1.2.1 Safety

1.2.1.1 General Product Safety Directive

The General Product Safety Directive (GPSD) 2001/95/EC aims to ensure that only safe products are made available on the market. The GPSD applies in the absence of other EU legislation, national standards, Commission recommendations or codes of practice relating to safety of products. It also complements sector specific legislation. Specific rules exist for the safety of toys, electrical and electronic goods, cosmetics, chemicals and other specific product groups[8]. The GPSD establishes obligations to both businesses and Member States' authorities:

[5] These include GSM standard (2G), UMTS (3G), HSDPA (3G+), LTE (often also called 4G), 5G, or similar

[6] For examples: Google's Android, BlackBerry OS, Apple's iOS, Nokia's Symbian, Microsoft's Windows Phone, or similar

[7] A feature phone is a mobile phone that incorporates features such as the ability to access the Internet and store and play music but lacks the advanced functionality of a smartphone.

[8] https://ec.europa.eu/info/business-economy-euro/product-safety-and-requirements/consumer-product-safety/standards-and-risks-specific-products_en (accessed on 27 February 2019)

- Businesses should place only products which are safe on the market, inform consumers of any risks associated with the products they supply. They also have to make sure any dangerous products present on the market can be traced so they can be removed to avoid any risks to consumers.

- Member States, through their appointed national authorities, are responsible for market surveillance to check that products on the market are safe. Information about dangerous products found on the market has to be reported to the Rapid Alert System for non-food dangerous products (RAPEX).

1.2.1.2 Radio Equipment Directive

The Radio Equipment Directive 2014/53/EU (RED) ensures a Single Market for radio equipment by setting essential requirements for safety and health, electromagnetic compatibility, and the efficient use of the radio spectrum. It applies to all products using the radio frequency spectrum, including smartphones.

The Radio Equipment Directive requires that manufacturers ensure that the radio equipment is accompanied by instructions and safety information. Such information has to include, where applicable, a clear description of accessories and components, including software, which allow the radio equipment to operate as intended.

In the recital of the Radio Equipment Directive there is moreover a clear reference to mobile phones and their compatibility with a common charger.

1.2.1.3 Main standards and testing methods

Main standards and testing methods on safety include:

- IEC 60065:2014 - Audio, video and similar electronic apparatus - Safety requirements.

- IEC 60950-1:2005+AMD1:2009+AMD2:2013 CSV - Information technology equipment - Safety - Part 1: General requirements.

- IEC 62209-1:2016 - Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices. Devices used next to the ear (Frequency range of 300 MHz to 6 GHz).

- IEC 62368-1:2014 - Audio/video, information and communication technology equipment - Part 1: Safety requirements.

1.2.2 Chemicals

1.2.2.1 CLP Regulation

The Classification, Labelling and Packaging (CLP) Regulation (EC) No 1272/2008 is based on the UN's Globally Harmonised System (GHS) and its purpose is to ensure a high level of protection of health and the environment, as well as the free movement of substances, mixtures and articles.

Since 1 June 2015, CLP is the only legislation in force in the EU for classification and labelling of substances and mixtures. CLP is legally binding across the Member States and directly applicable to all industrial sectors. It requires manufacturers, importers or downstream users of substances or mixtures to classify, label and package their hazardous chemicals appropriately before placing them on the market. Hazard classes used in CLP cover physical, health, environmental and additional hazards.

CLP is also the basis for many legislative provisions on the risk management of chemicals. In addition, the notification obligation under CLP requires manufacturers and importers to submit classification and labelling information for the substances they are placing on the market to a database (the "C&L Inventory"') held by the European Chemical Agency (ECHA).

1.2.2.2 REACH Regulation

The Regulation (EC) No 1907/2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) aims to improve the protection of human health and the environment from the risks that can be posed by chemicals because of their intrinsic properties. REACH establishes procedures for collecting and assessing information on the properties and hazards of substances.

Companies are responsible for collecting and communicating information on the properties and uses of the substances they manufacture, import or use in their products above one tonne a year. Depending on the volume of the substance, different rules apply. The Regulation also calls for the progressive substitution of the most dangerous chemicals (referred to as "Substances of Very High Concern") when suitable alternatives have been identified. SHVCs are defined as:

1. Substances meeting the criteria for classification as carcinogenic, mutagenic or toxic for reproduction (CMR) category 1A or 1B in accordance with the CLP Regulation.
2. Substances which are persistent, bio-accumulative and toxic (PBT) or very persistent and very bio-accumulative (vPvB) according to REACH Annex XIII.
3. Substances on a case-by-case basis, which cause an equivalent level of concern as CMR or PBT/vPvB substances.

Once a substance is identified as an SVHC, it is included in the Candidate List. ECHA regularly assesses the substances from the Candidate List to determine which ones should be included in the Authorisation List (Annex XIV). Once a substance is included in an Authorisation List, this can be used/produced only if

a. The risk to human health or the environment is adequately controlled, or
b. It can be demonstrated that the socio-economic benefits compensate the impacts, also taking into account possible alternatives

A Restrictions List (Annex XVII) is also periodically revised. Once a substance is included in the Restrictions List, specific or general uses of such substance are prohibited.

Article 33 of REACH establishes the right of consumers to be able to obtain information from suppliers on substances in articles and also suppliers of articles are obliged to provide industrial/professional users or distributors with certain pieces of information on articles containing substances with irreversible effects on human health or the environment.

1.2.2.3 ROHS Directive

Smartphones are in the scope of the Restriction of Hazardous Substances Directive 2011/65/EU (ROHS), included as "IT and telecommunications equipment". The legislation restricts the use of certain hazardous substances used in electrical and electronic equipment, which have to be substituted by safer alternatives. As listed in the amended Annex II of the Commission Delegated Directive (EU) 2015/863, restricted substances are:

- Lead (0.1 %)
- Mercury (0.1 %)
- Cadmium (0.01 %)
- Hexavalent chromium (0.1 %)
- Polybrominated biphenyls (PBB) (0.1 %)
- Polybrominated diphenyl ethers (PBDE) (0.1 %)
- Bis(2-ethylhexyl) phthalate (DEHP) (0.1 %)
- Butyl benzyl phthalate (BBP) (0.1 %)

- Dibutyl phthalate (DBP) (0.1 %)
- Diisobutyl phthalate (DIBP) (0.1 %)

The restriction of DEHP, BBP, DBP and DIBP does not apply to cables or spare parts for the repair, the reuse, the updating of functionalities or upgrading of capacity of Electrical and Electronic Equipment (EEE) placed on the market before 22 July 2019. Further exemptions are provided in Annex III and Annex IV.

1.2.3 Materials

1.2.3.1 EU list of Critical Raw Materials (CRM)

The Commission's communication COM(2017) 490 "on the 2017 list of Critical Raw Materials for the EU" indicates 27 raw materials that can be defined as critical because risks of supply shortage and their impacts on the economy are higher than those of most of the other raw materials (see Table 3).

Table 3: EU list of Critical Raw Materials on 13 September 2017

Raw Material		
1. Antimony	10. Germanium	19. Phosphorus
2. Baryte	11. Hafnium	20. Scandium
3. Beryllium	12. Helium	21. Silicon metal
4. Bismuth	13. Indium	22. Tantalum
5. Borate	14. Magnesium	23. Tungsten
6. Cobalt	15. Natural graphite	24. Vanadium
7. Coking coal	16. Natural rubber	25. Platinum Group Metals
8. Fluorspar	17. Niobium	26. Heavy Rare Earth Elements
9. Gallium	18. Phosphate rock	27. Light Rare Earth Elements

1.2.3.2 Import of minerals from conflict-affected and high-risk areas

The EU Regulation 2017/821 establishes a Union system for supply chain due diligence in order to curtail opportunities for armed groups and security forces to trade in tin, tantalum and tungsten, their ores, and gold. Minerals and metals covered by the EU Regulation 2017/821 are listed in Table 4.

Table 4: Conflict minerals and metals covered by the EU Regulation 2017/821

Description	Volume threshold (kg)
Tin ores and concentrates	5 000
Tungsten ores and concentrates	250 000
Tantalum or niobium ores and concentrates	To be adopted no later than 1 July 2020
Gold ores and concentrates	To be adopted no later than 1 July 2020
Gold, unwrought or in semi-manufactured forms, or in powder with a gold concentration lower than 99,5 % that has not passed the refining stage	100
Tungsten oxides and hydroxides	100 000
Tin oxides and hydroxides	To be adopted no later than 1 July 2020
Tin chlorides	10 000
Tungstates	100 000

Tantalates	To be adopted no later than 1 July 2020
Carbides of tungsten	10 000
Carbides of tantalum	To be adopted no later than 1 July 2020
Gold, unwrought or in semi-manufactured forms, or in powder form with a gold concentration of 99,5 % or higher that has passed the refining stage	100
Ferrotungsten and ferro-silico-tungsten	25 000
Tin, unwrought	100 000
Tin bars, rods, profiles and wires	1 400
Tin, other articles	2 100
Tungsten, powders	2 500
Tungsten, unwrought, including bars and rods obtained simply by sintering	500
Tungsten wire	250
Tungsten bars and rods, other than those obtained simply by sintering, profiles, plates, sheets, strip and foil, and other	350
Tantalum, unwrought including bars and rods, obtained simply by sintering; powders	2 500
Tantalum bars and rods, other than those obtained simply by sintering, profiles, wire, plates, sheets, strip and foil, and other	150

This Regulation, which took effect on 1 January 2012, was designed to provide transparency and certainty as regards the supply practices of Union importers, and of smelters and refiners sourcing minerals and metals from conflict-affected and high-risk areas. Union importers of these minerals or metals have disclosure obligations:

- Make available to Member State competent authorities the reports of any third-party audit carried out or evidence of conformity with a supply chain due diligence scheme recognised by the Commission;
- Make available to their immediate downstream purchasers all information gained and maintained pursuant to their supply chain due diligence with due regard for business confidentiality and other competitive concerns;
- Publicly report as widely as possible, including on the internet, on their supply chain due diligence policies and practices for responsible sourcing.

Where a Union importer can reasonably conclude that metals are derived only from recycled or scrap sources, it has to disclose publicly its conclusion and describe in detail the supply chain due diligence measures exercised. With the exception of this disclosure requirement, this Regulation does not apply to recycled metals.

1.2.3.3 Main standards and testing methods

Main standards and testing methods on materials have been identified only for plastics:

- ISO 1043-1:2011 - Plastics - Symbols and abbreviated terms - Part 1: Basic polymers and their special characteristics. The standard defines abbreviated terms for the basic polymers used in plastics, symbols for components of these terms, and symbols for special characteristics of plastics.
- ISO 1043-2:2011- Plastics - Symbols and abbreviated terms - Part 2: Fillers and reinforcing materials. The standard specifies uniform symbols for terms referring to fillers and reinforcing materials.

- ISO 1043-3:2016 - Plastics - Symbols and abbreviated terms - Part 3: Plasticizers. The standard provides uniform symbols for components of terms relating to plasticizers to form abbreviated terms.

- ISO 1043-4:1998 - Plastics - Symbols and abbreviated terms - Part 4: Flame retardants. The standard provides uniform symbols for flame retardants added to plastics materials.

- ISO 11469:2016 - Plastics - Generic identification and marking of plastics products. The standard specifies a system of uniform marking of products that have been fabricated from plastics materials. Provision for the process or processes to be used for marking is outside the scope of this International Standard.

1.2.4 Functional and performance aspects

1.2.4.1 Batteries

The Batteries Directive 2006/66/EC intends to contribute to the protection, preservation and improvement of the quality of the environment by minimising the negative impact of batteries and accumulators and waste batteries and accumulators. It also ensures the smooth functioning of the internal market by harmonising requirements as regards the placing on the market of batteries and accumulators. With some exceptions, it applies to all batteries and accumulators, no matter their chemical nature, size or design.

The Directive:

- Prohibits the marketing of batteries containing some hazardous substances (Batteries and accumulators must not have a lead, mercury or cadmium content above the fixed threshold limits of 0.004%, 0.0005% and 0.002% by weight, respectively, unless labelled in accordance with the Directive. Specific labelling requirements are outlined in the directive where these thresholds are exceeded);

- Defines measures to establish schemes aiming at high level of collection and recycling;

- Fixes targets to Member States for collection and recycling activities;

- Sets out provisions on labelling of batteries (in particular, all batteries have to be marked with the crossed-out wheeled bin symbol indicating "separate collection");

- Sets out provision on their removability from equipment: Member States have to ensure that manufacturers design appliances in such a way that waste batteries and accumulators can be readily removed, either by end-users or by independent qualified professionals.

Producers of batteries and accumulators and producers of other products incorporating a battery or accumulator are moreover given responsibility for the waste management of the batteries and accumulators that they place on the market.

1.2.4.2 External power supply

External Power Supplies (EPS) are subject to the EU ecodesign regulation (EC) No 278/2009. They convert power input from the mains into lower voltage output for smartphones and a large variety of other electric and electronic products.

Ecodesign requirements for EPS are mandatory for all manufacturers and suppliers wishing to sell their products in the EU. These requirements cover both the "active" efficiency, i.e. the average efficiency when power is supplied to, and the "no-load" power consumption, i.e. the power that the supply still uses when connected to the power mains but not supplying electricity to any device.

An EU Code of Conduct (CoC) on Energy efficiency of EPS is also available, the version 5 being released in 2013. The Code of Conduct is a voluntary initiative targeting single voltage external AC/DC and AC/AC power supplies for electronic and electrical appliances, which also include mobile phone chargers. The initiative aims to minimise the energy consumption of external power supplies both under no-load and load conditions in the output power range 0.3W to 250W.

At international level, an international efficiency marking protocol for EPS was developed by the U.S. EPA. This provides a system to designate the minimum efficiency performance of an EPS, so that finished product manufacturers and government representatives can easily determine a unit's efficiency. This mark demonstrates the performance of the EPS when tested to the internationally supported test methods (U.S. Department of Energy 2013).

In June 2009, a campaign[9] for the introduction of a voluntary agreement for a common charger for mobile phones was launched. many of the world's largest mobile phone manufacturers signed an EC-sponsored Memorandum of Understanding (MoU), agreeing to make most new data-enabled mobile phones marketed in the European Union compatible with a to-be-specified common EPS. All signatories agreed to develop a common specification for the EPS to allow for full compatibility and safety of chargers and mobile phones. The standard was published in December 2010 as EN 62684:2010 "Interoperability specifications of common EPS for use with data-enabled mobile telephones" and in January 2011 as IEC 62684:2011. Vencovsky et al. (2014) found that 99% of data-enabled phones sold in Europe in 2013 were compliant with the MoU. An updated version of IEC 62684:2018 has been published this year that makes it clearer that compliance with the MoU is equivalent to compliance with the standard. This standard specifies the interoperability based on Micro USB-B technologies. According to this standard the EPS must operate in the following ranges:

- 100-230 V
- 50-60 Hz
- 0 to 35 °C
- Up to 90% of relative humidity.

USB Micro-B is currently giving way to USB Type-C. Many manufacturers (Apple, Google, Lenovo, LG, Motorola, Samsung, and Sony) have signed a new MoU[10] committing that new smartphone models will be chargeable through a USB Type-C connector or cable assembly. For these purposes, the relevant standard is IEC 63002:2016 "Identification and Communication Interoperability Method for External Power Supplies Used with Portable Computing Devices". The objective of this International Standard is to support interoperability of external power supplies used with the increasing variety of portable computing devices that implement the IEC 62680-1-2 "USB Power Delivery" with the IEC 62680-1-3 "USB Type-C" connector standards. Broad market adoption of this International Standard is expected to make a significant contribution to the global goals of consumer convenience and re-usability of power supplies by building a global market system of IEC 62680 compliant devices and facilitating interoperability across different product categories. However, the new agreement still allows manufacturers to use also vendor-specific connectors.

[9] http://ec.europa.eu/growth/sectors/electrical-engineering/red-directive/common-charger_en (accessed on 9 October 2018)

[10] https://www.digitaleurope.org/wp/wp-content/uploads/2019/01/2018.03.20-MoU%20on%20the%20future%20of%20Common%20Charging%20Solutions%20(1)%20(1)%202.pdf (accessed on 22 February 2019)

1.2.4.3 Packaging and Packaging Waste Directive

The Packaging and Packaging Waste Directive 2004/12/EC seeks to reduce the impact of packaging and packaging waste on the environment by introducing recovery and recycling targets for packaging waste, and by encouraging minimisation and reuse of packaging. A scheme of symbols, currently voluntary, has been prepared through Commission Decision 97/129/EC. These can be used by manufacturers on their packaging so that different materials can be identified to assist end-of-life recycling. The latest revision of the Packaging and Packaging Waste Directive was published on 29 April 2015 with the adoption of Directive (EU) 2015/720 of the European Parliament and of the Council amending Directive 94/62/EC as regards the consumption of lightweight plastic carrier bags.

1.2.4.4 Guarantees for consumers

The Consumer Sales Directive 1999/44/EC regulates aspects of the sale of consumer goods and associated legal guarantees. According to the 1999/44/EC Directive the term guarantee shall mean any undertaking by a seller or producer to the consumer, given without extra charge, to reimburse the price paid or to replace, repair or handle consumer goods in any way if they do not meet the specifications set out in the guarantee statement or in the relevant advertising.

The duration of the guarantee for new products must be at least 2 years. The minimum duration is applied in the majority of EU-countries. Longer durations are applied in some countries (e.g. Sweden, Ireland, the Netherlands and Finland) depending on the expected lifespan of the item sold. The duration of the guarantee for second hand goods can be lower (minimum 1 year).

The seller must deliver goods to the consumer, which are in conformity with the contract of sale, and then further specifies presumption of conformity of a number of conditions. All Member States introduced in their national law a "reversal of burden of proof" of at least 6-months. This is the period within which the lack of conformity is presumed to have existed at the time of delivery and the seller is thus liable to the consumer, i.e. the seller must prove that the item was not defective. After six months the burden of proof shifts to the consumer, i.e. the consumer must prove that the product was defective.

Article 3 of the Consumer Sales Directive indicates a list of remedies that should be provided to the consumer in the case of a defect (i.e. repair, replacement, reduction in price and rescission of contract). In the first place, the consumer may require the seller to repair the goods or he may require the seller to replace them.

In addition, Directive 2011/83/EU on consumer rights defines the concept of "commercial guarantee" (also known as "warranty"), which can be offered by sellers or producers in addition to the legal guarantee obligation. This can either be included in the price of the product or at an extra cost.

The average consumer does not seem to be aware of the provisions set by legal guarantees. At EU level, awareness of commercial guarantees lies at 67% while only 35% are also aware of the legal guarantee period in their country: the majority of consumers in half of EU Member States think that the legal guarantee period is a single year. Additional coverage over a wider range of cases (e.g. accidental damage, water damage) is increasingly being offered to consumers as a complimentary service, in sales campaigns or in return for additional payment (Watson et al. 2017).

In 2018 the European Commission plans to propose "A New Deal for Consumers"[11]. This consists in the revision of the Injunctions Directive, with a view of fully exploiting the potential of injunctions by addressing the main problems faced by consumers in obtaining redress, and by diminishing significant disparities among Member States in the level of the use of the injunction procedure and its effectiveness. The Commission announced that the revision of the Injunction Directive would be presented as a "New Deal for Consumers" package together with other possible legislative actions on EU consumer law directives:

- Providing consumers with rights to individual remedies/redress against unfair commercial practices (by amending the Unfair Commercial Practices Directive);
- Ensuring more proportionate, effective and deterrent financial penalties to tackle breaches of consumer laws (by amending the Unfair Commercial Practices Directive, Unfair Contract Terms Directive, Consumer Rights Directive and Price Indication Directive);
- Introducing additional transparency requirements for online platforms, especially on whom consumers conclude contracts with when buying on online platforms (by amending the Consumer Rights Directive);
- Extending some consumer rights to contracts where consumers provide data instead of paying with money (by amending the Consumer Rights Directive);
- Simplifying some rules and requirements, such as information requirements and rules on sending back goods and reimbursement (by amending the Consumer Rights Directive and/or Unfair Commercial Practices Directive).

1.2.4.5 Durability and reparability

A press release of the European Parliament[12] informed the public about the request by MEPs of making goods and software easier to repair and update. Parliament highlights the importance of promoting a longer product lifespan, in particular by tackling programmed obsolescence for tangible goods and for software, and making spare parts affordable. More specifically, recommendations include:

- "Minimum resistance criteria" to be established for each product category from the design stage
- Extension of guarantees to fully cover periods of time in which repair is expected
- Promotion of repairs and second-hand sales
- Avoidance of technical, safety or software solutions which prevent repairs from being performed, other than by approved firms or bodies
- Ease of disassembly of essential components (such as batteries and displays), unless for safety reasons
- Availability of spare parts which are indispensable for the proper and safe functioning of the goods 'at a price commensurate with the nature and life-time of the product'
- Introduction of an EU-wide definition of "planned obsolescence" and of a system that could test and detect the "built-in obsolescence", as well as "appropriate dissuasive measures for producers".

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[11] http://www.europarl.europa.eu/legislative-train/theme-area-of-justice-and-fundamental-rights/file-new-deal-for-consumers (accessed on 18 April 2018)
[12] http://www.europarl.europa.eu/news/en/press-room/20170629IPR78633/making-consumer-products-more-durable-and-easier-to-repair (accessed on 21 March 2018)

- Development of an EU label to inform consumers better about product's durability, eco-design features, upgradeability in line with technical progress and reparability.

At Member State level, the French decree 2014-1482 published in December 2014[13] put new requirements on retailers to inform consumers about the durability of their products and the availability of spare parts, under the threat of fine of 15000 EUR. Manufacturers are required to deliver the parts needed for repairs within two months. The French decree also extends the burden of proof on the seller in the case of a fault within 24 months. Planned obsolescence is also a legal offence punishable by 300000 EUR. Planned obsolescence is defined as "all techniques by which a producer seeks to deliberately limit product life in order to increase the replacement rate" (Transform Together 2018).

Additionally, Sweden has lowered the VAT on the repair of certain products and allowed the tax deduction of repair costs. However, ICT products are not yet covered in this legislative context (Transform Together 2018). In Belgium, VAT is set at 6% for the repair of bicycles, shoes and clothes[14].

Out of the legislative context, some manufactures claim to meet specific standards and certifications to ensure a more durable smartphone:

- The Galaxy S8 Active claims to be tested to achieve both MIL-STD-810G[15] specification and IP68 certification[16]. This MIL-STD (also called MIL-SPEC, military standard, or MilSpecs) was developed by the U.S. Defense Department to test the survivability of devices that might be used by troops in the harshest conditions. Phones meet MIL-SPEC by undergoing a range of trials, among which a Transit Drop Test (Method 516.6 Procedure IV).

- A specific test method is also proposed by CTIA Certification, with a Device Hardware Reliability Test Plan (version 1.1) published in August 2017[17]. CTIA Hardware Reliability Certification is a voluntary initiative run by a trade association for the American market.

- IEC 60529 - Degrees of protection provided by enclosures (IP Code) (Table 5) is an important standard to classify products based on the degrees of protection provided against the intrusion of solid objects (including body parts like hands and fingers), dust, accidental contact, and water in electrical enclosures. The standard aims to provide users more detailed information than vague marketing terms such as waterproof. This standard defines the IP codes, which are designed as a 'system for classifying the degrees of protection provided by the enclosures of electrical equipment'. The IP Code (or International Protection Rating, sometimes also interpreted as Ingress Protection Rating) consists of the letters IP followed by two digits and an optional letter. The first number (from 0 to 6) in the rating code represents the degree of protection provided against the entry of foreign solid objects, such as fingers or dust (Table 6). The second number (from 0 to 8) represents the degree of protection against the entry of moisture (Table 7). IP67 and IP68 are the

[13] Decree No. 2014-1482 of 9 December 2014 concerning Disclosure Requirements and Supply of Spare Parts

[14] https://www.unizo.be/advies/welke-btw-tarieven-moet-u-toepassen (accessed on 30 May 2018)

[15] MIL-STD-810G available at http://everyspec.com/MIL-STD/MIL-STD-0800-0899/MIL-STD-810G_12306/ (accessed on 12 March 2019)

[16] https://insights.samsung.com/2017/08/11/drop-testing-samsungs-most-durable-smartphone-2/ (accessed on 13 February 2018)

[17] https://api.ctia.org/docs/default-source/certification/ctia-device-hardware-reliability-test-plan-ver-1-1.pdf (accessed on 7 June 2018)

highest level of protection claimed by some manufacturers. An IP code with an 'X' in place of the first or second number means that a device has not been tested with respect to the corresponding type of protection. Devices are not required to pass every test below the claimed rating, although many companies test their smartphones at various protection levels. Examples of how some devices are rated by manufacturers:

- The iPhone 8 and 8 Plus are rated with an IP67 rating, which means that they are fully protected from dust (6) and can also withstand being submerged in 1m of static water for up to 30 mins (7).

- The Samsung Galaxy S8 is rated IP68. This means that, like the iPhone 8 (and 8 Plus), the Galaxy S8 can withstand being submerged in static water, but the specific depth and duration must be disclosed by the company, which in this case is 1.5 meters for up to 30 minutes.

- The Sony Xperia XZ is rated with an IP65 and IP68 rating, meaning that it is protected from dust and against low-pressure water jets, such as a faucet, when all ports are closed. The company also specifies that the Z5 can be submerged in 1.5 meters of fresh water for up to 30 mins.

Table 5: meaning of IP codes used to claim the Smartphone's level of protection

IP codes	First Digit - SOLIDS	Second Digit - LIQUIDS
IP67	Protected from total dust ingress.	Protected from immersion between 15 centimetres and 1 meter in depth.
IP68	Protected from total dust ingress.	Protected from long term immersion up to a specified pressure.

Table 6: Solid protection levels set by the IEC 60529[18]

Level	Effective against	Description
0	-	No protection against contact and ingress of objects
1	>50 mm	Any large surface of the body, such as the back of a hand, but no protection against deliberate contact with a body part
2	>12.5 mm	Fingers or similar objects
3	>2.5 mm	Tools, thick wires, etc.
4	>1 mm	Most wires, slender screws, large ants etc.
5	Dust protected	Ingress of dust is not entirely prevented, but it must not enter in sufficient quantity to interfere with the satisfactory operation of the equipment
6	Dust tight	No ingress of dust; complete protection against contact (dust tight). A vacuum must be applied. Test duration of up to 8 hours based on air flow

Table 7: Moisture protection levels set by the IEC 60529[19]

[18] https://www.cnet.com/how-to/how-waterproof-are-the-new-iphones-heres-what-all-the-ratings-mean/ (accessed on 13 February 2018)

Level	Protection against	Effective against	Details
0	None	-	-
1	Dripping water	Dripping water (vertically falling drops) shall have no harmful effect on the specimen when mounted in an upright position onto a turntable and rotated at 1 RPM.	Test duration: 10 minutes Water equivalent to 1 mm rainfall per minute
2	Dripping water when tilted at 15°	Vertically dripping water shall have no harmful effect when the enclosure is tilted at an angle of 15° from its normal position. A total of four positions are tested within two axes.	Test duration: 2.5 minutes for every direction of tilt (10 minutes total) Water equivalent to 3 mm rainfall per minute
3	Spraying water	Water falling as a spray at any angle up to 60° from the vertical shall have no harmful effect, utilizing either: a) an oscillating fixture, or b) A spray nozzle with a counterbalanced shield. Test a) is conducted for 5 minutes, then repeated with the specimen rotated horizontally by 90° for the second 5-minute test. Test b) is conducted (with shield in place) for 5 minutes minimum.	For a Spray Nozzle: Test duration: 1 minute per square meter for at least 5 minutes Water volume: 10 litres per minute Pressure: 50–150 kPa For an oscillating tube: Test duration: 10 minutes Water Volume: 0.07 l/min per hole
4	Splashing of water	Water splashing against the enclosure from any direction shall have no harmful effect, utilizing either: a) an oscillating fixture, or b) A spray nozzle with no shield. Test a) is conducted for 10 minutes. Test b) is conducted (without shield) for 5 minutes minimum.	Oscillating tube: Test duration: 10 minutes, or spray nozzle (same as IPX3 spray nozzle with the shield removed)
5	Water jets	Water projected by a nozzle (6.3 mm) against enclosure from any direction shall have no harmful effects.	Test duration: 1 minute per square meter for at least 15 minutes Water volume: 12.5 litres per minute Pressure: 30 kPa at distance of 3 m

[19] https://www.cnet.com/how-to/how-waterproof-are-the-new-iphones-heres-what-all-the-ratings-mean/ (accessed on 13 February 2018)

6	Powerful water jets	Water projected in powerful jets (12.5 mm nozzle) against the enclosure from any direction shall have no harmful effects.	Test duration: 1 minute per square meter for at least 3 minutes Water volume: 100 litres per minute Pressure: 100 kPa at distance of 3 m
6K	Powerful water jets with increased pressure	Water projected in powerful jets (6.3 mm nozzle) against the enclosure from any direction, under elevated pressure, shall have no harmful effects. Found in DIN 40050, and not IEC 60529.	Test duration: at least 3 minutes Water volume: 75 litres per minute Pressure: 1000 kPa at distance of 3 m
7	Immersion, up to 1 m depth	Ingress of water in harmful quantity shall not be possible when the enclosure is immersed in water under defined conditions of pressure and time (up to 1 m of submersion).	Test duration: 30 minutes - ref IEC 60529, table 8. Tested with the lowest point of the enclosure 1000 mm below the surface of the water, or the highest point 150 mm below the surface, whichever is deeper.
8	Immersion, 1 m or more depth	The equipment is suitable for continuous immersion in water under conditions which shall be specified by the manufacturer. However, with certain types of equipment, it can mean that water can enter but only in such a manner that it produces no harmful effects. The test depth and duration is expected to be greater than the requirements for IPx7, and other environmental effects may be added, such as temperature cycling before immersion.	Test duration: Agreement with Manufacturer Depth specified by manufacturer, generally up to 3 m
9K	Powerful high temperature water jets	Protected against close-range high pressure, high temperature spray downs. Smaller specimens rotate slowly on a turntable, from 4 specific angles. Larger specimens are mounted upright, no turntable required, and are tested freehand for at least 3 minutes at distance of 0.15–0.2 m. There are specific requirements for the nozzle used for the testing. This test is identified as IPx9 in IEC 60529.	Test duration: 30 seconds in each of 4 angles (2 minutes total) Water volume: 14–16 litres per minute Pressure: 8–10 MPa (80–100 bar) at distance of 0.10–0.15 m Water temperature: 80°C

Test methods are developed and used also by consumers testing organizations (Table 8) in order to test and inform consumers about different performance aspects and durability of their products (e.g. battery performance, resistance to specific stresses as rain, water submersion, shocks).

Table 8: Examples of durability tests carried out by Consumer Testing Organizations[20]

Test Type	Description
Running time test	The running time test is performed by a robot that repeats a list of common tasks until the battery is empty. This includes: voice calls, standby, playback of on-line videos, taking of pictures, scrolling on digital maps.
Rain test	The mobile phones are switched on and connected to a network. A measurement according to EN 60529 - 2000-09 is performed. A raining appliance is used to give an even rain distribution according to IPx1 (7.2 l/h). The phones lie horizontally on a rotary table and are irrigated for 5 minutes. The correct function is assessed immediately, after one day, after 2 days and after 3 days.
Water resistance submersion	Only devices that are claimed to be waterproof (IPxx) are tested. They are submerged into water tube at the stated maximum depth for 30 minutes to verify the waterproofness. The correct functioning is assessed immediately, after one day, after 2 days and after 3 days.
Shock resistance tumble test	The durability against mechanical shocks (e.g. drops) is tested with a tumbling barrel to simulate an 80 cm fall against a stone surface, as described in EN 60065. Handsets are switched on and set into operation (call) and are put into a tumbling drum (tumbling height of 80 cm) for 50 rotations (100 drops) and the damages are checked after each 25 and 50 rotations.
Scratch resistance test	The scratch resistance of the phones' displays and their bodies is examined. Therefore, a hardness test pencil (ERICHSEN, Model 318 S) is used. A rating for the display is generated depending on the maximum load that does not lead to permanent scratches on the device under test.

1.2.4.6 Other standards and testing methods

In response to the Commission's Mandate 543[21], the CEN/CENELEC JTC10 "Energy-related products – Material Efficiency Aspects for Eco-design"[22] has been created. The CEN/CENELEC JTC10 aims to develop general standards on material efficiency aspects for Energy-related Products, which can be used to support the policy making process. The standards, planned to be published in 2019/2020, will be followed, wherever needed, by vertical implementation. Six working groups have been formed:

- WG1: Terminology
- WG2: Durability
- WG3: Reparability, upgradability and reusability
- WG4: Ability to Remanufacture

[20] Based on input from Consumers Testing Organisations

[21] M/543 COMMISSION IMPLEMENTING DECISION C(2015)9096 of 17.12.2015 on a standardisation request to the European standardisation organisations as regards ecodesign requirements on material efficiency aspects for energy-related products in support of the implementation of Directive 2009/125/EC of the European Parliament and of the Council

[22] https://www.cenelec.eu/dyn/www/f?p=104:7:1299206399119101::::FSP_ORG_ID:2240017 (accessed on 1 June 2018)

- WG5: Recyclability, recoverability and recycled content (including critical raw materials)
- WG6: Provision of information (including critical raw materials).

Other standards and testing methods on functional and performance include:

- IEC 61960-3:2017 - Secondary cells and batteries containing alkaline or other non-acid electrolytes. Secondary lithium cells and batteries for portable applications. Prismatic and cylindrical lithium secondary cells, and batteries made from them
- IEC 61966-2-1:1999 - Multimedia systems and equipment - Colour measurement and management - Part 2-1: Colour management - Default RGB colour space – sRGB.
- IEC 62133-1:2017 - Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications – Part 1: Nickel systems
- IEC 62133-2:2017 - Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications – Part 2: Lithium systems
- ISO 3664:2009 - Graphic technology and photography – Viewing conditions
- ISO 3741:2010 - Acoustics -- Determination of sound power levels and sound energy levels of noise sources using sound pressure -- Precision methods for reverberation test rooms
- ISO 3744:2010 - Acoustics -- Determination of sound power levels and sound energy levels of noise sources using sound pressure -- Engineering methods for an essentially free field over a reflecting plane
- ISO 3745:2003 - Acoustics -- Determination of sound power levels of noise sources using sound pressure -- Precision methods for anechoic and hemi-anechoic rooms
- ISO 7779:2010 - Acoustics -- Measurement of airborne noise emitted by information technology and telecommunications equipment
- ISO 9241-400:2007 - Ergonomics of human--system interaction -- Part 400: Principles and requirements for physical input devices.
- ISO 9296:2017 - Acoustics -- Declared noise emission values of information technology and telecommunications equipment
- ISO 11201:2010 - Acoustics -- Noise emitted by machinery and equipment -- Determination of emission sound pressure levels at a work station and at other specified positions in an essentially free field over a reflecting plane with negligible environmental corrections
- ISO 12646:2015 - Graphic technology -- Displays for colour proofing -- Characteristics
- Standard ECMA-74- Measurement of Airborne Noise emitted by Information Technology and Telecommunications Equipment

1.2.5 End-of-Life of the product

1.2.5.1 Waste Directive

Directive 2008/98/EC, amended by Directive (EU) 2018/851, sets the basic concepts and definitions related to waste management, such as definitions of waste, recycling, recovery. It explains when waste ceases to be waste and becomes a secondary raw material (so called end-of-waste criteria), and how to distinguish between waste and by-products. The Directive lays down some basic waste management principles: it requires that waste is managed without endangering human health and harming the environment, and in particular without risk to water, air, soil, plants or animals, without causing a nuisance through noise or odours, and without adversely affecting the countryside or places of special interest. Waste legislation and policy of the EU Member States shall apply as a priority order the following waste management hierarchy:

1. Prevention
2. Preparation for reuse
3. Recycling
4. Recovery
5. Disposal.

The Directive introduces the "polluter pays principle" and the "extended producer responsibility". It incorporates provisions on hazardous waste and waste oils, and includes two new recycling and recovery targets to be achieved by 2020: 50% preparing for re-use and recycling of certain waste materials from households and other origins similar to households, and 70% preparing for re-use, recycling and other recovery of construction and demolition waste. The Directive requires that Member States adopt waste management plans and waste prevention programmes. These also include measures to encourage the design of safer, more durable, re-usable and recyclable products.

Annex III of the Waste Framework Directive 2008/98/EC also defines which properties render waste hazardous.

1.2.5.2 Waste Electrical and Electronic Equipment (WEEE) Directive

Smartphones fall in the scope of the WEEE Directive 2012/19/EU as "small IT and telecommunication equipment (no external dimension more than 50 cm)".

According to Article 4, Member States shall encourage cooperation between producers and recyclers and measures to promote the design and production of EEE, notably in view of facilitating re-use, dismantling and recovery of WEEE.

Annex VII of WEEE lists a series of materials and components to remove and collect separately for depollution at the EOL of products:

- Polychlorinated biphenyls (PCB) containing capacitors in accordance with Council Directive 96/59/EC of 16 September 1996 on the disposal of polychlorinated biphenyls and polychlorinated terphenyls (PCB/PCT),
- Mercury containing components, such as switches or backlighting lamps,
- Batteries,
- Printed circuit boards of mobile phones generally, and of other devices if the surface of the printed circuit board is greater than 10 square centimetres,
- Toner cartridges, liquid and paste, as well as colour toner,
- Plastic containing brominated flame retardants,
- Asbestos waste and components which contain asbestos,
- Cathode ray tubes (the fluorescent coating has to be removed),

- Chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC) or hydrofluorocarbons (HFC), hydrocarbons (HC). Equipment containing gases that are ozone depleting or have a global warming potential (GWP) above 15, such as those contained in foams and refrigeration circuits: the gases must be properly extracted and properly treated. Ozone-depleting gases must be treated in accordance with Regulation (EC) No 1005/2009,
- Gas discharge lamps,
- Liquid crystal displays (together with their casing where appropriate) of a surface greater than 100 square centimetres and all those back-lighted with gas discharge lamps,
- External electric cables (the mercury shall be removed),
- Components containing refractory ceramic fibres as described in Commission Directive 97/69/EC of 5 December 1997 adapting to technical progress for the 23rd time Council Directive 67/548/EEC on the approximation of the laws, regulations and administrative provisions relating to the classification, packaging and labelling of dangerous substances,
- Components containing radioactive substances with the exception of components that are below the exemption thresholds set in Article 3 of and Annex I to Council Directive 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation,
- Electrolyte capacitors containing substances of concern (height > 25 mm, diameter > 25 mm or proportionately similar volume)[23]
- These substances, mixtures and components shall be disposed of or recovered in compliance with Directive 2008/98/EC.

Article 14 allows Member States to require producers to show purchasers, at the time of sale of new products, information on collection, treatment and disposal of EEE. These can include: (a) the requirement not to dispose of WEEE as unsorted municipal waste and to collect such WEEE separately; (b) the return and collection systems available to them, encouraging the coordination of information on the available collection points irrespective of the producers or other operators which have set them up; (c) their role in contributing to re-use, recycling and other forms of recovery of WEEE; (d) the potential effects on the environment and human health as a result of the presence of hazardous substances in EEE; (e) the meaning of the symbol shown in Annex IX, which must be applied to each EEE placed on the market. Moreover, article 15 establishes that in order to facilitate the preparation for re-use and the correct and environmentally sound treatment of WEEE, including maintenance, upgrade, refurbishment and recycling, Member States must take necessary steps to ensure that producers provide information free of charge about preparation for re-use and treatment in respect of each type of new EEE placed for the first time on the market within one year after the equipment is placed on the market.

[23] Substance of concern could be defined based on Annex II of RoHS Directive 2011/65EU (+ exemptions in Annex III and Annex IV); Annex XVII (restriction list) and Annex XIV (authorisation list) of REACH; Annex III of the Waste Framework Directive 2008/98/EC

1.2.5.3 Extended Product Responsibility

To raise levels of high-quality recycling, improvements are needed in waste collection and sorting. Collection and sorting systems are often financed in part by extended producer responsibility (EPR) schemes, in which manufacturers contribute to product collection and treatment costs[24].

All Member States of the EU have implemented EPR schemes on the four waste streams for which EU Directives recommend the use of EPR policies: packaging, batteries, End-of-Life Vehicles (ELVs) and Electrical and Electronic Equipment (WEEE). In addition, a number of Member States have put in place additional schemes for products that are not directly addressed in EU-wide legislation (e.g. for tyres, graphic paper, oil and medical waste) (OECD 2014).

In order to recycle waste electrical and electronic equipment (WEEE) properly and in environmentally sound manner, it is necessary that old equipment is collected separately from other waste. Smartphones are generally included in EPR systems together with other EEE and covered as part of a larger collection and treatment ICT group. Collection networks have been established at point of sales and through public waste management authorities. In Germany, it has been reported by stakeholders involved in the development of this study that consumers can use an "eSchrott" (WEEE) app since 2013 to display the nearest collection point for old electrical appliances.

Costs for collection and treatment are shared by producers according to market share. In countries like Germany, producers must provide an insolvency-proof guarantee upon registration in order to ensure e-waste is being properly treated and recovered even if the original producer is no longer in the market. In Belgium, EUR 0.05-0.09 (incl. VAT) are charged for the purchase of a new smartphone with the aim to fund collection schemes for used smartphones. E-waste recyclers in Belgium have to place bids on appliances collected through Recupel. The winning bidder has a right to purchase 50% of the lot and others can purchase the rest by aligning to the winning price. Stakeholders involved in the development of this study reported that the collection scheme is highly profitable since purchase prices for high-value WEEE are considerably higher than the taxes to be paid for the same amount of products, at least in the case of smartphones.

Moreover, article 15 of the WEEE Directive requires producers to provide information free of charge about preparation for re-use and treatment for each type of EEE placed on the market. To this purpose, APPLIA and DIGITALEUROPE developed an online database where recyclers can access all recycling information for EEE: the I4R platform[25].

Any seller of electrical or electronic appliances is obliged to take back old appliances upon sales of new ones, whilst large distributors of electrical and electronic equipment are obliged to take back WEEE free of charge and to inform consumers about the created return facilities. That means that stationary/online shops with EEE sales/shipment areas of at least 400 m^2:

- Have to take back WEEE in exchange for a new product, as long as the WEEE is of equivalent type and has fulfilled the same functions (1:1 Take-back) and
- Have to take back small WEEE (no external dimension more than 25 cm) without the obligation to buy any new EEE (0:1 Take-back).

However, many waste smartphones from private households are collected also by:

- Public waste management authorities;

[24] COM(2015) 614 final
[25] https://i4r-platform.eu (accessed on 4 June 2018)

- Manufacturers, telecom operators, charities, NGOs and other parties.

In the latter case, smartphones are typically collected for refurbishment or direct resale in Europe or abroad. Some companies also established individual return systems by mail. There are some programmes to mail EOL smartphones back free of charge[26] [27].

1.2.6 Ecolabels and Green Public Procurement

Environmental Labelling and green public procurement criteria have been developed to help customers and public authorities to identify and purchase smartphones that meet environmental criteria. Criteria typically cover energy use, sustainable sourcing of materials, product life extension, restrictions in the use of hazardous materials and conflict minerals, as well as social aspects. However, the market uptake of ecolabeled products appears so far limited.

According to stakeholders involved in the development of this study, sustainability criteria for smartphones should also cover the provision of software updates. When a smartphone manufacture stops providing software updates, older phones automatically become obsolete due to security issues, although they can be still usable.

1.2.6.1 Blue Angel

Criteria for the award of the Blue Angel ecolabel to mobile phones have been setup in Germany. The last version of the criteria is dated July 2017. To the knowledge of the authors of this report, for the time being the label has been awarded only to Fairphone 2.

The Blue Ange for mobile phones considers climate protection, reduction of energy consumption, increased resource efficiency and the avoidance of harmful substances and waste as key objectives of environmental protection. The ecolabel may be awarded to devices featuring the following environmental properties:

- Product longevity Low user exposure to electromagnetic radiation;
- Design that supports maintenance and recycling;
- High-value (secondary) batteries;
- Compliance with fundamental social standards.

Besides, the Blue Angel distinguishes a product whose manufacturer actively supports an improved take-back and recycling scheme. Requirements are summarised in Annex I.

1.2.6.2 TCO

TCO Certified is an international third party sustainability certification scheme for IT products. Although covering mobile phones, no model is awarded with this standard.

TCO is a type-1 label certifying that products fulfil requirements along its life cycle:

- Manufacturing (social responsible manufacturing, environmental management system)
- Use phase (climate, ergonomics, health and safety, extended product life and emissions)

[26] https://www.deutschepost.de/de/e/electroreturn.html (accessed on 30 May 2018)
[27] https://www.apple.com/de/trade-in/ (accessed on 30 May 2018)

- End of life (reduction of hazardous content and chemicals, design for recycling)

The second and last version of criteria for smartphones is the TCO Certified Smartphones 2.0, which has been released in November 2015. Requirements needed to be met by TCO Certified Smartphones are summarised in Annex I. At the moment there are no models awarded and registered as TCO Certified[28].

The launch of the next generation of TCO Certified ("Generation 8") is expected in December 2018[29]. The new set of criteria is planned to include resource efficiency aspects such as the availability of spare parts for critical components (e.g. battery and display).

1.2.6.3 EPEAT

EPEAT is a free source of environmental product ratings allowing the selection of high-performance electronics. The system began in 2003 with a stakeholder process convened by the U.S. Environmental Protection Agency and has grown to become a global environmental rating system for electronics. Managed by the Green Electronics Council, EPEAT currently tracks more than 4400 products from more than 60 manufacturers across 43 countries.

Manufacturers register products in EPEAT based on the devices' ability to meet certain required and optional criteria that address the full product lifecycle, from design and production to energy use and recycling:

- Bronze-rated products meet all of the required criteria in their category.
- Silver-rated products meet all of the required criteria and at least 50% of the optional criteria,
- Gold-rated products meet all of the required criteria and at least 75% of the optional criteria.

The U.S EPEAT registry uses a lifecycle based sustainability standard developed by UL (Underwriter Laboratories). In particular, mobile phones are addressed by UL 110[30]. Requirements applied to smartphones are listed in Annex I. The EPEAT, with 33 registered mobile phone models from 4 different manufacturers (i.e. Apple, Google, LG, Samsung)[31], seems the most popular eco-label for mobile phones.

1.2.6.4 iFixit

iFixit has developed a Reparability Score for smartphones[32] (see Annex II). Points are gained based on the ease of opening the device, the types of fasteners and tools used, the complexity of replacing key components, upgradability and modularity of the device.

As part of the Horizon 2020 project Sustainably Smart, which focuses on material efficiency of smart devices[33], iFixit is working to upgrade the scoring system and create a more objective and robust methodology which can allow the assessment at part level.

[28] http://tcocertified.com/product-finder/ (accessed on 11 July 2018)
[29] http://tcocertified.com/new-generation-tco-certified/#draftcriteria (accessed on 30 May 2018)
[30] epeat.net/...round/UL%20110%20Verification%20Requirements%20-%20FINAL.pdf (accessed on 23 March 2018)
[31] https://ww2.epeat.net/Companies.aspx?stdid=0&epeatcountryid=0 (accessed on 30 May 2018)
[32] https://www.ifixit.com/smartphone_repairability (accessed on 8 April 2019)
[33] https://www.sustainably-smart.eu/ (accessed on 11 July 2018)

1.2.6.5 Green public procurement

There are examples of green public procurement requirements for smartphones in the EU and worldwide:

- The Scottish Procurement established a new suite of frameworks for the supply of ICT client devices in 2016, which included mobile phones[34]. In the framework contract for Information and Communications Technology (ICT), client devices bidders must meet or exceed the EPEAT Gold or Silver compliance requirements (depending on the product category), as well as reduce packaging and extend the lifetime of their products. Award criteria also cover social aspects (e.g. work conditions and supply chain control).
- In the U.S., Federal government agencies and many states, provincial, and local governments are required to buy greener electronics (including mobile phones) off of the EPEAT registry, where manufacturers register their products stating the environmental performance of their products.
- In Japan the Law on Promoting Green Purchasing sets out criteria including provisions for material efficiency and it specifically covers mobile phones.

[34] http://ec.europa.eu/environment/gpp/pdf/news_alert/Issue69_Case_Study_139_Scotland.pdf (accessed on 18 April 2018)

2 MARKET

This section provides indications about the market of the product, to better understand its penetration, the involved life cycle costs, main business practices, trends and associated consequence at material efficiency level.

2.1 Basic market data

2.1.1 Market sales

Smartphones came onto the consumer market in the late 90s but only gained mainstream popularity with the introduction of Apple's iPhone in 2007 (Statista, 2018a). Smartphones have rapidly overtaken basic mobile phones and feature phones (Figure 1), as well as other small electronics as digital cameras, GPS, MP3 players, calculators, voice recorders. Every two out of three mobile phones that were shipped globally in 2014 were smartphones: the introduction of smartphones on the market has changed the behaviour of both consumers and businesses (Watson et al. 2017).

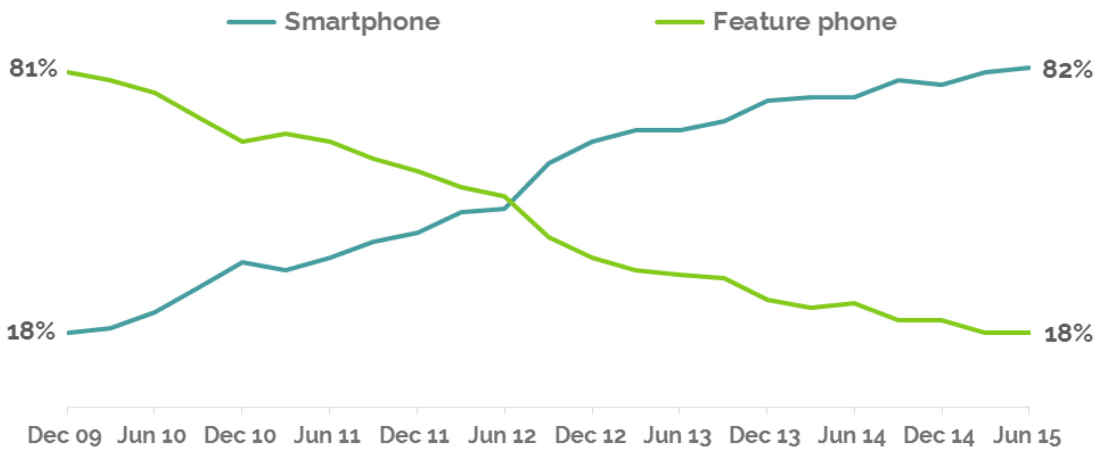

Figure 1: Smartphone and feature phone ownership in the UK (Source: Farmer 2015)

The smartphone industry has been steadily developing and growing, both in market size, as well as in models and suppliers. Almost 1.5 billion smartphones were sold to end users in 2016, an increase from less than 300 million units in 2010 (Statista 2018b).

The smartphone market has been reported to stop is growth in 2016. Smartphone sales between 2015 and 2016 dropped by 2% in US, Great Britain, Germany, France, Italy, Spain, China, Australia, and Japan. As the smartphone industry matures, fewer consumers are moving between brands and market growth has increasingly relied on replacing existing devices (Kantar World Panel 2017). No market data has been found to confirm this trend also for 2017-2018. Smartphone shipments worldwide are projected to add up to 1.71 billion in 2020 (Statista, 2018a), a tenfold increase from 2009 although an asymptotic limit appears approached (Figure 2).

Sales of smartphones in Western Europe increased from 115.4 million units in 2013 to 125.6 million units in 2017 (+9%). Sales reached a peak of 135 million units in 2015, after which they decreased by 3-4% (Statista 2018c). Sales are instead increasing in Central and Eastern Europe, from 50.9 million units in 2013 to 85.2 million units in 2017 (+67%) (Statista 2018d). The overall picture for Europe results in an increase of shipments from 166.3 million units in 2013 to 210.8 units in 2018 (+27%). Sales in Europe represent around 15% of the global sales of smartphones (Figure 3).

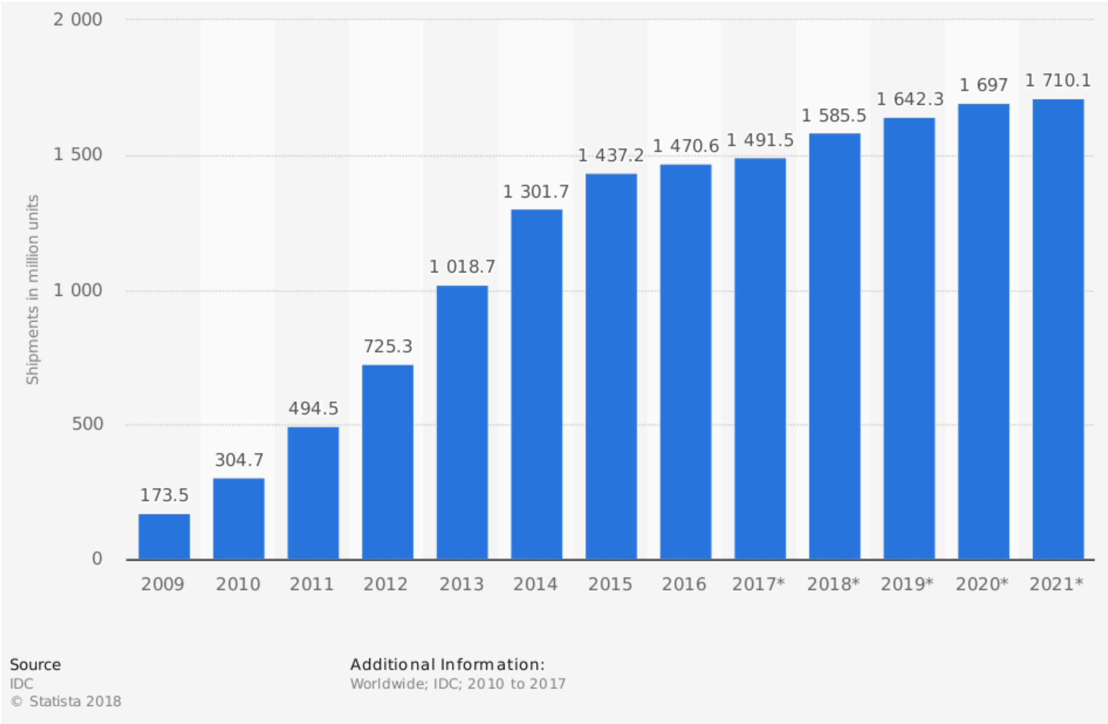

Figure 2: Global smartphone shipment forecast from 2010 to 2021 (million units) (Statista 2018e)

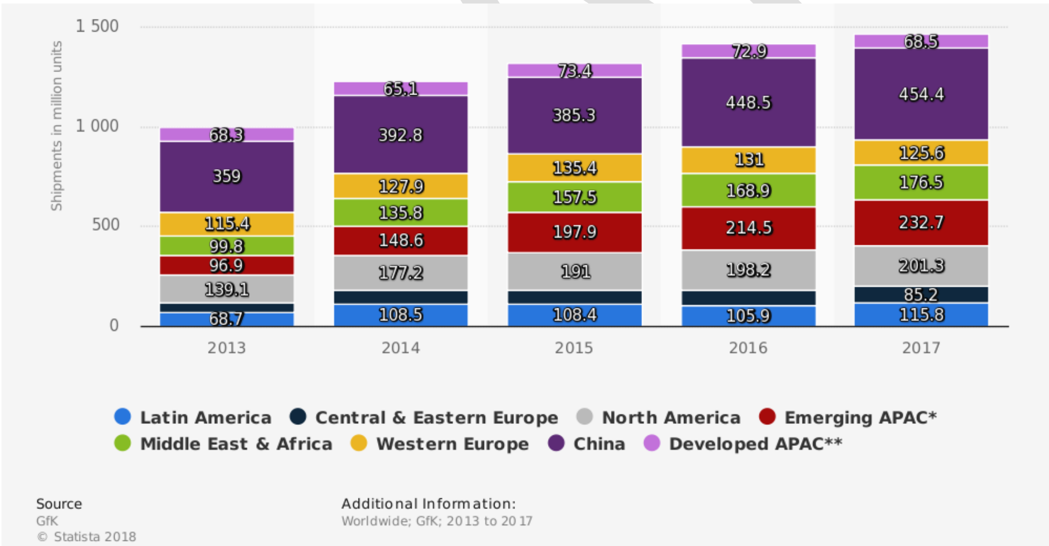

Figure 3: Smartphone unit shipments worldwide from 2013 to 2017 (in million units), by region (Statista 2018f)

In terms of total value, sales of smartphones in 2017 were 56 billion USD in Western Europe (Statista 2018g) and 21.2 billion USD in Central and Eastern Europe Statista 2018h), which add to 77.2 billion USD. Total value of sales has increased constantly since 2013.

Values of single units in 2017 for Western Europe and for Central and Eastern Europe would correspond to 446 and 249 USD, respectively. Compared to 2013, the single unit value has decreased by 16% in Eastern Europe while it has remained almost constant in Western Europe. The European average is 366 USD, 10% less than in 2013.

2.1.2 Market penetration

The number of smartphone users is forecast to grow from 2.1 billion in 2016 to around 2.5 billion in 2018 (Figure 4), with smartphone penetration rates increasing as well. Over 36% of the world's population is projected to use a smartphone by 2018, up from about 10% in 2011 (Statista 2018i) and 21.6% in 2014 (Statista 2018b). Higher penetration levels are achieved in some markets and saturation may be reached soon in developed countries (e.g. in Japan 97% of mobile subscribers have smartphones) (Benton et al. 2015).

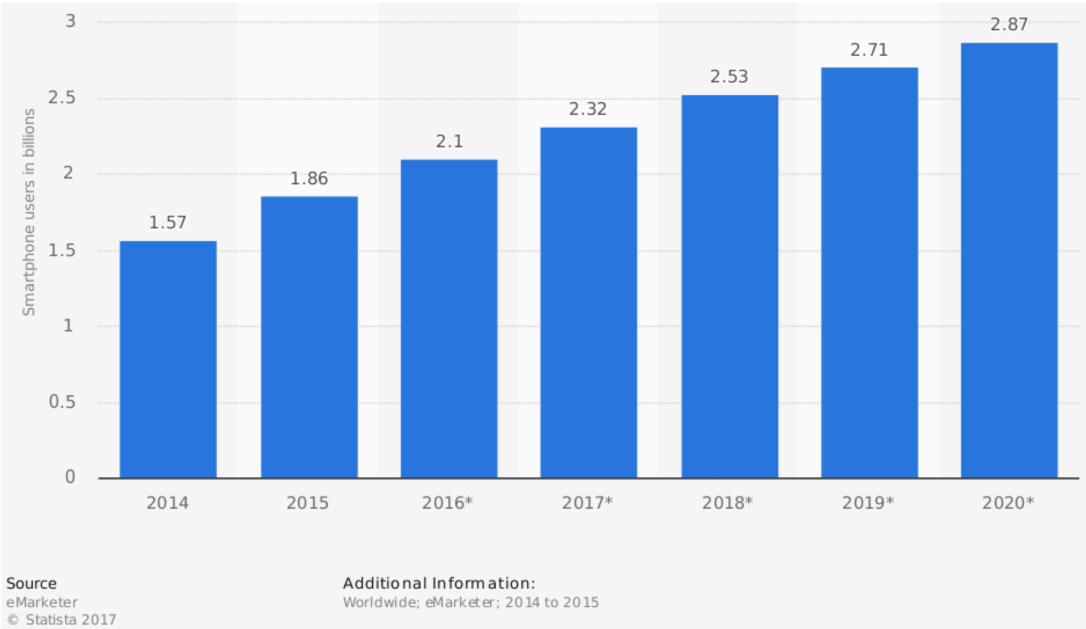

Figure 4: Number of smartphone users worldwide from 2014 to 2020 (in billions) (Statista 2018i)

China, the most populous country in the world, leads the smartphone industry. The number of smartphone users in China is forecast to grow from around 563 million in 2016 to almost 675 million in 2019. Around half of the Chinese population is projected to use a smartphone by 2020 (Statista 2018i). This would correspond to about a quarter of all smartphone users in the world (Statista 2018a).

The smallest regional market for smartphones is the Middle East and Africa, where smartphone penetration will stand at an estimated 13.6% (Statista 2018b). The highest penetration rates are instead registered in Western Europe and North America. It is estimated that in 2018 about 64% of the population of those regions will own a smartphone. Market penetration has increased significantly in the last years in both regions: from 22.7% in 2011 in Western Europe, and from 51% in 2014 for North America (Statista 2018b, 2018j). Smartphone penetration per capita in Central & Eastern Europe has been estimated to increase from 13.3% in 2011 to 58.2% in 2017. Penetration rates appear significant in the most populated countries of Europe:

- The number of smartphone users in France was estimated to reach 43.35 million in 2017. From 2015 to 2022 the number of smartphone users is expected to grow by 17.68 million users (+26%). Most individuals without a smartphone still own a regular mobile phone and only 7% of the population own no type of phones (Statista 2018k). In relative terms, the share of monthly active smartphone users is projected to increase from 59% of the total population in 2016 to 78.5% in 2022 (Statista 2018k).

- The number of smartphone users in Germany was estimated to reach 55.46 million in 2017 (Statista 2018l). In relative terms, the share of monthly active smartphone users is projected to increase from 61% of the total population in 2016 to 78.5% in 2022 (Statista 2018m).
- The number of smartphone users in Italy was estimated to increase from 26.8 million in 2015 to 31.5 million in 2017 (Statista 2018n). In relative terms, the share of monthly active smartphone users is projected to increase from 46% of the population in 2014 to 65% in 2021 (Statista 2018o).
- The number of smartphone users in Spain was estimated to reach 30.3 million in 2017. From 2015 and 2021 the number of user is expected to grow by 7.7 million to 34.3 million users (+16%) (Statista 2018p). In relative terms, the share of monthly active smartphone users is projected to increase from 59% of the population in 2016 to 72% in 2022 (Statista 2018q).
- The number of monthly active smartphone users in the United Kingdom (UK) is projected to grow steadily from 41.09 million in 2015 to 53.96 million in 2022 (Statista 2018r). In relative terms, the share of monthly active smartphone users is projected to increase from 62% of the population in 2014 to 78% in 2022 (Statista 2018s).

However, ownership differs across age groups. For example, 88% of 16-24 year olds owned smartphones in 2014 in the UK, compared to 14% of those over 65 (Benton et al. 2015).

2.1.3 Market shares by vendor

Until the first quarter of 2011, Nokia was the leading smartphone vendor worldwide with a 24% market share (Statista 2018a). As represented in Figure 5, the leading smartphone vendors in 2016 were Samsung and Apple, with about 20-25% and 15% of the share respectively, followed by Huawei, OPPO and Vivo (IDC, Statista 2018i). Other prominent smartphone vendors include Lenovo and Xiaomi (IDC, Statista 2018a). At the end of 2017, Apple had a worldwide market share of 19%, surpassing Samsung (Statista 2018t).

China is not only home of three of the top smartphone vendors (Huawei, Lenovo and Xiaomi), but it is also the largest smartphone market in the world (Statista 2018u). Shares vary depending on the country and the year considered. For example, in the UK the most popular mobile device vendor has been Apple since 2010, which had a total market share of 49% in the first eight months of 2017. In January 2017, the total market share of the Apple iPhone 7 Plus in terms of total smartphone sales in the UK was higher than all others (Statista 2018s).

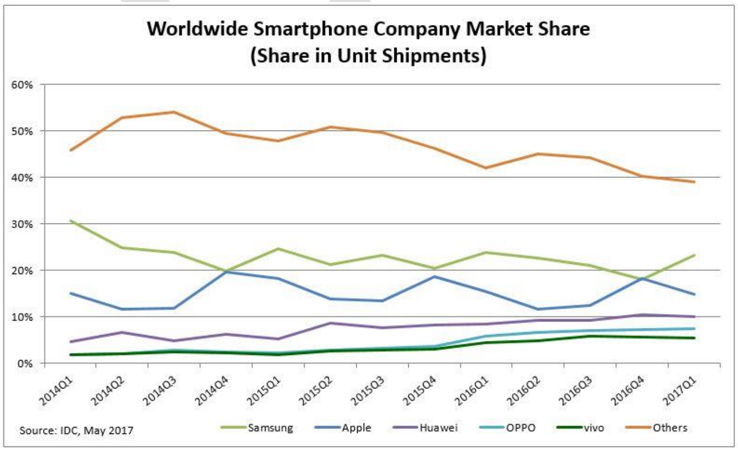

Figure 5: Worldwide Smartphone Company Market Share from 2014 to first quarter of 2017 (Share in Unit Shipments) (IDC)

2.1.4 Market shares by operating system

Google's Android is the clear leader among operating systems with a global market share of more than 80%. Apple's operating system iOS is its main competitor, accounting for about 15% of the share (Statista 2018a). The two operating systems amounted to 352.67 million Android units and 77.04 million iOS units being shipped in the final quarter of 2016 (Statista 2018e) (see also Figure 6, Figure 7, Figure 8). There are however differences between regional markets; in the United States for example, the market is almost equally divided between Android and iOS (Statista 2018v).

Microsoft's Windows Phone is another smartphone operating systems on the market. Symbian, which was used extensively on mobile phones and early generations of smartphones by leading manufacturers, such as Samsung, LG, Motorola and Nokia, was a dominant player on the market in 2009 and 2010. Due to the growing popularity of Android, which most major smartphone manufacturers adopted as their OS of choice, and Nokia's partnership with Windows Phone, which began in 2011, Symbian was pushed off the market in 2014 (Statista 2018v). It has been also reported by stakeholders involved in the development of this study that Blackberry stopped shipping products with Blackberry 10 in 2015 and switched to Android.

Although the main producers of operating systems are based in the U.S., the Chinese smartphone industry may dominate the market in the future: China could control about a third of the smartphone market in 2017 (Statista 2018e).

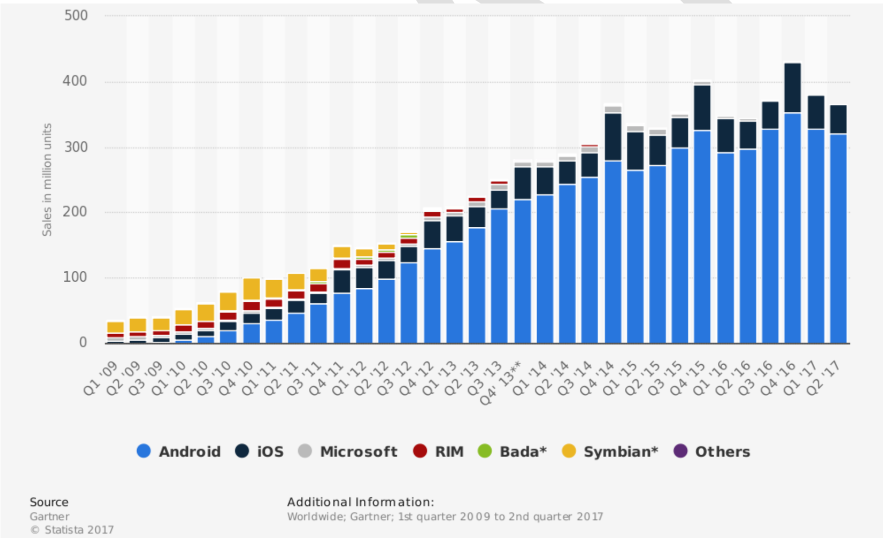

Figure 6: Global smartphone sales to end users by operating system from 1st quarter 2009 to 2nd quarter 2017 (in million units) (Statista 2018w)

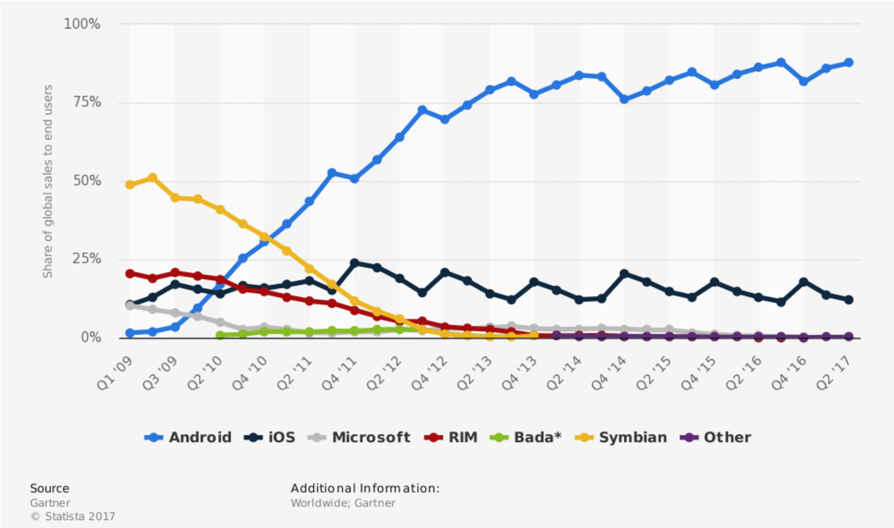

Figure 7: Global market share held by the leading smartphone operating systems in sales to end users (Statista 2018z)

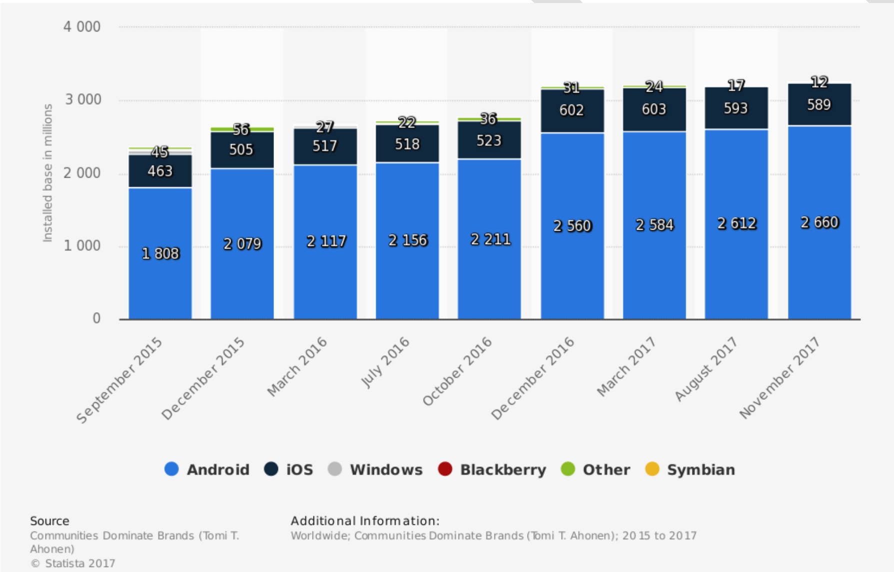

Figure 8: Installed base of smartphones by operating system from 2015 to 2017 (in million units) (Statista 2018aa)

2.2 Key actors

Different actors play an important role in the smartphone business:

- Mobile phone producers, which have a direct influence on the design and servicing of smartphones (Watson et al. 2017). The landscape of producers is characterised by the large established global companies such as Apple, Samsung, Sony and Nokia[35]. Start-

[35] Nokia's mobile phone section was bought by Microsoft and ran on a Microsoft operating system, but announced that production would seize in summer 2017. Meanwhile, Finnish company HMD began production of Nokia-branded Android phones in 2014

up companies, such as Fairphone, that have sustainability as a core element of their business, are gaining popularity although their market share is still quite small.

- Software producers, which make business through the use of a device (e.g. Google, Apple, and other digital services and app developers) and have interest in securing agreements with hardware providers and providing up-to-date software along the lifetime of smartphones to avoid the installation of a different operating system (Benton et al. 2015).
- Retailers, which are among the biggest providers of mobile phones, which can influence customers towards certain business models, and which can enter 2nd-hand markets (Watson et al. 2017). Many EU countries also oblige retailers under specific conditions (e.g. size of shop) to provide a collection point for WEEE[36]. For large retail chains of electronics and white goods, sales of mobile phones represent a minor element of total turnover, however these sales are growing in importance. For more specialised retailers the share of turnover represented by phone sales can be as high as 80%, with the remaining 20% represented by reparations, tablets or accessories.
- Network service providers, which are large sellers/providers of mobile phones which they sell via subscriptions of network services to attract and keep customers (Watson et al. 2017). They can have a strong influence over how often customers upgrade their telephones, but also have relevance to warranties, repair and refurbishment processes. The range of models via which network service providers are offering mobile phone upgrades have been diversifying rapidly over the past few years in global markets and now can include leasing and buy-back upgrades. Sales of phones do not directly generate profits for the service providers (some service providers even claim it is a cost). The providers' main turnover is via data and network services and subscriptions for these.
- Mobile phone repairers, which are more and more frequent to find. Phone producers/electronics retailers increasingly demand that repair shops are certified in order to activate product warranties (Watson et al. 2017). However, there is also a wide range of repairers ranging from authorised, through unauthorised but above-board repairers, to grey actors. For repair companies, repair of mobile phones is in general a large part of the business representing up to 95% of the turnover. However, accessories are of increasing importance (up to 80% of turnover for a company).
- Refurbishers and 2nd-hand sellers, which commercialise 2nd-hand IT with warranties (Watson et al. 2017). These can be single shops, as well as chains. Market is expanding as smartphone prices increase. There is also an overlap between companies involved in mobile phone repair and 2nd-hand sales.

[36] For instance, in Spain, shops with a surface larger than 400 m^2 must accept small electronic devices (as smartphones) with no burden for customers (https://www.ecolec.es/sociedad/que-hago-con-el-raee/, accessed on 21 March 2018)

2.3 Costs

2.3.1 Purchase price

Statistics available online (Statista 2018ab) indicate that the average selling price for smartphones in Europe was 366 USD in 2017 (310 USD as worldwide average in 2014). This would correspond to about 320 EUR[37].

Over the last few years, mid-range smartphones accounted for about 40-50% of all smartphone shipments, while low-end's share varied between 26-34% and high-end held from 20-28% of the share. Smartphones that cost less than 150 USD (about 130 EUR) are considered low-end models. Mid-range smartphone retail prices vary from 150 USD to 550 USD. Any smartphone above 550 USD (about 480 EUR) fits in the high-end category (Statista 2018ab).

Since 2010, the average selling prices of smartphones worldwide has varied within the mid-range category. In 2010, customers paid, on average, 440 USD for a smartphone, the highest price over the last six years. The average selling price of smartphones worldwide was 333 USD in 2013, 310 USD in 2014, and 305 USD in 2015, with further reductions predicted for the future years (Statista 2018ab), as also shown in Figure 9.

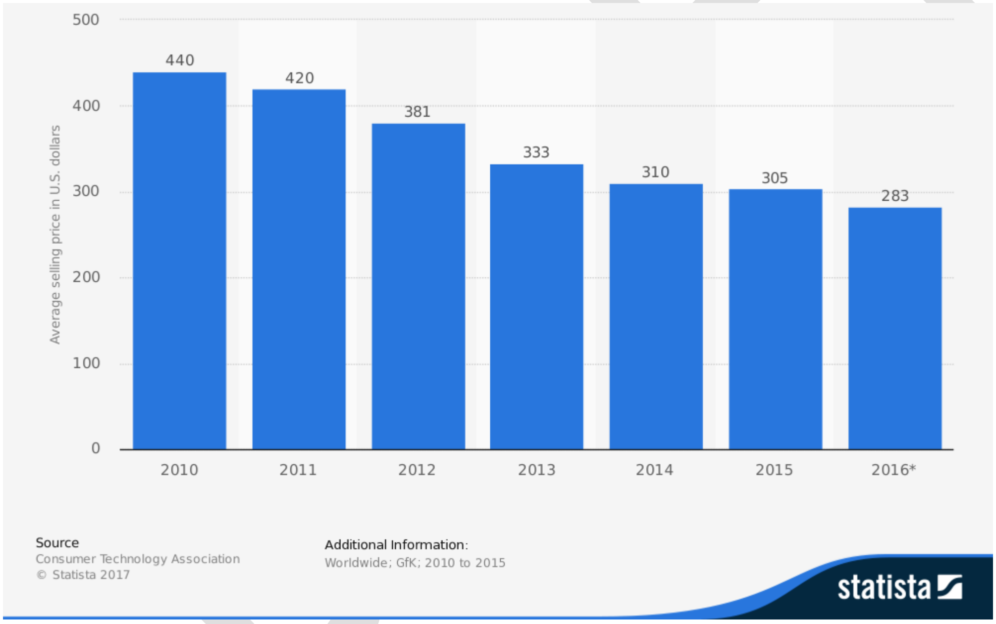

Figure 9: Average selling price of smartphones worldwide from 2010 to 2016 (in USD) (Statista 2018ab)

The average selling price for an Android smartphone was 231 USD in 2015. In comparison, Blackberry smartphones costed about 348 USD and Windows Phones had an average selling price of 247 USD in the same year. By 2018, Windows Phones are projected to become the most affordable smartphones, with an average selling price of 195 USD. Android

[37] Considering an exchange rate of 0.8712 EUR / USD on 9 October 2018 (https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html)

smartphones are forecast to cost 202 USD by 2018. iPhones have the highest average selling price: the average cost of an iPhone in 2015 was 652 USD. A decline in the average selling price of Android smartphones (202 USD) and iPhones (610 USD) is expected by 2018 (Statista 2018ab).

According to Counterpoint Research (2016), more than half of the Australian, Chinese, German and Saudi smartphone users revealed that they would be willing to spend more than 400 USD to replace their current device. More than one third of German and Australian users would be willing to spend more than 500 USD in their next smartphone purchase. Apple dominates the installed base in both countries, and more than 85% of the Apple users would not switch brands. Willingness to pay more than 400 USD significantly decreases in the other countries investigated in the survey (30% in Thailand, 27% in South Africa, 23% in Malaysia, 13% in Japan, 5% in India).

Globally, the average value of 2nd hand smartphones could be estimated to be around 140 USD per device (Watson et al. 2017). A study financed by WRAP (Culligan and Menzies 2013) investigated more in detail the value of electronics for trade-in and re-sale. Although not covering smartphones, the study analysed tablets, which can be considered, to some extent, as a proxy for smartphones. The study provides indication about the depreciation of electronic devices (Table 9). Like most new consumer items, most value is lost in the first year with depreciation slowing over subsequent years. For example, the residual value could be on average:

- 54% of the original price for 1 year old product
- 32% after 2 years
- 20% after 3 years.

Trade-in could be no longer economic after 4-5 years.

Table 9: Depreciation of tablets from year to year (Culligan and Menzies 2013)

Product Types	Year			
	2010	2011	2012	2013
Kindle Fire 7"			129	60
Galaxy Tab 2 7.0			160	65
iPad Mini			279	180
Galaxy Tab 2 10.1			279	160
Ipad 4th Gen			460	275
Asus Nexus 7			160	90
Acer Icona W700			600	365
Galaxy tab 10.1			300	100
Ipad 2		499	275	150
Acer Icona tab A200		210	125	70
Kindle 4			80	40
TF101		300	170	100
Ipad 1	499	275	150	100
Average refurb, repair & logistical cost A GBP	43.22	43.22	43.22	43.22
Average refurb/repair & logistical cost B GBP	29.19	29.19	29.19	29.19

2.3.2 Margins

The purchase price (PP) of products is given by the manufacturing costs (MC) plus the margins added, which could be simplified as follows (adapted from Boyano et al. 2017):

PP = MC x (1+MM) x (1 + RM) x (1+VAT)

Where:

- MC = material costs, considered to include the cost of the smartphone's parts
- MM = manufacturing margins, considered to include additional costs (e.g. investment and operational costs associated with manufacturing, product design, software, Intellectual Property, certifications)
- RM = aggregated sale margin
- VAT = value-added tax (e.g. 21.6% as average in the EU in 2015)

PP of Fairphone 2 was reported to be about 1.5 times MC, and MM to be about 20% of MC (Fairphone 2015). MC of Galaxy S has been indicated to increase from 213 USD for the S3 to 375 USD for the S9+ (+76%). Since PP would have increased instead from 599 USD for the S3 to 840 USD for the S9+ (+40%), it means that the ratio of PP to MC has decreased from 2.8 to 2.2[38]. The same source indicates that MC and PP of iPhones have increased from 174 USD and 599 USD (about 3.5 times the MC) for the iPhone 3G to 370 USD and 999 USD (about 2.7 times the MC) for the iPhone X. MM could be up to 40% of MC in the case of the iPhone 5[39].

In terms of manufacturing costs (see

[38] https://hipertextual.com/2018/06/precio-smartphones (Accessed on 6 March 2019)
[39] https://www.digitaltrends.com/mobile/iphone-cost-what-apple-is-paying/ (Accessed on 6 March 2019)

Table 10, made from data reported in Statista 2018ac):

- Display was reported to be the most important component (20% of the total manufacturing cost), followed by apps/baseband processor (17%) and mechanicals (12%). These 3 components make together up to 50% of the manufacturing costs;
- 75% of the total manufacturing cost is reached by adding 3 components (electromechanicals (8%), radio frequency power amplifier (RF/PA) (7%) and cameras (6%));
- 90% of the total manufacturing cost is reached by further including 2 additional components (user interface (5%) and power management (4%));
- Other 5 components (box contents, conversion costs, blue tooth and wireless local-area network (BT/WLAN), battery, glue logic & micro-controller units (MCU)) make the remaining 10% of the manufacturing costs.

Such orders of magnitude find some level of confirmation on the web[40] [41].

As commented by some stakeholders involved in the development of this study, environmental externalities (for instance related to extraction of raw materials, long-distance transportation, end-of life treatment) are not accounted in the manufacturing costs but they could cause a significant distortion of the product price compared to the "real" costs, biasing the market towards early product replacement.

[40] https://www.digitaltrends.com/mobile/iphone-cost-what-apple-is-paying/ (Accessed on 6 March 2019)

[41] https://technology.ihs.com/601100/galaxy-s9-materials-cost-43-more-than-previous-versions-ihs-markit-teardown-shows (Accessed on 6 March 2019)

Table 10: Bill of materials cost for Google Pixel XL by component in 2016 (in USD) (Statista 2018ac)

Part	Cost (USD)	%
Display	58.0	20.3%
Apps/baseband processor	50.0	17.5%
Mechanicals	35.0	12.2%
Memory	26.5	9.3%
Electromechanicals	24.0	8.4%
RF/PA	19.5	6.8%
Cameras	17.5	6.1%
User interface	15.5	5.4%
Power management	11.0	3.8%
Box contents	10.0	3.5%
Conversion costs	7.8	2.7%
BT/WLAN	5.0	1.7%
Battery	4.0	1.4%
Glue logic & MCU	2.0	0.7%
Total	285.8	

2.3.3 Repair/refurbishment costs

Some smartphone manufacturers publish repair and/or spare part costs on their website. For example, Fairphone publishes on its website the price of smartphone's module as spare parts and claims that each module can be replaced without the need to return the entire device. Spare part price of each module, expressed as percentage of the purchase price of the Fairphone 2, is reported in Table 11. Apple instead publishes on its website the repair prices in different countries (e.g. Spain, as reported in

Table 12). In addition, Culligan and Menzies (2013) provided indication about the impact that average refurbishment and repair costs have on the life cycle value of tablets (which can be considered as a proxy for smartphones) (Table 13).

Table 11: Indicative price of spare parts, reported as percentage of the Fairphone 2 purchase price[42]

Spare part	Relative price (as % of the product's purchase price
Display	16%
Back cover	6%
Battery	4%
Charging port module	4%

[42] Calculated based on the information available on https://shop.fairphone.com/en/spare-parts and https://shop.fairphone.com/en/buy-fairphone2-2/ (accessed on 5 September 2018)

Table 12: iPhone's repair service pricing applied by Apple in Spain[43]

iPhone model	Screen repair only (EUR)	Other damages (EUR)
iPhone X	321.10	611.10
iPhone 8 Plus	201.10	451.10
iPhone 8	181.10	401.10
iPhone 7 Plus	201.10	401.10
iPhone 7	181.20	371.10
iPhone 6s Plus	201.10	391.10
iPhone 6s	181.10	351.10
iPhone 6 Plus	181.10	391.10
iPhone 6	161.10	351.10
iPhone SE iPhone 5s, iPhone 5c, iPhone 5	161.10	311.10
iPhone 4s	To consult "the other damage" tariff	241.10

Table 13: Breakdown of refurbishment cost for PC Tablets (Culligan and Menzies 2013)

Product Type	Logistic cost from a single user GBP (A)	Logistic cost - regional depot GBP (B)	Standard refurb cost GBP	Cleaning, storage and dispatch cost GBP	Re-packaging cost material GBP	Recycle Cost Avg GBP	Total GBP
Kindle Fire 7"	14.5		12.11	2.5	2.75	1.52	33.38
Kindle Fire 7"		0.47	12.11	2.5	2.75	1.52	19.35
Galaxy Tab 2 7.0	14.5		12.11	2.5	2.75	1.52	33.38
Galaxy Tab 2 7.0		0.47	12.11	2.5	2.75	1.52	19.35
iPad Mini	14.5		12.11	2.5	2.75	1.52	33.38
iPad Mini		0.47	12.11	2.5	2.75	1.52	19.35
Galaxy Tab 2 10.1	14.5		12.11	2.5	2.75	1.52	33.38
Galaxy Tab 2 10.1		0.47	12.11	2.5	2.75	1.52	19.35
Ipad 4th Gen	14.5		12.11	2.5	2.75	1.52	33.38
Ipad 4th Gen		0.47	12.11	2.5	2.75	1.52	19.35
Asus Nexus 7	14.5		12.11	2.5	2.75	1.52	33.38
Asus Nexus 7		0.47	12.11	2.5	2.75	1.52	19.35
Acer Icona W700	14.5		12.11	2.5	2.75	1.52	33.38
Acer Icona W700		0.47	12.11	2.5	2.75	1.52	19.35
Galaxy tab 10.1	14.5		12.11	2.5	2.75	1.52	33.38
Galaxy tab 10.1		0.47	12.11	2.5	2.75	1.52	19.35
Ipad 2	14.5		12.11	2.5	2.75	1.52	33.38
Ipad 2		0.47	12.11	2.5	2.75	1.52	19.35
Acer Icona tab A200	14.5		12.11	2.5	2.75	1.52	33.38
Acer Icona tab A200		0.47	12.11	2.5	2.75	1.52	19.35
Kindle 4	14.5		12.11	2.5	2.75	1.52	33.38
Kindle 4		0.47	12.11	2.5	2.75	1.52	19.35
TF101	14.5		12.11	2.5	2.75	1.52	33.38
TF101		0.47	12.11	2.5	2.75	1.52	19.35
Ipad 2	14.5		12.11	2.5	2.75	1.52	33.38
Ipad 2		0.47	12.11	2.5	2.75	1.52	19.35

[43] https://support.apple.com/es-es/iphone/repair/service/pricing (accessed on 5 September 2018)

2.3.4 Overview of life cycle costs

The life cycle cost information collected for smartphones and presented in the sections above is summarised in Table 14.

Table 14: Summary of life cycle cost information for smartphones

Cost category	Average value (1) (2)
Purchase price • Low-end • Medium • High-end Value of the product	 < 130 EUR/product 320 EUR/product > 480 EUR/product 54% of original price after 1 year, 32% of original price after 2 years, 20% of original price after 3 years
Installation costs	Not relevant
Maintenance costs	Not relevant
Repair/refurbishment costs (3)	About 15-40% of the product price for display; usually above 10% of the product price for other repairs
Disposal costs (EUR/product)	In accordance to the WEEE directive provisions, producers fulfil their responsibility of financing the costs of collection, treatment, recovery and environmentally sound disposal of domestic WEEE deposited at collection facilities. To some extent these costs are passed over to the consumer in the final purchase price. WEEE financing is a part of selling price, with relevant differences across the EU. In UK the fee is not visible, in Italy the fee is visible to trade partners, but not to consumers, in France the fee is visible also to final consumer. Costs also vary from country to country, logistic costs are a main source of variability. Manufacturers can leverage on economies of scale to ensure that collection and treatment costs are optimised.
Note: (1) VAT included (2) Costs are quantified on the basis of the information collected in Section 1.3 and considered representative for 2018 (3) Where relevant	

2.4 Market drivers, trends and circular business models

The following market drivers and trends have been identified for smartphones:

1. Quality of screen and camera are leading drivers of purchase (Kantar World Panel 2017). However, also the longevity of the battery is an important feature (Benton et al. 2015, Priya et al. 2016). According to some manufacturers, customers are demanding highly portable devices with batteries that can last all day, which requires successful products to be highly integrated, thin, light, and durable to withstand the rigours of everyday use.

2. Internet sales continue to increase in total market share, along with shopping through value-based websites like Amazon and eBay. In the US, a third of smartphone sales were made online in 2016, up from 27% in 2014, while 34% of purchases in Urban China were transacted online. Global trade and the rise of online retail make it easier to buy cheaper smartphones from abroad which do not necessarily need to comply

with European standards and regulations, e.g. regarding hazardous substances, potentially causing health risks to the consumers (Transform Together 2018).

3. Smartwatches were expected to become as popular as phones. These wearable smartphones have achieved good levels of penetration only in some markets (e.g. 16% in the US, 9% in Europe). The brands experiencing significant success are those which focused on individual needs through niche products, rather than on a fit-all-purposes device. Wearables appear to be appealing to consumers interested in monitoring health parameters and track their performance, but do not have gained much application beyond that (Kantar World Panel 2017). The use of fingerprint readers and other biometric identifiers (e.g. eye, face recognition) is instead expected to continue increasing (Deloitte 2016). A more disruptive technology could be the introduction on the market of foldable phones with flexible displays[44].

4. Virtual reality (VR), augmented reality (AR), artificial intelligence (AI), and virtual assistants may produce a big impact, and several companies are investing in this direction (e.g. Google's Daydream VR and Project Tango, Facebook's Oculus, Samsung's Gear VR, Asus' Zenfone AR, Microsoft's HoloLens, HTC's Vive VR, Apple's AR) (Kantar World Panel 2017). As mobile VR/AR grows, screen size will remain at the top of the feature preference list, since delivering the most realistic user experience relies on devices with large AMOLED screens. This fits with the current market trend towards the sales of screens above 5". However, the high-resolution requirements and AMOLED screens present a challenge to manufacturers wanting to lower their cost of production (Kantar World Panel 2017).

5. Services may play a more important role in particular those related to multimedia streaming (e.g. music, videos, TV) (Kantar World Panel 2017). Morever, there is a recent trend towards storing and process information remotely in the cloud (e.g. Dropbox, Google Docs). Offloading tasks to the cloud means older hardware can be used, including second-hand devices. More durable hardware could be helpful, and performance diagnosis software would need to be integrated to ensure that the agreed service commitments (e.g. speed to load webpages) were met (Benton et al. 2015).

6. In June 2016, the first 500 megabit per second (Mbit/s) mobile broadband services were launched in South Korea, with a gigabit per second (Gbit/s, equivalent to 1,000 Mbit/s) service planned for 2019. Delivering 1 Gbit/s connection over a mobile network is a significant technological achievement. However, this can come with questions over the actual need, and commercial viability, of such high speeds. Over half of UK adults have a 4G connection, and this already offers peak headline speeds of over 300 Mbit/s across parts of the UK. This headline speed is higher than the maximum speeds available from the majority of active fixed broadband connections. A 2 Mbit/s connection is sufficient to deliver a high-definition television image to a 40 inch screen, and even a 20 Mbit/s connection is more than sufficient to download high-definition videos to a five-inch smartphone screen. Although a large household might have many bandwidth-consuming devices (e.g. multiple TV sets) which might have an aggregate demand close to 1 Gbit/s at peak times, smartphones are owned and used by individuals, and typical usage does not need for 1 Gbit/s. There is no consumer application that currently requires a Gbit/s connection to a mobile phone and there are no websites, at the moment, that can transfer data at 1 Gbit/s (Deloitte 2016). On the other hand, the fast development of mobile broadband services is a critical factor for determining the obsolescence of devices. Vodafone, for example, is

[44] https://www.androidauthority.com/best-foldable-phones-922793/ (Accessed on 6 March 2019)

planning to shut off its 3G network in 2020, with the potential cut-off of many smartphones from data services[45].

7. Sales of smartphones could stop to increase, especially in developed economies, also because of the relatively high price of new smartphones, compared to the technological innovation brought by new models. This could result in lower replacement/upgrade rates, or longer times of use of the device from the other side (Watson et al. 2017).

8. Early upgrade programmes were designed by retailers to convince consumers to upgrade their devices on a frequent basis – usually every 12 months – improving revenues and keeping customers locked into a specific smartphone vendor and carrier. However, these programmes did not result being attractive to consumers, also due to the fact that the market is saturated and offering no disruptive but similarity competitive technologies. Some manufacturers (e.g. Apple and Samsung) now offer branded upgrade plans directly to consumers, but sales from these channels remain a small part of the overall smartphone business (Kantar World Panel 2017). This is now being challenged by rising demand for SIM-only services and reluctance to accept long binding periods (Watson et al. 2017).

9. Businesses increasingly have to compete on price and user experience rather than impressive features to attract and retain customers (Benton et al. 2015). Quality of materials and design has become an important area of innovation also for low and mid-range devices, where full metal and glass designs can be now found (Kantar World Panel 2017). The apparent tendency to all-glass, bezel-free smartphones could increase the area of the phone that is susceptible to cracks and breakages[46].

10. Premium market saturation and slowing pace of technology change can also be an opportunity for the 2nd-hand market (Benton et al. 2015). Repair, refurbishment and 2nd-hand sales are growing in association with take-back/buy-back schemes operated by producers/retailers/network service providers (Watson et al. 2017). 2nd-hand premium devices from developed countries can compete with low-end and mid-tier devices in developing countries, where there is still only 10% smartphone penetration of the mobile market, and projections indicate rapid growth rates will continue, especially in urban areas. Penetration may be further boosted by prices falling, e.g. smartphones costing less than 100 USD or even less than 50 USD (Benton et al. 2015).

11. Due to consumers' increasing dependence on smartphones, a strong demand for rapid repair services (under one hour) has developed in recent years. Fast-repairers are experiencing significant growth and require physical repair shops. Phones could be borrowed to consumers for longer repairs. This could be enabled by increasing reliance on "cloud off-loading" to allow easy transfer of data to a temporary borrowed phone.

12. More attention is paid by manufacturers on durability and reparability aspects in the design stage also to reduce the warranty costs (Watson et al. 2017).

In this context, business strategies undertaken in the smartphones market can be divided in two main groups:

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[45] https://www.gsmarena.com/vodafone_netherlands_will_kill_its_3g_network_in_2020-news-28762.php (accessed on 6 June 2018)
[46] https://www.theverge.com/2017/3/29/15104372/glass-screen-smartphone-design-lg-g6-samsung-galaxy-s8 (accessed on 18 April 2018)

- Some are focusing their R&D and marketing efforts on the upgrade of models and the integration of new technological features;
- Others are contributing to the development of circular business models (Watson et al. 2017) that can allow increasing / retaining / recovering the product's value (e.g. by extending the longevity of the smartphone and/or facilitating its take-back, repair, refurbishment and resale).

Circular business models can in general cover:

- Design of the product and provision of extended support and accessories:
- Reuse-promoting activities and markets:

The growth in circular businesses is leading to partnerships and interactions across the value chain between sellers of phones (producers, retailers, network service providers), repairers, 2nd-hand sellers and refurbishers. At the same time, some service providers are developing in-house refurbishment and repair services (Watson et al. 2017). No model can be considered as the best one, being all options potentially contributing to improve the resource efficiency of smartphones.

2.4.1 Design of the product and provision of extended support and accessories

The design of smartphones can potentially integrate the use of more sustainable materials and the consideration of durability, reparability and upgradeability aspects (for hardware, software and firmware). The selection of more sustainable materials can contribute to mitigate the environmental impacts of smartphones[47]. However, consumers seem more interested in the reliability of electronic products and in saving costs (Watson et al. 2017). This calls for design approaches aimed at ensuring a satisfactory use of smartphones over time (by reducing the likelihood of failures) and facilitating their disassembly, repair and upgrade.

Some companies have advertised their smartphones showing how their products are tested and remanufactured. However, there are currently no minimum quality standards available at EU or national level. Other companies have explored the concept of modular phone (e.g. Google, ZTE, Puzzlephone, Fairphone) (Watson et al. 2017), although only Fairphone and Shiftphone[48, 49, 50] seem to have been able to bring it to the market.

The lifetime of smartphones can be extended also through accessories (e.g. new covers) which can protect the device from damages and/or give them a new look (which could possibly reduce the likelihood to replace the phone with a new model).

Apart from hardware considerations, design of smartphones also concerns firmware and software issues (Watson et al. 2017). The availability of extended support is an essential condition for ensuring the functionality of smartphones over time and reducing the risk of

[47] More sustainable materials generally refer to material options that are assessed as being less critical with respect to environmental, economic and social issues. In practice, these can for instance include, if supported by evidence: recycled or bio-based materials, materials that do not pose any social or chemical concerns, materials characterised by a lower embodied carbon/energy.
[48] https://www.theverge.com/2016/9/2/12775922/google-project-ara-modular-phone-suspended-confirm (accessed on 6 June 2018)
[49] https://www.techradar.com/news/they-were-supposed-to-be-the-future-so-why-havent-modular-phones-taken-off (accessed on 6 June 2018)
[50] https://www.shiftphones.com/en/ (accessed on 8 April 2019)

replacing prematurely the device. This can include the provision of spare parts, firmware/software updates, and online support, as well as the availability of features facilitating the transfer and deletion of data, and the restoration of passwords and settings. Such characteristics can also have an influence over the resale value of smartphones (Benton et al. 2015).

The implementation of design approaches aimed at promoting the use of smartphones over time could be stimulated also through extended guarantee policies (Watson et al. 2017).

A more detailed description of key design aspects is provided in section 4.

2.4.2 Reuse-promoting activities and markets

When a failure cannot be avoided, smartphones can be repaired and re-used by the same or a new user. The same occur when discarded devices are collected. In both cases a smartphone can be either refurbished, to make it again fully functional, or remanufactured, to restore it to original "as new" conditions[51]. In any case, reuse of products and recovery of parts avoid the production of new parts.

Repair activities are attractive for smartphones because of the relatively high price of the product. In recent times, several examples of small, independent services can be found, besides officially authorised networks, which can offer repair training and services, used devices and parts. Access to repair manuals, diagnostic tools, original components, and specialised repair equipment is in some cases restricted to authorised centres only. Cooperation with independent repairers can be limited by factors as: safety, guarantee and quality issues related to customer satisfaction and producer liability, intellectual property rights, competition in the repair market. The unavailability of original spare parts can in particular result in the purchase of 2nd hand smartphones to cannibalise for components, or in the use of compatible parts, of the same or lower quality, from other sources. By not issuing original parts, producers could be undermining the quality of repairs made through independent channels and losing a potential source of income (Watson et al. 2017). However, manufacturers pointed that other important elements to take into account include: the training of repairers and the control over the quality of the repair operation, as well as contractual issues.

Repair operations undertaken by independent repairers could compromise the consumer's warranty. However, from another perspective, they can avoid the return of functional products to manufacturers and retailers (Benton et al. 2015). The possibility to apply a warranty on repaired products would be important to build trust and deliver a good service, especially for repairers that are not certified by manufacturers. Repair services are also challenged by the cost of work, which could be counter balanced through the implementation of lower VAT or tax breaks (Watson et al. 2017).

The circular business model that seems to be most widely implemented is the take-back and buy-back of used phones and their remanufacturing/refurbishment for resale and/or revalorisation of their parts (Watson et al. 2017). The majority of the value of devices lies in their highly engineered parts, rather than raw materials (Figure 10). This means that this route is more valuable than recycling. Opportunities for the re-use of parts include the use of older screens and cameras in low cost devices, and the use of batteries to power LED lighting (Benton et al. 2015).

[51] When the product is considered a waste, it is referred to as "preparation for reuse"

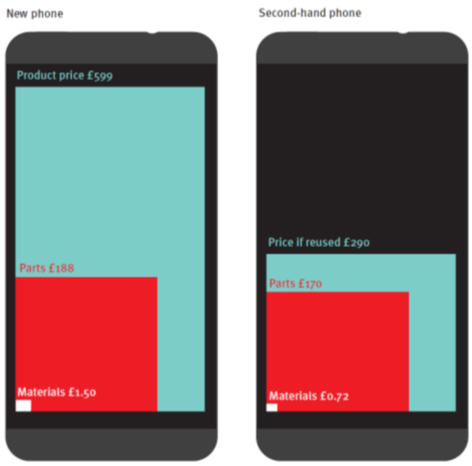

Figure 10: Contribution of materials and parts to the total product price for new and 2nd hand phones (Benton et al. 2015)

Devices which are still relatively new can be reused internally by manufacturers. Older devices can be sold in 2nd hand markets (Benton et al. 2015). The market for 2nd hand mobile phones has been growing since the early 2000s in developing countries. It is only more recently with smartphones that 2nd hand markets have become more important also in developed countries (Watson et al. 2017). The 2nd hand market of smartphones is expected to rise globally from 53 million in 2013 to 257 million in 2018. However, old devices are sold or traded only in 12% of upgrades. The reuse of smartphones in 2018 could account for about 8% of the global market (Benton et al. 2015).

Mugge et al. (2017) suggest a positive attitude of consumers towards reused smartphones because of the perceived environmental benefits. However, the growth in the 2nd hand market can be correlated also with the higher price of new devices. Nearly two thirds of smartphones live a 2nd life in Germany and in the U.S., either as new sale or exchange between users. When a new high-end smartphone model is introduced, previous models become available on 2nd hand markets. Best quality used goods are re-circulated in domestic markets, while lower quality goods go to markets with lower purchasing power (Watson et al. 2017). 2nd hand smartphones can be competitive with mid-to-low end devices: for instance, the Moto E had great success in 2012, in part because it was retailed for 90 GBP (130 USD), but the 2-year older Galaxy S3 had slightly superior specifications, and sold on eBay for 70-140 GBP (see Figure 11). Makov et al. (2019) highlight that depreciation can vary depending on the brand and the perceived quality.

Figure 11: Specifications of two similar smartphones sold in the UK in 2012 and 2014 (Benton et al. 2015)

While some producers are fully engaged with international refurbishment and resale companies, others fear that uncontrolled resale could damage their image through the sale of low-quality 2nd-hand versions of their phones. This problem seems to have been reduced with the establishment of large, international refurbishing companies. However, some refurbishers find that the supply of take-back phones is too limited and that better methods for marketing and incentivising consumers to return their phones should be developed. A retailer can act both as an official WEEE collector for discarded mobile phones, and in a separate take-back-and-buy channel, where they purchase used phones from consumers (in the understanding that they are not waste since intended for reuse) (Watson et al. 2017). Collaboration between carriers, retailers, software providers and consumers could facilitate the recovery of devices that would be otherwise scrapped or stored away. However, it is reported that many phones in developed countries are kept at home unused (e.g. in US and UK, where unused devices make up to 58 billion USD). Between 27% and 36% of US consumers said they keep an old phone because they "don't know what to do with it"; 17% were "too lazy" to get rid of them. Consumers could be incentivised to sell their old devices by being made aware of the value the devices still have and the availability of platforms to sell them (Benton et al. 2015). Device deposits have been also introduced to promote the return of used phones to the original manufacturer either for refurbishing or for recycling[52].

Take-back services can allow the recovery of parts and materials, and the proper recycle / final disposal of the device. For example, remade[53] is a French organization specialised in the remanufacturing of a specific brand of smartphone (iPhones). The entire process is conducted in France and includes the repair of screens (often only the glass needs replacement), motherboards and back covers. In 2017, Remade refurbished more than 600000 smartphones. These are mainly 1 year old phones supplied from leasing programmes for iPhones in the US[54].

However, 2nd hand phones shipped to developing countries typically end in open landfills once they are disposed, with negative consequences for human health and the environment, at least until modern e-waste recycling facilities will be deployed there. Closing the loop[55] collects client's phones for reuse/recycle purposes. For each phone, a waste phone is collected from developing countries and brought back to countries with appropriate recycling infrastructures. The programme also allows manufacturers to buy and recycle old phones from developing countries for each new phone put on the market (Transform Together 2018).

Refurbishment and 2nd hand businesses are also affected by the Consumer Sales Directive. For example, sellers of 2nd hand phones in Nordic Countries have the same minimum guarantee obligations as sellers of new phones. In practice, however, only a six month guarantee period is effectively applied in most cases. Enforcing the full guarantee period could have both negative (increase of costs) and positive (increase of consumer confidence) effects (Watson et al. 2017).

Sustainable Product Service Systems (SPSS) could be an additional strategy of interest within the circular economy. The core concept of these models is that businesses retain ownership on the product and rather sell a service to consumers. SPSS can be broadly classified as (Hobson et al. 2018):

[52] www.shiftphones.com/en/deposit/ (accessed on 7 June 2018)
[53] https://www.remade.com/ (accessed on 12 March 2019)
[54] http://trendnomad.com/refurbished-phone-smarter-than-the-latest-model/ (accessed on 12 March 2019)
[55] http://www.closingtheloop.eu/ (last accessed on 01/02/19)

1. Product-Oriented (selling a good with additional services);
2. Use-Oriented (leasing or renting goods with attached services); and
3. Result-Oriented (providing a service rather than just material goods).

The offer of products as services provides an incentive, to the actor offering the service, to optimise their products in terms of material efficiency aspects such as their durability, reparability, upgradability, and suitability for remanufacturing. However, it should be pointed out that this does not represent by default an improvement of the material efficiency of the product (for example in case upgrades are frequently offered by providers).

3 USER BEHAVIOUR

This section provides information about how consumers use and interact with the product and the technologies applied in it. This is fundamental to understand up to which point the impacts of products are influenced by users and/or inherent design and performance characteristics.

3.1 Conditions of use and behavioural aspects

Smartphones have changed the world in a relatively short time frame (around a decade) and have become an essential tool and accessory for users. Over 36% of the world's population is estimated to use a smartphone these days and penetration per capita in Central & Eastern Europe has been estimated to be almost 60% in 2017 (Statista 2018i).

The devices are used for many different purposes, and as a result have made many other small electronic devices (e.g. digital cameras) unnecessary (Watson et al. 2013). Smartphones are multifunctional devices and they need mobile telecommunication (telco) networks and the internet in order to deliver all their functions. Popularity of smartphones also increases the overall data traffic in networks.

3.1.1 Type of phone and age of users

A majority of consumers in both developed and high-growth economies owns a mobile phone, although there are some differences in the types of mobile devices owned (Figure 12). In general, younger users are more likely to own a smartphone than older users, although there can be some exceptions (Nielsen 2013).

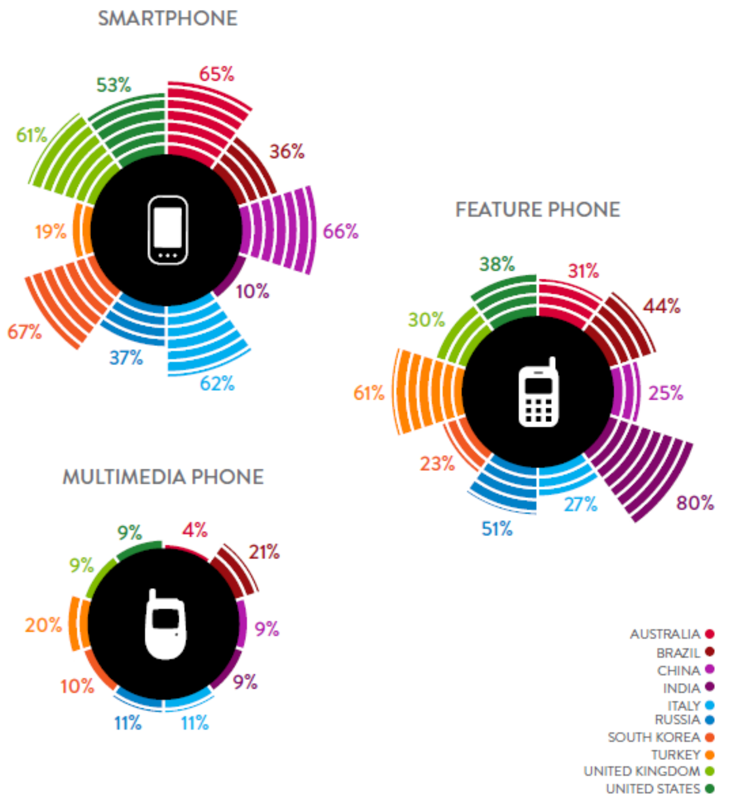

Figure 12: Use of mobile phones in different countries (Nielsen 2013)

3.1.2 Functionalities

Browsing the internet and gaming are amongst the most popular activities on a smartphone across different countries (Figure 13). Voice calls remain the preferred choice of communication in some markets (e.g. Germany and Japan), although messaging is more and more popular especially in emerging Asian and African markets. Watching videos and spending time on social networks are the fifth and sixth most popular activities on a smartphone (Counterpoint Research 2016).

It is reported that on average, a consumer in the US spends about 644 minutes per month in voice calls (164.5 voice call per month) and exchanges about 764 text messages (Nielsen 2013).

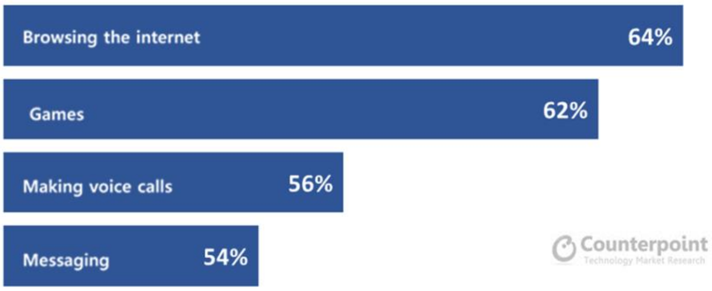

Figure 13: Global daily use behaviour (Counterpoint Research 2016)

The use of internet in smartphones is mainly associated with search engines, checking of email accounts and visiting social networks. These are the most common activities carried out weekly with a smartphone in countries like France, Spain, and the UK (Statista 2018k, 2018p, 2018s). As shown in Figure 14, the use of these services is increasing over time, as well as the use of data communication services(Deloitte 2016).

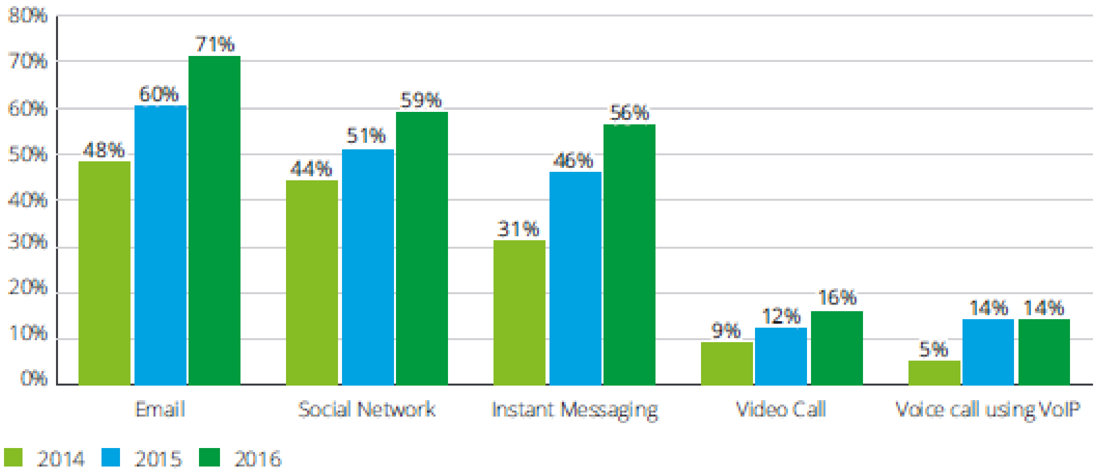

Figure 14: Smartphone users who use data communication services weekly in the UK(%) (Deloitte 2016)

Interestingly, as shown in Figure 15, the use of smartphones for voice calls, which is the primary function of phones, seems to be decreasing over time (Deloitte 2016).

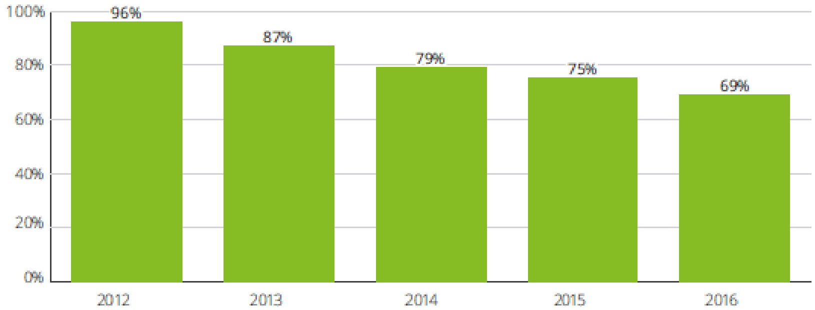

Figure 15: Use of smartphones for standard phone calls in the UK from 2012 to 2016 (%) (Deloitte 2016)

Applications are one of the most disruptive innovations of the last decade and have played a core role for the commercial success of smartphones (Figure 16). Apps tend to be most successful for tasks which are undertaken regularly (Deloitte 2016).

Applications installed on smartphones devices often track user's location, contributing to higher battery drain, as well as to privacy concerns, which could be limited by disabling features when not needed. However, smartphones can also offer the opportunity to drive sustainable development through the use of certain apps. For example, applications facilitating sharing economy practices and providing information about products (e.g. environmental impacts, energy-efficiency) are becoming increasingly popular and can represent an efficient way of using a smartphone (Transform Together 2018).

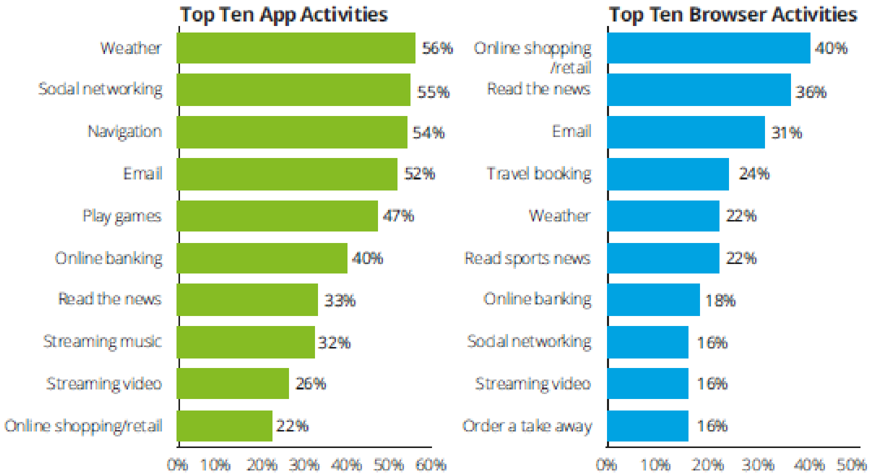

Figure 16: Top ten activities accessed in the UK when using an app or a browser (%) (Deloitte 2016)

Another important functionality of smartphones is their ability to take pictures (Figure 17). In the UK, for instance, it has been observed that photo taking and sharing has increased in the last years. 27% of people took photos on a daily basis in 2016, more than double than in 2015. At the same time, there has been a corresponding increase in daily photo posting to social media and sharing via instant messaging, from 5% to 12%. Videos are also becoming more and more popular, also because of faster connectivity speeds and the availability of sharing applications and social media platforms (Deloitte 2016). However, video viewing is not considered universally a full replacement of TV (Nielsen 2013).

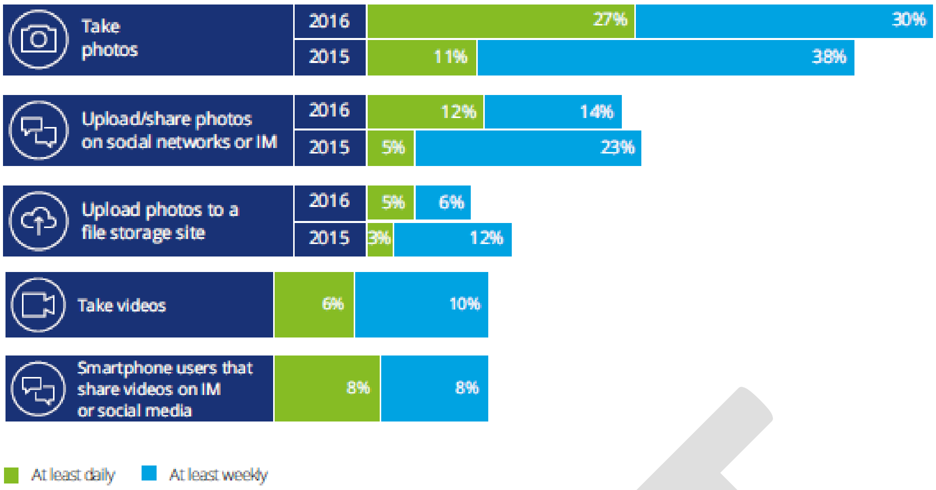

Figure 17: Photo and video taking and sharing in the UK in 2015 and 2016 (%) (Deloitte 2016)

With respect to other features, only 12% of users were reported to use the voice assistant in the UK in 2016, and another 21% were using the fingerprint identity verification method to log into their devices (Statista 2018r). However, more recent data for the UK market seems to indicate that the frequency of use of such services has increased significantly in the recent period (Deloitte 2018). Moreover, it has been reported by stakeholders involved in the development of this study that also other forms of identifications, as face identification, are available since 2017.

Smartphones compete with other devices such as laptops and tablets for a range of applications. According to a survey conducted in the UK (Deloitte 2016), smartphones would be the preferred device for checking social networks, calling using internet, playing games, taking photos and recording videos.

3.1.3 Time and place of use

People spend more time on their smartphones than any other device: smartphones are taking a central stage of consumer life (Figure 18). Almost half of respondents to a global survey spent more than 5 hours per day on their smartphone. Additionally, one in four users spent more than 7 hours every day on their smartphone (Counterpoint Research 2016).

Figure 18: Time Spent on Smartphones Daily (Counterpoint Research 2016)

The use of smartphones can enhance social lives, but also comes with risks (e.g. dependency, distraction, arguments). In the UK, a tenth of smartphone owners instinctively reach for their phones as soon as they wake up, and not just to turn off their alarm. A third reaches for their phones within five minutes of waking, and half within a quarter of an hour. A similar pattern takes place at night. Two thirds of smartphone owners do not check their phones at night, however, over three quarters of smartphone owners check their phones within one hour before going to sleep; half within 30 minutes; a quarter within five minutes; and a tenth immediately before. Exposure to light, including that from a screen just before going to sleep, can confuse the brain into thinking it is still day-time, and inhibit the process of falling asleep. Screens should be turned off at least an hour before turning out the lights. Alternatively, night-time modes should be used that make screens with warmer and yellower tones instead of standard blue lights. As with most emerging technologies, consumers need to find a balance between usefulness and overuse of smartphones (Deloitte 2016).

3.1.4 Purchasing behaviour

The main factor consumers in the UK are taking into consideration when making a decision about purchasing a new smartphone is the price, while the main reason for purchasing a new smartphone is that the consumer's current device is out of date (Statista 2018r).

Environmental concerns do not seem to be a key driver of purchase for most consumers. Retailers do not report any increased interest in smartphones made from materials which embed lower environmental impacts, or modular devices which can facilitate the repair and/or upgrade of their parts. This is confirmed also by some manufacturers, who indicate that the user experience with the phone and the value for money are what really matter for most consumers (Nielsen 2013; Watson et al. 2017).

3.2 Causes of replacement

According to a recent study (Watson et al. 2017) discarded or replaced phones are often replaced because of functional obsolescence driven by launching of new models and features, and by social expectations. However, loss of performance, failures and breakages of smartphones can still be important reasons for replacing the product in Europe.

The decision on whether to repair or replace the device may depend on a number of factors, such as: type and value of the product, lifetime considerations, functionality of new/alternative products and technologies, emotional attachment. The decision can also be influenced by sociodemographic factors (e.g. age, relationship with technology, attitude towards new vs. conserving the old, social pressures).

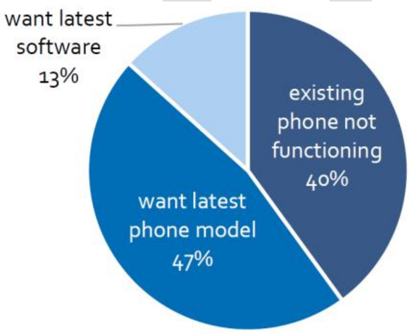

Figure 19: Reasons for smartphone replacement (Watson et al. 2017)

3.3 Product's lifetime

The average upgrade cycle for most smartphone buyers was 23 months in 2014[56]. According to the results of a global consumer survey (Counterpoint Research 2016), the average global smartphone replacement cycle was 21 months in 2016 (Figure 20). Emerging market consumers seem more assertive in replacing their device than consumers in developed markets. This could be triggered by the growth of Chinese brands offering higher specification devices at affordable prices, as well as by the rise of 2nd hand and refurbished smartphones (Counterpoint Research 2016). In alignment with the figure just provided, another survey (Kantar World Panel 2017) indicates that the average life cycle of smartphones increased from 18.3 months in 2013 to 21.6 months in 2016 in the most populated countries of the Europe (Figure 21). Consumers of developed countries would be holding their phones longer than in the last years, perhaps as a consequence of the slower speed of innovation.

Figure 20: Average replacement cycle for smartphones in 2016 (Counterpoint Research 2016)

	USA	China	EU5	France	Germany	Great Britain	Italy	Spain
2016	22.7	20.2	21.6	22.2	20.3	23.4	21.6	20.5
2015	21.6	19.5	20.4	21.6	18.8	23.5	17.7	20.0
2014	20.9	21.8	19.5	19.4	18.2	22.0	18.7	18.2
2013	20.5	18.6	18.3	18.0	17.1	20.0	18.6	16.6

Figure 21: Average time of first use of smartphones by country (number of months) (Kantar World Panel 2017)

A review study for the German context (Prakash et al. 2015) also reports that the time of first use is 2 years for new mobile phones. This would increase to 2.5 years considering 2nd hand use. This could be due to the fact that mobile phone contracts in Germany usually run over 2 years. With the conclusion of a contract, a new model is often purchased and the old device taken out of service. Such outcomes are aligned with indications from Stiftung Warentest,

[56] https://www.wsj.com/articles/your-love-of-your-old-smartphone-is-a-problem-for-apple-and-samsung-1519822801 (accessed on 1 March 2018)

according to which 42% of users in Germany exchange their mobile phone within 2 years. Around 16% of users change phones every 3 years, with another 12% every 4 years. Only about 20% of respondents exchange their mobile phone less frequently than every 5 years (Prakash et al. 2015).

However, the lifespan of a mobile phone can range from 1.7 up to 7.99 years[57], with the median reported to decrease from 4.8 to 4.6 years (-3%) between 2000 and 2005 (Bakker et al. 2014). According to data available on the website of the German WEEE registry (EAR), 6 years would instead be the average time before a mobile phone reaches the end-of-life[58], probably due to reuse of mobile phones and/or the storage of unused devices at home.

[57] Encyclopedia of mobile phone behavior / Zheng Yan, editor. Information Science Reference (an imprint of IGI Global), Hershey PA (USA). ISBN 978-1-4666-8239-9 (hardcover) -- ISBN 978-1-4666-8240-5 (ebook)

[58] German register for waste electric (WEEE registry), https://www.stiftung-ear.de/hersteller/produktbereiche-regelsetzung-und-regeln/produktuebergreifende-arbeitsgruppe-pbue/regelsetzung-garantiehoehe (accessed on 13 June 2018)

4 TECHNICAL ANALYSIS AND SYSTEM ASPECTS

This section provides technical elements for the analysis of material efficiency aspects as durability, reparability and recyclability. These include the analysis of: key functionalities, parts and materials used in the product; strategies to avoid/overcome typical limiting states; EOL practices. System aspects and trade-offs are also addressed. The aim is to set the basis for the identification of a preliminary list of design measures which can improve the material efficiency of products.

4.1 Technological aspects

4.1.1 Design and innovation

Decisions taken during the design of a product can have consequences over its entire life cycle. These can for instance address: functionalities and target levels of performance, aesthetic considerations, type and quality of parts, their durability and disassemblability, supply, safety and recyclability of materials. The design phase plays a key role in determining the impacts of a product. Trade-offs can be in particular associated to different design strategies addressing material efficiency aspects as durability, reparability and recyclability, as discussed in Section 4.7.

Mobile phones are changing every subsequent generation in terms of quality, computational power, size of parts, and materials. The Moore's law (doubling of computational power every two years) contributes to define the raw materials needed to produce the devices (Transform Together 2018). Mobile phones are becoming more powerful and, consequently, the energy consumption of their parts (e.g. chipsets and screens) increases (Transform Together 2018). Miniaturisation is also leading to use fewer resources, expressed as overall mass, although some of them can be precious and/or critical.

Smartphones on the market can be considered to belong to the fourth generations of mobile communication systems (Agrawal et al. 2015), while the fifth generation is going to be available shortly. The main features of each generation are described below:

1. The first generation of mobile communication networks was introduced in 1980s and was based on the analog 1G system. The most popular were the Advanced Mobile Phone System (AMPS) in the US and the Nordic Mobile Telephone (NMT) and the Total Access Communication System (TACS) in Europe. Analog systems were based on circuit switching technology, which supported transfer speed of up to 2.4kbps and offered only voice communication.
2. The second generation, conceived as 2G technology, was introduced in late 1980s and was based on low-band digital data signaling. Analog technology was replaced by Digital Access techniques such as TDMA (Time Division Multiple Access) and CDMA (Code Division Multiple Access). The most popular 2G wireless technology is known as Global Systems for Mobile Communications (GSM). The CDMA breaks down voice and data transmission on a signal by codes, whereas TDMA breaks them down by time slots. The result in both cases is an increased network capacity for the wireless carrier and a lack of interference. Transfer speeds of 64 kbps were provided.
3. The third generation (3G) was introduced at the end of 1990s. The 3G brought disruptive transformation in the mobile communication by providing peak data rates of at least 200 kbit/s. The most important technology was the Universal Mobile Telecommunications System (UMTS). The UMTS uses the W-CDMA, TD-CDMA, or TD-SCDMA air interfaces. The main components includes BS (Base Station) or nod B, RNC (Radio Network Controller), apart from WMSC (Wideband CDMA Mobile Switching Centre) and SGSN/GGSN. The W-CDMA gave additional advantages of high transfer rate, and increased system capacity and communication quality. In the W-CDMA system, the data is split into separate packets, which are then transmitted and reassembled in the correct sequence at the receiver by using the code that is sent with each packet. The UMTS systems are designed to provide a range of data rates (up to 144 kbps for moving vehicles, up to 384 kbps for pedestrians and up to 2 Mbps for indoor or stationary users). The 3G allowed multimedia applications such as video and photography, and the provision of services like mobile television, GPS (global positioning system), video call and conferencing, high speed mobile internet access.

4. The fourth generation (4G) was introduced at the end of 2000s, also due to an increased demand of data transfer. Better modulation techniques were used to improve the upload and download rate of data. The Long Term Evolution (LTE) was the evolution of universal mobile telephone system (UMTS). Its components are named "evolved UMTS terrestrial radio access" (E-UTRA) and "evolved UMTS terrestrial radio access network" (EUTRAN). The basic architecture of LTE contains a separate IP connectivity layer for all the IP based services and Evolved Packet System (EPS) which handles the overall communication procedure. Since LTE allows for inter-operation with existing systems, there are various paths available to connect to LTE: both an operator with a GPRS/EDGE network or a Non-3GPP systems can connect to a LTE network. LTE can have download rates of about 100 Mbps in update rate of 50 Mbps. Higher rates can be achieved if multiple-input multiple-output (MIMO), i.e. antenna arrays, are used. Moreover, it provides better quality of communication, easy access to internet, streaming media, video calling services. A 5G is currently under development which should allow, among other things, data transfer at a speed of 1 Gbps.
5. 5G is the latest generation of cellular mobile communications, which targets high data rate, reduced latency, energy saving, cost reduction, higher system capacity, and massive device connectivity. The first phase of definition of 5G specifications is planned to be completed by April 2019, to be followed by commercial deployment[59].

When smartphones were introduced on the market, products were innovating rapidly: the average time new models spent on the market was 6-9 months in 2010, whilst the average shelf time was about three years prior to 2007[60]. However, longer update cycles could be adopted now (Watson et al 2017).

4.1.2 Functions

Products are conceived to deliver certain functions. The analysis of functions (also referred to as functional analysis in this report) is fundamental to understand the purpose of a product, identify the parts needed and define their technical specifications. Functions of a product and their relative importance can be analysed following the principles of the standard EN 12973:2000 – Value Management[61].

A smartphone has been described in section 1.1.3 as follows:

- It is an electronic device primarily designed for mobile communication (making phone calls, text messaging) and use of internet services;
- It can be used for long-range communication over a cellular network of specialized base stations known as cell sites, including LTE (often also called 4G), HSDPA (3G+), UMTS (3G) or GSM standard (2G);
- It is functionally similar to wireless, portable computers (e.g. tablet PCs), since

  - designed for battery mode usage, and connection to mains via an external power supply is mainly for battery charging purposes,

  - presenting an operating system (Google's Android, BlackBerry OS, Apple's iOS, Nokia's Symbian, Microsoft's Windows Phone), WiFi connectivity, web browsing capability, and ability to accept sophisticated applications;

[59] https://en.wikipedia.org/wiki/5G (accessed on 4 April 2019)
[60] http://money.cnn.com/2011/01/31/technology/new_smartphone/index.htm (accessed on 1 March 2018)
[61] 5 steps are defined: 1) Identification and list of functions; 2) Organisation of the functions; 3) Characterisation of the functions; 4) Setting the functions in a hierarchical order; 5) Evaluation of the functions

- It has a display size between 3 and 6 inches and a high-resolution touch screen interface, in place of a physical keyboard.

Functions of a smartphone could be classified as:

- Communication functions (phone calls making, text messaging, access to web services, keyboard, touch-screen interface);
- Portable operability (rechargeable battery input, duration of battery, computational features);
- Multimedia functions (camera features, audio/video recording, audio/video reproduction, screen size and resolution).

According to the information collected in the former sections 2 and 3, the following functions seem particularly important for consumers:

- Size of the screen, camera, quality aspects as reliability and screen resolution (Kantar World Panel, 2017)
- Longevity of battery, internet access, and high specification camera (Benton et al. 2015).

A classification of smartphone's functions is reported in Table 15.

Table 15: Smartphone's functions and related characteristics

Function	Required characteristic
Safe access, communication and connectivity	- Cellular Band communication - Wi-Fi Networks Connections - Internet Access - Microphone and video - Keyboard and/or touch-screen - Near Field Communication (NFC) - USB/cable connection - Infrared/blue-tooth connection - GPS connection - Tethering - Recognition technologies (e.g. fingerprint sensors, face ID)
Multimedia reproduction	- Functional display (size and resolution) Integrated photo and video-camera
Portable operability	- Rechargeable battery, power supply and connector - Duration cycle of the battery - Updatable operating system and software
Longevity	- Resistance to stresses - Longevity of battery - Ease of repair and upgrade

4.1.3 Parts

The delivery of functions is done by parts. Smartphones is composed of between 500 to 1000 different components, many of which are extremely small (Wiens 2014).

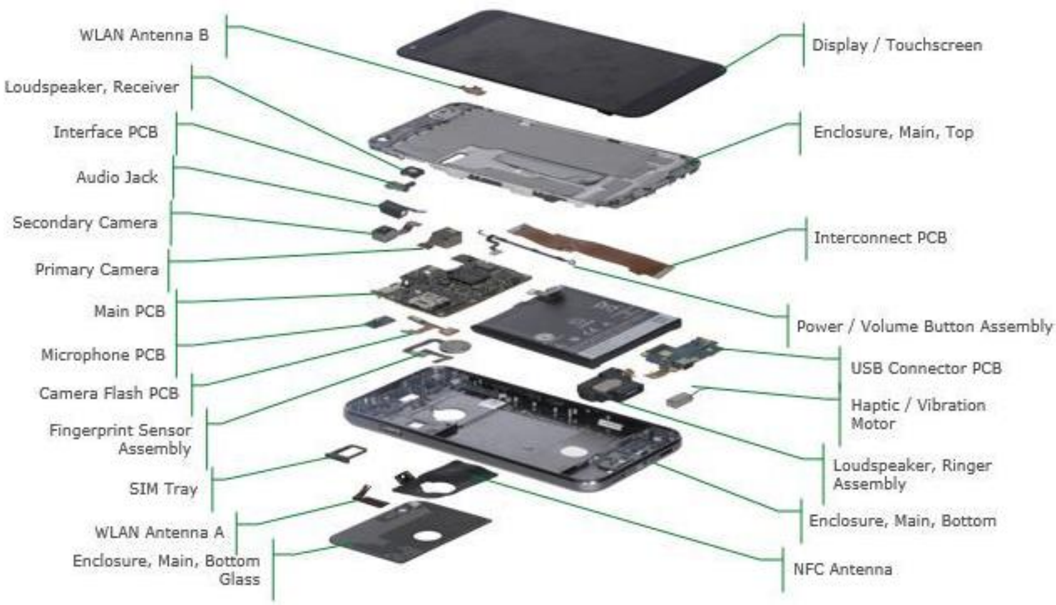

Figure 22: Parts of a smartphone: exploded view based of the Google Pixel XL[62]

The main parts of a smartphones are described below.

4.1.3.1 Frame and back cover

The phone is typically designed to find a balance between aesthetics and durability. Frame and back cover are the endo- and exo-skeleton of smartphones and are typically made of metals (mainly aluminium, copper and iron/steel alloys), plastics, glass and ceramics (Andrae 2016; Manhart et al. 2016; Proske et al. 2016).

4.1.3.2 Screen

The screen of smartphones is the interface which allows users to visualise information on their devices. A standard three-part screen consists of a display, a capacitive layer (touch screen) and a glass cover. For several models on the market, such parts are glued together and form one unit.

In terms of size, most displays sold in 2016 were larger than 5" (Kantar World Panel 2018). Alternative technologies can be applied for the visualisation of information (Fossbytes 2017):

1. Liquid Crystal Displays (LCDs), where a backlight is transmitted through some polarizers and filters and result in different colours in the display. The light is not being generated by the display itself. When the display is black, no light gets through its crystal. However, the light behind the display is still being generated meaning that the smartphone is still using a bit of battery;
2. Light-Emitting Diodes (LEDs), where pixels are illuminated by light-emitting-diodes (also known as LEDs) which produce red, green, and blue colours. The display itself is generating the different colours. This means that no energy is used when a pixel is off and colour is black, resulting beneficial for the battery life;

[62] https://www.businesswire.com/news/home/20161025005551/en/Google-Pixel-XL-Manufacturing-Cost-Line-Rival (accessed on 6 March 2019)

3. OLED (Organic Light-Emitting Diode), where pixels actually produce their own light. These pixels are called "emissive". OLED are typically used in high-end phones although they are is becoming popular since they have a very fast response time and allow making curved and flexible screens, good view angles and an always-on display mode[63];
4. AMOLED (Active Matrix OLED) is a type of OLED technology used in smartphones which is more energy efficient thanks to the use of at least two thin-film transistors that control the current flowing of each pixel.

Manufacturing costs of different display panels are reported in Figure 23. The cost of OLED displays is relatively higher than other types of displays, however, smartphones with OLED displays are more expensive also because they generally include also other high-end parts (e.g. camera, chip)[64].

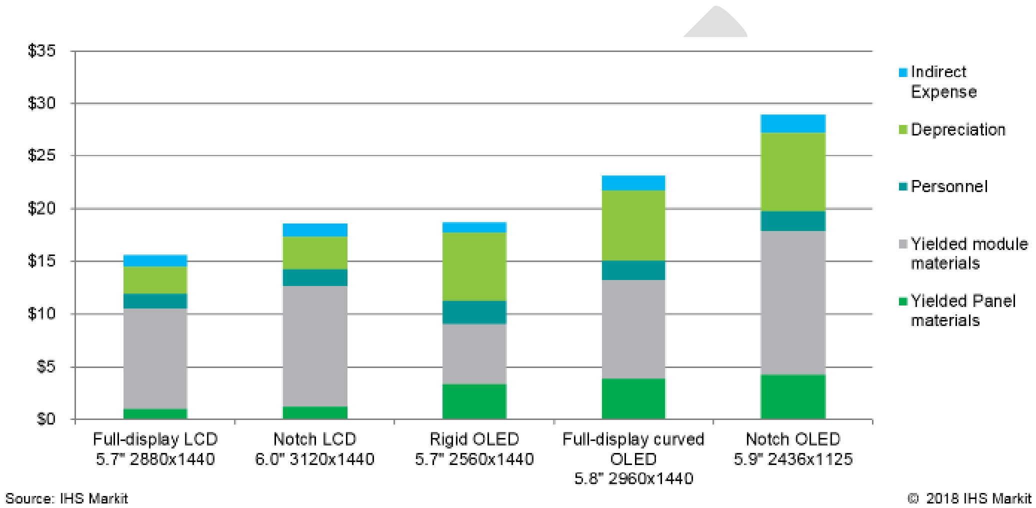

Figure 23: Manufacturing cost of different display panels[65]

The touch screen consists of a capacitive layer typically based on Projected Capacitive Touch (PCT) technology. A voltage is applied to a grid to create a uniform electrostatic field. When a conductive object touches the PCT panel, it distorts the electrostatic field of the electrodes that are nearby the touch point. This is measurable as a change in the electrode capacitance. If a finger bridges the gap between two of the electrodes, the charge field is further affected. The capacitance can be changed and measured at every individual point on the grid. Therefore, this system is able to accurately estimate the touch position (Li Du 2016).

The glass cover is the outer part of a screen. Modern smartphones feature a toughened glass (commonly an alkali-aluminosilicate glass)[66]. This increases the durability of the display in terms of scratch- and drop-resistance and ensures a clear visualisation of images. Strengthened glass panels are getting more and more durable. Corning's Gorilla Glass 4, for example, offers twice the protection of its predecessor (Gorilla Glass 3). Both Gorilla Glass and Apple's ion-strengthened glass have been chemically altered via ion exchange to improve their strength. The process involves the exchange of

[63] http://www.displaymate.com/Galaxy_S10_ShootOut_1S.htm#Table (accessed on 4 April 2019)
[64] http://www.displaymate.com/iPhoneXS_ShootOut_1s.htm (accessed on 10 April 2019)
[65] https://technology.ihs.com/603423/smartphone-display-with-notch-design-estimated-to-cost-about-20-percent-more-ihs-markit-says (accessed on 10 April 2019)
[66] https://www.androidguys.com/tips-tools/types-of-smartphone-glass/ (accessed on 27 March 2019)

sodium ions in the glass material with larger potassium ions under high temperature. The end result is a material that is more impact resistant and scratch-proof than regular glass[67].

Recently, a new type of glass that can heal itself from cracks and breaks has been developed. This is made from a low weight polymer called "polyether-thioureas" and can heal breaks when pressed together by hand without the need for high heat to melt the material[68].

4.1.3.3 Battery

Batteries of phones are normally based on lithium-ion (Li-ion) technology (Fossbytes 2017) and can be removable either by end-users or only by professionals.

Lithium polymer (Li-poly) is the latest technology commercially available for smartphones where a polymer electrolyte is used, instead of a liquid one. Li-ion and Li-poly batteries have the same chemical composition, but one of their differences is that Li-ion batteries have a tendency to overheat and need to have an active protection circuit to prevent overheating. Since Li-poly batteries do not require such protection circuit they allow thinner formats of cells. Another characteristic of the Li-poly batteries is that they do not suffer from memory effect[69, 70]. Li-ion batteries have a higher energy density and cos less for their manufacturing[71].

Solid-state lithium batteries could represent one of the main evolutions of Li-ion batteries for the future (Science for Environment Policy 2018), as well as silicon anode batteries, energy-harvesting nanogenerators, durable nanowire batteries and organic "flash" batteries[72].

4.1.3.4 Electronics

The "System-on-a-Chip" or SoC (also known as an IC chip) is one the most important part of a smartphone. This comprises the CPU (Central Processing Unit), the GPU (Graphics Processing Unit), the modem, the display and video processors, and other electronics that turn the product into a functional system. Most of smartphones use the same architecture from ARM[73]. Some companies instead make their proprietary processors but these are compatible with ARM's system architecture (Fossbytes 2017).

With respect to modems (Fossbytes 2017), these are communication components used in smartphones to receive and send information. Every SoC manufacturer has its own brand of modems. The fastest one is the Cat. 9 LTE modem. However, this can be used at its full potentiality only if the level of speed is supported in the cellular network.

[67] https://smartphones.gadgethacks.com/how-to/4-most-durable-premium-smartphones-for-clumsy-people-0175454/#jump-comparisonchart (accessed on 23 March 2018)
[68] https://www.theguardian.com/technology/2017/dec/18/smashed-cracked-phone-screen-self-healing-glass-university-of-tokyo (accessed on 23 March 2018)
[69] The "memory effect" happens when rechargeable batteries are not fully discharged between charge cycles; as a result the battery "remembers" the shortened cycle and is thus reduces its capacity
[70] https://www.themobileindian.com/news/understanding-cell-phone-batteries-5168 (accessed on 8 April 2019)
[71] https://www.quora.com/Which-type-of-battery-for-smartphone-is-better-Li-Ion-or-Li-Po (accessed on 8 April 2019)
[72] https://enterprisersproject.com/article/2018/10/5-mobile-phone-battery-breakthroughs-watch (accessed on 10 April 2019
[73] https://www.arm.com/ (accessed on 8 March 2019)

4.1.3.5 Memory and storage

No smartphone can function without a RAM and an internal memory storage system (Fossbytes 2017). The internal memory storage system ranges typically from 32GB to 256GB. With respect to the RAM, most mobile devices are shipped with LPDDR3 or LPDDR4, while some high-end smartphones are shipped with LPDDR4X RAM. LP stands for "Low-Power" and reduces the total voltage of these chips, making them highly efficient and giving mobile phones an extended battery life. LPDDR4 is more efficient and powerful than LPDDR3, while the LPDDR4X is the fastest, most efficient, but expensive. Newer generations of RAM are going to be introduced, such as LPDDR5. In terms of capacity the current RAM usually ranges between 2 GB and 8 GB. Terminating or uninstalling unused apps can result in the availability of more RAM and can improve the performance of a smartphone.

4.1.3.6 Firmware and software

Smartphones are run through an Operating System (OS) and firmware. An operating system allows the device to run applications and programs, therefore, bringing advanced functions that were previously restricted to computers only (Statista 2018z). The firmware is a kind of software that serves for specific purposes related to hardware parts.

Updates are provided by manufacturer on a regular basis to fix problems and security issues. Updates are as important as the physical elements of a smartphone to ensure a longer life of the device and to reduce phone replacement rates. A lack of updates might indeed make smartphones obsolete while its hardware is still fully functioning (Watson et al. 2017).

4.1.3.7 Multimedia and connections

Multimedia-related parts include the camera and audio components as microphone, speakers, headset connector. In particular, all smartphones come with rear-facing and front-shooting cameras. The camera comprises up of three main parts: the sensor (which detects light), the lens (the component in which light comes through), and the image processor. While the megapixels on the smartphone are still an important part of the camera, they carry less importance than in the past. Instead, the primary limiting factor is the camera sensor of the phone and how sensitive it is when light passes through the lens. Each sensor behaves differently from smartphone to smartphone. Since smartphones have small sensor sizes, they tend to perform badly in low-light areas. This is an area where camera sensor manufacturers have been working to improve the performance of the device (Fossbytes 2017). Interactivity with the user is also possible through USB ports.

4.1.3.8 Other functional parts

Smartphones come with a vibration mechanism and with sensors that provide specific functionalities (Fossbytes 2017):

- Accelerometer, which is used by apps to detect the orientation of the device and its movements, as well as allows the phone to react to the shaking of the device (e.g. to change music);
- Gyroscope, which works with the Accelerometer to detect the rotation of the device, for features like tilting the phone to play racing games or to watch a movie;
- Digital Compass, which helps the device to find the North direction, for map/navigation purposes;
- Ambient Light Sensor, which automatically sets the screen brightness based on the surrounding light, thus helping to reduce the eyes strain and to conserve the battery life;
- Proximity Sensor, which detects the proximity of the device with the body, so that the screen is automatically locked when brought near the ears to prevent unwanted touch commands.

4.1.3.9 Accessories

A smartphone can include a set of accessories in the sale package:

1. Headset;
2. Transfer cable;
3. External Power Supply (charger);

Instead of including a captive charger and data transfer cable, it could be more efficient to use a detachable charger (RPA 2014). Interoperability of chargers can be ensured by the compliance with the IEC 62684:2018 "Interoperability specifications of common external power supply (EPS) for use with data-enabled mobile telephones" that is based on the common use of USB 2.0 Micro B interfaces. However in March 2018 several manufacturers have signed a MoU committing, by three years from the signature date, to produce smartphones that will be chargeable through a USB Type-C connector or cable assembly (RPA 2014). For these purposes, the relevant EPS interoperability standard is IEC 63002:2016 "Identification and Communication Interoperability Method for External Power Supplies Used with Portable Computing Devices". However, an effective saving of materials can be achieved only if the sale of EPSs is decoupled from the sales of the smartphones (RPA 2014; Sustainably SMART 2019).

Others accessories generally not sold by the OEM but necessary for a smartphone to function properly over time include:

- Micro SD cards and micro SIMs;
- Protection accessories: protective cases (also called bumpers) and screen protectors.

4.2 Materials

4.2.1 Bill of Materials

Compiling a precise list of materials contained in a smartphone is difficult due to tightly protected Intellectual Property and variations between models and manufacturers over time.

Prunel et al. (2015) indicate that the weight of mobile communication appliances can range from 60 g (when the display size is 1.5", for a surface of 7 cm^2) to 200 g (when the display size is 6.5", for a surface of 120 cm^2). However, this is beyond the scope of this study, which focuses on 4-6.5" smartphones.

Data available for 32 models of smartphones produced by Huawei[74] shows a range in weight from 142.4 g to 232 g. Battery represents around 25-30% of the product weight and together with glass and ceramic materials represent more than 50% of the smartphone mass.

Weights of 15 models of smartphones produced by Apple[75] instead ranges from 112 g to 208 g, with an apparently higher weight for newer models. The relative weight of batteries has passed from about 25% for older models to about 40% for the newest ones. Interestingly, stainless steel is reported to be used more than aluminium and plastics. However, a variation in the use of different materials over time is also appreciable.

[74] https://consumer.huawei.com/en/support/product-environmental-information/ (accessed on 31 January 2019)
[75] https://www.apple.com/lae/environment/reports/ (accessed on 31 January 2019)

The weights of smartphone models from Fairphone (170 g for a size of 75.5 cm^2) (Proske et al. 2016) and Samsung[76] are also included in the range described above.

Based on the available data, the weight of smartphone could be estimated approximately as 29 g per display size inch (+/- 15%). A smartphone has been reported (Manhart et al. 2016) to have, on average, a display size of 75.53 cm^2 and a weight of 160 grams, including 39 g for the battery, and excluding accessories and packaging.

The mass of a smartphone in general consists of metals (mainly aluminium, copper and iron/steel alloys, but also minor quantities of other elements used for specific applications because of their properties, including rare earth elements and conflict minerals), glass and ceramics, plastics, and other materials (Andrae A. 2016; Manhart et al. 2016; Proske et al. 2016).

Screens are manufactured mainly from aluminosilicate glass, a mixture of aluminium oxide and silicon dioxide, which is then placed in a hot bath of molten salt. These are pressed together when the glass cools, producing a layer of compressive stress on the glass and increasing its strength and resistance to mechanical damage. A thin, transparent, conductive layer of indium tin oxide is deposited on the glass in order to allow it to function as a touch screen. Several rare earth elements are also present in very small quantities to produce the colours displayed on the screen (Compoundchem 2014).

The majority of smartphones use lithium ion batteries. These batteries tend to use lithium cobalt oxide as the positive electrode in the battery (though other transition metals are sometimes used in place of cobalt), whilst the negative electrode is formed from carbon in the form of graphite. Batteries also have an organic solvent which acts as the electrolytic fluid. The lithium in the positive electrode is ionised during charging of the battery, and moves into the layers of the graphite electrode. During discharge, the ions move back to the positive electrode. The battery is usually housed in an aluminium casing (Compoundchem 2014).

A wide range of elements and compounds are used in the electronics of a phone. The main processor of the phone is made from pure silicon, which is then exposed to oxygen and heat in order to produce a film of silicon dioxide on its surface. Parts of this silicon dioxide layer are then removed where current is required to flow. Silicon does not conduct electricity without being doped with other elements; this process involves the silicon being bombarded with a variety of different elements, which can include phosphorus, antimony, arsenic, boron, indium or gallium. Different types of semiconductor (P or N) are produced depending on the element used, with boron being the most common type of P-type dopant (Compoundchem 2014). The micro-electrical components and wiring in the phone are composed mainly of copper, gold, and silver. Tantalum is also used, being the main component of micro-capacitors. A range of other elements, including platinum and palladium are also used. Solder is used to join electrical components together. This was usually composed of tin and lead but in recent years lead-free alternatives have been developed, many of which use a combination of tin, silver and copper (Compoundchem 2014).

The microphone and speaker of the phone both contain magnets, which are usually neodymium-iron-boron alloys, though dysprosium and praseodymium are often also present in the alloy. These are also found in the vibration unit of the phone (Compoundchem 2014).

The casing can be made of metal or plastic, or a mix of the two. Metal casings can be made of magnesium alloys, whilst plastic casings are carbon based. The casing can often contain flame retardant compounds. Efforts have been being made to minimise the use of brominated flame retardants (Compoundchem 2014).

[76] https://images.samsung.com/is/content/samsung/p5/sec/aboutsamsung/sustainability/pdf/2018/2018Life-CycleAssessmentforHHPandDisplay_180831.pdf (accessed on 8 March 2019)

The current trend in smartphone body design seems to be towards the use of high-grade materials (as aluminium, stainless steel or even titanium) instead of commonly used plastics and also specialty ceramics and toughened glass are used increasingly (Triggs 2019). Environmental burdens embedded in materials, can be higher for smartphones that have larger size and functionalities, use more advanced chips and/or higher-grade materials.

A list of the most common materials used in smartphones is provided in

Table 16. The Bill of Materials is in general represented at elemental level, so that compounds as alumina silicates used in display's glass, PVC and flame retardants are not addressed. Another illustrative Bill of Materials at compound level is provided in Table 17. Additional materials are necessary for packaging, documentation and accessories (Ercan et al. 2016) as head-set, USB-cable, charger, including a quite relevant amount of plastic materials. Packaging (Proske et al. 2016) is typically made of fibre (e.g. cardboard) and, to a lower extent, plastic materials[77].

With respect to the origin of materials, many smartphone materials are sourced in China, via companies that have traditionally been reticent to reveal too much about their methods (Nield 2015). Nevertheless, some companies like Fairphone are committed to provide transparency about their supply chain[78].

Selection of materials is a key factor for determining the environmental impacts of smartphones. For example, it has been reported that the impact on climate change of primary aluminium is about 20 kg CO_{2eq} per kg of materials when produced from coal-based electricity, and this drops to about 5 kg CO_{2eq} per kg of materials when produced using hydro-based electricity. The carbon footprint of most plastics is instead about 4-5 kg CO_{2eq} per kg of material. Recycled aluminium has an even lower impact on climate change.

Table 16: Bill of Materials at elemental level for an average smartphone (Manhart et al. 2016)

Material	Common Use	Content per smartphone (g)	Content in all smartphones made since 2007 (t)	CRM listed (Y/N)
Aluminium (Al)	Case	22.18	157 478	N
Copper (Cu)	Wires, alloys, electromagnetic shielding, PCB, speakers, vibration alarm	15.12	107 352	N
Plastics	Case	9.53	67 663	N
Magnesium (Mg)	Case	5.54	39 334	N
Cobalt (Co)	Lithium-ion battery	5.38	38 198	Y
Tin (Sn)	Solder paste	1.21	8 591	N
Iron (steel) (Fe)	Case	0.88	6 248	N
Tungsten (W)	Vibration alert module	0.44	3 124	Y
Silver (Ag)	Solder, PCB	0.31	2 201	N
Gold (Au)	PCB	0.03	213	N
Neodymium (Nd)	Speakers Magnets	0.05	355	Y
Praseodyimium (Pr)	Speakers Magnets	0.01	71	
Tantalum (Ta)	Capacitors	0.02	142	
Indium (In)	Display	0.01	71	Y

[77] https://www.apple.com/lae/environment/reports/ (accessed on 31 January 2019)
[78] http://open.sourcemap.com/maps/57bd640851c05c0a5b5a8be1

Palladium (Pd)	PCB	0.01	71	N
Gallium (Ga)	LED-backlights	0.0004	3	Y
Gadolinium (Gd)	LED-backlights	0.0002	1	Y
Europium (Eu)	LED-backlights	0.0001	-	Y
Cerium (Ce)	LED-backlights	0.00003	-	Y
Others	(glass, ceramic, semiconductors)	99.29	-	Y

Table 17: Illustrative Bill of Materials at compound level for a smartphone (Andrae 2016)

Raw material	**Content per smartphone**	
	(g)	**(%)**
Iron/steel alloys (primary)	16.250	7%
Allumium alloys (primary)	8.690	4%
Copper alloys (primary)	36.250	16%
Gold (primary)	0.121	0%
Silver (primary)	0.198	0%
Nickel	1.500	1%
Tin	2.000	1%
Palladium	0.034	0%
Zinc	1.213	1%
Acrylonitrile butadiene styrene	22.500	10%
Poly(methy methacrylate)	1.875	1%
PA (Nylon)	1.625	1%
PVC	18.750	8%
Polyethylene-high-density	8.625	4%
Polyester (e.g. polyethylene terephthalate)	2.875	1%
Polycarbonate	2.625	1%
Polypropylene	1.313	1%
Polyurethane	1.625	1%
Epoxy	20.000	9%
Fiberglass	43.750	19%
Glass	33.750	15%
Total	225.569	

4.2.2 Critical Raw Materials and minerals from conflict-affected and high-risk areas

Of the 83 stable and non-radioactive elements in the periodic table, more than 60 can be found in smartphones (Manhart et al. 2016). Most of them are metals, with some of them like iron and aluminium, available in large quantities. For others, there are potential supply concerns and risks. For instance, some of these materials are included in the EU list of critical raw materials[79]:

- Cobalt is used as cathode material in Li-on battery chemistries with extended lifetime, on average 5.38 g per device (Manhart et al. 2016). A large portion of the mined cobalt

[79] COM(2017) 490 (see section 1.2.3)

production (around 50%) is in the DRC, where a significant amount of cobalt is mined by unregulated artisanal and small-scale mining practices (ASM).

- Tungsten is used in the vibration alert module, on average 0.44 g per device (Manhart et al. 2016).
- Indium is used in displays, on average 0.01 g per device (Manhart et al. 2016).
- Gallium is used in Power Amplifiers (PAs) to amplify voice and data signals to the appropriate power level allowing their transmission to the network base-station and in LED-backlights. The use of Gallium is on average 0.0004 g per device (Manhart et al. 2016).
- 16 (out of 17) rare earth elements (REE) are of relevant for smartphones. Neodymium, praseodymium and dysprosium are used to allow smartphones to vibrate through permanent magnet motors (also called NIB magnets); terbium and dysprosium are used in tiny quantities in touchscreens to produce the colours of a phone display (Nield 2015). The majority of REE production taking place in China.

Furthermore, smartphones also require conflict minerals (also referred to as 3TG = Tungsten, Tantalum, Tin, and Gold). These materials come from areas where they are mined in conditions of armed conflict and in which human rights abuses are common. They are then sold or traded by armed groups. This is an issue particularly associated with the DRC[80]. As described in section 1.2.3, the EU Regulation 2017/821 establishes a Union system for supply chain due diligence of 3TG minerals and ores that will be mandatory from 2021 for the EU importers.

Some manufacturers are currently committed in supply chain transparency and/or due-diligence on conflict minerals. For example, Fairphone (2016) sources fairtrade certified gold for its phones and has extended its supply chain due-diligence programmes beyond 3TG to include cobalt, as well as Apple did (Apple 2018a). Currently 9 out of every 10 smelters in Apple's supply chain are reported to have been verified as conflict-free or are undergoing audits. Manufacturers like Samsung, Sony, Apple and Huawei are also members of the Responsible Cobalt Initiative (RCI)[81], which is driving the supply chain due diligence system and standards for cobalt (Transform Together 2018). Other responsible mining initiatives have been developed by NGOs and/or mining companies (e.g. Alliance for Responsible Mining[82], Responsible Minerals Initiative[83], Enough Project[84], Initiative for Responsible Mining Assurance[85], Towards Sustainable Mining Initiative[86], The Finnish Network for Sustainable Mining[87], European Partnership for Responsible Materials[88], Global e-Sustainability Initiative[89]).

[80] http://ec.europa.eu/trade/policy/in-focus/conflict-minerals-regulation/ (accessed on 8 March 2019)
[81] https://www.firstcobalt.com/responsibility/responsible-cobalt-initiative/ (accessed on 8 March 2019)
[82] http://www.responsiblemines.org/en/# (accessed on 18 October 2018)
[83] www.responsiblemineralsinitiative.org/ (accessed on 18 October 2018)
[84] https://enoughproject.org/products/reports/conflict-minerals (accessed on 18 October 2018)
[85] https://responsiblemining.net/ (accessed on 18 October 2018)
[86] http://mining.ca/towards-sustainable-mining (accessed on 18 October 2018)
[87] https://www.kaivosvastuu.fi/finnish-sustainability-standard-for-mining-translated-into-english/ (accessed on 18 October 2018)
[88] https://europeanpartnership-responsibleminerals.eu/ (accessed on 18 October 2018)
[89] https://gesi.org/ (accessed on 18 October 2018)

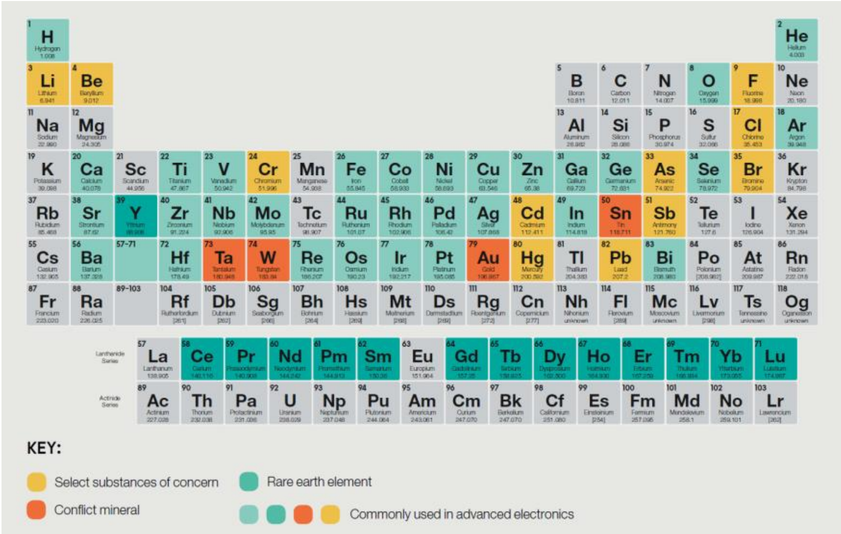

Figure 24: Chemical elements in smartphones (Jardim 2017)

4.2.3 Recycled materials

Smartphones contain a wide variety of materials, often speciality metals. Recycled materials could be used in smartphones, especially those presenting a high recycling rate like precious metals (gold and silver), base metals and alloys (copper and steel). Unfortunately, this is not the case of REE and other priority materials such as Indium, Gallium, Litium and Tantalum (Compoundchem 2015).

Some companies have started to pay attention on the use of recycled materials (Jardim 2017). However, the recycled content of smartphones, and particularly of high-grade materials, still remains relatively low (Transform Together 2018).

For most manufacturers the secondary materials use is mainly limited to plastic. Samsung uses recycled plastic in travel adaptors (20% content of recycle plastics), in ear phone cases and in packaging trays. The use of recycled plastic is not feasible for electrical parts of the phone according to stakeholders of this study.

Fairphone has reported to use recycled copper and tungsten in its devices. To prioritize which materials to tackle first, Apple has instead created Material Impact Profiles for 45 elements and raw materials, which combine environmental, social, and supply risk factors along the value chain (Apple 2018a).

Aluminium, tin, and cobalt have been identified as priority materials for the supply of secondary sources of materials. Regarding aluminium, Apple claims that the quality level requested in their products can be achieved only with clean material streams. For this reason, recycled aluminium is not mixed with other grades of scrap aluminium (Apple 2018a).

Apple has also reported to use 100% recycled tin for soldering the main logic board (Apple 2018a). Apple finally announced its target to create a closed- loop supply chain, where products are made using recycled or renewable materials only, and where Apple returns an equivalent amount of material back to the global market (Apple 2018a).

Despite some progress made in closing the loop on materials, smartphone manufacturers are at least partially reliant on virgin materials (Transform Together 2018). Sourcing and supply of recycled materials are the main constrains.

Although EOL smartphones can be a great source of high value secondary materials, recovery of some of the materials becomes challenging when mixed with other WEEE. According to some manufactures another barrier to the use of recycled material is also the perception that recycled materials are of lower quality than primary materials. The validity of this perception is variable depending on the material (e.g. paperboard, plastic, glass) and the application for which it is intended (Manhart et al. 2016).

Moreover, for materials for which there is not sufficient market availability, a higher recycled content in products does not necessarily have a positive effect as it will likely lead to a situation where lower amounts of secondary materials are used for other products (Manhart et al. 2016). When the market of certain recycled materials needs to be stimulated, it could be more appropriate to quantify recyclability targets (Cordella et al. 2019b).

4.2.4 Other substances of concern

Substances of concern are defined here as those chemicals that may have significant impact on both humans and the global environment, independently whether they are controlled by law or not. The use of these substances on the EU market is prohibited/restricted or gradually phased out through ROHS directive and REACH regulation (See section 1.2.2).

The smartphone industry is currently committed to limit the use of certain substances (Jardim 2017):

1. PVC: Due to possible formation of hazardous substances from the incineration of this type of plastic, some manufacturers have been reducing the content of PVC in the product. For instance, Sony (2018), Fairphone[90] and Apple (2018a) declared to have banned the use of PVC in their devices.
2. Brominated flame retardants (BFRs): Plastics containing brominated flame retardants have to be separated according to WEEE. These compounds can result in the release of highly toxic dioxins, among other hazardous chemicals, when scrap is burned (especially in case of rudimentary e-waste recycling operations). Because of this, industry is working to limit the use of parts and materials containing BFRs. Sony (2018) for instance claims not to use polybrominated diphenyl ethers, polybrominated biphenyls, hexabromocyclododecanes, in a progressive effort of phasing out BFRs. Sony has developed a bromine-free flame retardant for the manufacture of a polycarbonate plastic. Moreover, Sony has banned the use of tris(2-chloroethyl) phosphate, a chlorinated flame retardant identified to carry similar risks to those associated with brominated flame retardants, as well as phosphoric acid tris (2-chloro-1-methylethyl) ester (TCPP) and tris (1,3-dichloro-2-propyl) phosphate (TDCPP). Also Apple, LGE and Samsung have eliminated the use of BFRs (Jardim 2017). Moreover, other flame retardants such as hexabromocyclododecane (HBCDD) and tetrabromobisphenol A (TBBPA) have not been detected when specific parts of Fairphone 2 were tested[91].
3. Beryllium: Copper beryllium is used in electronic and electrical connectors, battery, undersea fibre optic cables, chips (consumer electronics and telecommunications infrastructure). Beryllium is used as an alloying element in copper to improve its mechanical properties without impairing the electric conductivity. Scrap generated during manufacturing in the EU are typically sent back to suppliers outside Europe for recycling. However, beryllium contained in the waste can end up in landfill or be down-cycled so that there is actually no post-consumer functional recycling of beryllium neither in Europe nor in the world (Jardim 2017). Beryllium and beryllium compounds are recognized as carcinogens and they can be released as dusts or fumes during processing and recycling. Exposure to these chemicals, even at very low levels and for short periods of time, can cause chronic beryllium disease (CBD), an incurable and debilitating lung disease. Beryllium is moreover included in the EU List of

[90] https://support.fairphone.com/hc/en-us/articles/215392683-How-about-hazardous-materials- (accessed on 19 April 2018)
[91] https://support.fairphone.com/hc/en-us/articles/215392683-How-about-hazardous-materials- (accessed on 19 April 2018)

Critical Raw Materials. Industry is working to avoid the use of such substances: Sony (2018) for instance is using no beryllium compounds, and also Apple (2018a) has reported to have eliminated Beryllium from all new product designs.

4. Antimony: this element is alloyed with lead or other metals to improve their hardness and strength and is used in the electronics industry to make some semiconductor devices, such as infrared detectors and diodes. Other uses include batteries, metal printing, cable sheathing. Antimony compounds are moreover used to make flame-retardant materials, paints, enamels, glass and pottery (CRM Alliance 2019). Antimony trioxide is recognized as a possible human carcinogen and exposure to high levels in the workplace, as dusts or fumes, can lead to severe skin problems and other health effects (Transform Together 2018). Antimony is also included in the EU List of Critical Raw Materials (COM(2017) 490). Several manufacturers (e.g. Apple, LGE, Sony, Samsung, Fairphone) have eliminated the use of Antimony (Jardim 2017).
5. Phthalates: used as softeners for PVC, some of these substances are classified as "toxic to reproduction" and are known to be hormone disrupters. Industry is working to eliminate specific phthalates. Sony (2018) for instance has succeeded in eliminating the phthalates DEHP, DBP, BBP, DIDP, DNOP and DINP. Fairphone[92] and Apple (2018a) have also reported to have eliminated these substances across their product portfolio. According to the ECHA (2013), in the specific case of DINP and DIDP, dermal exposure is not anticipated to result in a risk for the adult population, whereas a risk from the mouthing of toys and childcare articles with DINP and DIDP cannot be excluded.
6. Arsenic compounds: Sony (2018) has banned the use of LCD panels containing diarsenic trioxide and diarsenic pentoxide. Also Apple (2018b) claims to have restricted the use of Arsenic (50 ppm thresholds are set for LCD display glass, camera lens, trackpad glass, display cover glass, antifouling agents).
7. 1,3-propanesultone: used in the battery cell electrolyte, this is a SVHC. According to the harmonised classification and labelling approved by the European Union, this substance may cause cancer, is harmful if swallowed and is harmful in contact with skin[93].
8. Cadmium: this element can bio-accumulate in the environment and is highly toxic. The availability of cadmium-free substitutes for batteries (e.g. lithium-ion battery technologies) has reduced the risk of contamination by cadmium. Cadmium could be also present in pigment stabilizer, copper alloys in electronic contacts (Apple, 2018b).

Some manufactures have implemented a Substance Control system for "Environment-related Substances to be Controlled" (also referred to as "Controlled Substances") or "Restricted Substances" (Sony 2019, Apple 2018b).

4.2.5 Possible measures for reducing impacts of materials

As described above smartphones are made of a broad and heterogeneous list of materials, also including critical raw materials, minerals that could come from conflicting areas, and hazardous substances. Sustainability of the product could be improved by:

- Reducing and/or optimising the amount of materials used in the product, for example through the application of lean designs[94] and the avoidance of unnecessary accessories (as could be the case of external power supplies supplied with new products[95]);

[92] https://support.fairphone.com/hc/en-us/articles/215392683-How-about-hazardous-materials- (accessed on 19 April 2018)
[93] https://echa.europa.eu/substance-information/-/substanceinfo/100.013.017 (accessed on 13 June 2018)

- Increasing the amount of recycled and renewables-based materials. The recycled content can however be limited by aspects related to regulations and standards, market availability, technical design specifications. In terms of secondary materials, the use of recycled Aluminium, Copper, Tin and Tungsten appears already feasible for manufacturers;
- Avoiding/substituting hazardous materials with inherently safer solutions, as some manufacturers are doing.

Any strategy addressing the use of materials should ensure the fulfilment of technical specifications relating to the safety, performance and durability of the products. Moreover, possible trade-offs for other material efficiency aspects should be also assessed (Cordella et al. 2019b).

4.3 Manufacture

Smartphones are complex products for which increasing computing power, display and device size, and use of high-grade materials are demanded. Electronics are required in a smartphone (e.g. integrated circuits (IC), printed wiring boards (PWB), batteries, or displays) which production is a very energy intensive and pollutant process (Transform Together 2018). Environmental concerns are also due to the high consumption of water, including ultrapure water, for the cleaning and rinsing phases required in the production of smartphones, as well as the use of hazardous materials (Transform Together 2018).

The majority of smartphones are produced in Asia, mainly in China (e.g. Apple, Nokia, Xiaomi, Huawei), South Korea (Samsung), Japan (Sony), India (LG), or Taiwan (HTC). The production deployment in some of these countries raises also some social concerns about the working conditions associated to exposure to harmful chemicals, child labour exploitation, work overload and low wages (Transform Together 2018).

Some manufacturers are committing to reduce the impact of the production stage. For instance, Apple's supplier facilities have committed to Zero Waste to landfill and Apple's facilities in the 2018 were reported to use 100% of their electricity from renewables. However, overall energy consumption, water consumption and waste generation seem to have increased in absolute terms in the last five years (Apple 2018a), probably due to an increased market volume.

Selecting, monitoring and working closely with suppliers are also important to improve working conditions during manufacturing and assembly of parts. Companies are committed to improve working conditions along the product's supply chain, as for instance is the case of Fairphone (Transform Together 2018) and Apple[96]. The majority of the smartphone manufacturers have a supplier management and audit programme in place, although their efforts in this area can vary. Many of the big manufacturers are part of The Responsible Business Coalition (formerly known as Electronic Industry Citizenship Coalition), which requires its members to adhere to a Code of Conduct that sets standards on social, ethical and environmental issues. Apple and Fairphone are also part of the Clean Electronics Production Network (CEPN) which has the goal to move toward zero exposure of workers to toxic chemicals in the electronics manufacturing process (Transform Together 2018).

[94] Although this could come with possible trade-offs for other material efficiency aspects (see section 4.7)
[95] This should be coupled with the use of standard USB-C interfaces (IEC 63002:2016) to ensure interoperability between EPS owned by users. Information on technical specifications and interoperability of the accessories (voltage, power output and connector type) should be also provided.
[96] https://www.apple.com/supplier-responsibility/ (accessed on 8 April 2019)

4.4 Product's longevity

Depletion of materials and production of waste tend to decrease when the lifetime of a product is increased[97]. Designing long-lasting products is a key strategy to save materials and reduce the amount of waste to handle at the End of Life.

A product can function as required, under defined conditions of use, maintenance and repair, until a limiting state is reached. A limiting state is reached when one or more required functions/sub-functions are no longer delivered (Alfieri et al 2018a). The limiting state could either due to technical failure and/or other socio-economic conditions, so that the lifetime of a product can be differentiated between:

- Technical lifetime (European Environmental Agency 2017), which is the time span or number of usage cycles for which a product is considered to function as required, under defined conditions of use, until a first failure occurs[98];
- Functional lifetime (European Environmental Agency 2017), which is the time a product is used until the requirements of the user are no longer met, due to the economics of operation, maintenance and repair or obsolescence[99].

From a purely technical point of view, an extension of lifetime of products can be pursued through complementary strategies:

1. By increasing the durability of products and postponing the occurrence of a limiting state (Alfieri et al. 2018a, 2018b);
2. By increasing the upgradability of products and enhancing the functionality of a product (Cordella et al. 2018a);
3. By increasing the reparability of products and restoring the functionality of a product after a fault (Cordella et al. 2018a).

Point of action of such strategies in the lifetime of products is represented in Figure 25.

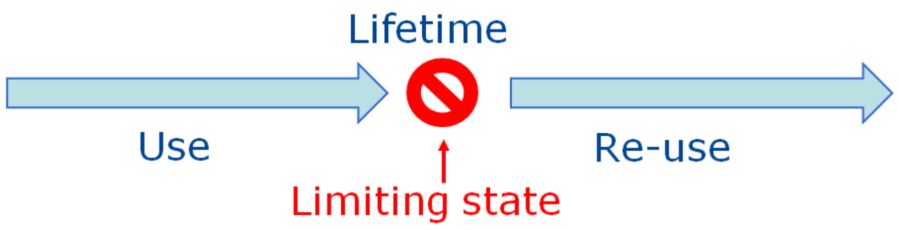

Figure 25: Extending the lifetime of products

Technical problems that could cause the replacement of a product and measures that could prevent it need thus to be analysed:

a. A durability analysis (Alfieri et al 2018b) will focus on how to delay limiting states over time by identifying stress conditions, design aspects and misuses that could produce failures of key

[97] This is generally the case when an increase of lifetime is not associated to design choices or repair/refurbishment operations requiring a significant addition of materials. Trade-offs among different material efficiency aspects could otherwise occur
[98] This can be modelled based on statistical data and accelerated tests
[99] This can be differentiated between first and successive users

parts and loss of function(s)/sub-function(s) during the normal and/or special conditions of operation. Key aspects and/or correction measures to increase the longevity of the product and its parts are identified.

b. A reparability/upgradability analysis (Cordella et al. 2018a) will focus on fixing a technical problem and/or extending the function lifetime by identifying barriers and factors influencing the chance of repair/upgrade, and more in general reuse. Key aspects and/or correction measures to increase the reparability and reusability of the product and its parts are identified. Considerations about re-manufacturability can also be included in this analysis.

The two analyses can be based on a common ground of information (see Figure 26):

1. The functional analysis of the product[100], in order to define main functions and sub-functions and to understand conditions of use and interactions between product and users (see Section 4.1);
2. Lifetime and durability expectation (see Section 3.3);
3. The analysis of limiting states, such as failures and other causes of replacements, their frequency and impacted parts, typical repair and upgrade operations;
4. The analysis of the barriers hindering the longevity and repair of products and of the environmental and economic costs and benefits, also taking quality aspects into account.

This information can also allow identifying priority parts where to focus any design action and further assessment, as well as setting preliminary objectives.

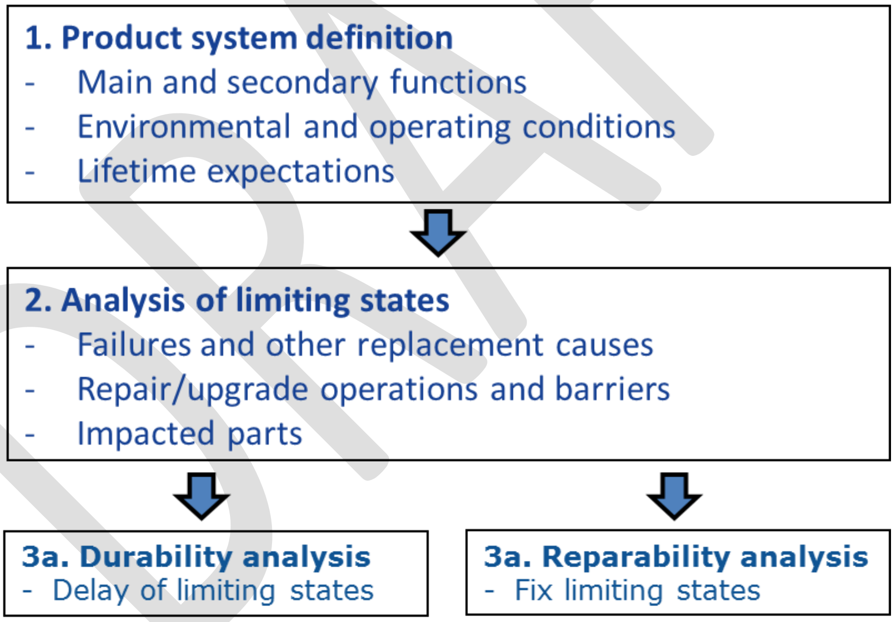

Figure 26: Approach for the analysis of durability and reparability of products

4.4.1 Limiting states

As described in section 3.3, discarded or replaced phones are often replaced because of functional obsolescence driven by launching of new models and features, and by social expectations (Watson et al. 2017).

[100] EN 12973:2000 - Value management

However, loss of performance, failures and breakages of smartphones are other important reasons for replacing the product. Technical factors producing failures and other limiting states include the stresses of product's parts and their capability to withstand these constrains and to provide a satisfactory performance level. Stress factors can be linked to environmental conditions (e.g. ambient temperature and humidity, mechanical shocks and vibration due to the transportation) or to operating conditions (e.g. electrical stresses, temperature variation during the turning on/off, shocks and vibration, drops, and mechanical impacts, ingress of dust and water). These stress factors can result in failures of the whole product due to short circuits or disconnection of main parts.

Sources of data about limiting states and failures statistics have been analysed including consumer's organization surveys and repairer's statistics and interviews.

A recent survey (OCU 2018b) reports that smartphones are characterized by the highest frequency of failures among a group of 10 products (5 appliances and 5 ICT products).
47% of faults occurred in the first 2 years of use, while an additional 39% of faults occurred between the 2nd and the 3rd year of use. The highest number of problems was related to the battery (42%) and to the operating system (14%).
Product failure in 2013 were reported to be due to the drop on a hard surface (43%) and the contact with water (35%) (Watson et al. 2017). However, these statistics could be less representative for current technologies and designs.
Although different from failure data, indirect information about limiting states can be gathered from repair statistics. The repair platform "Handyreparaturvergleich"[101] reports statistics about failures/repairs for common models of smartphones sold in Germany (see for instance Table 18 and Table 19). In particular, screens appear as the part of smartphones that are most frequently repaired. The dominant importance of screens has been confirmed by the repair organization "Vangerow"[102]. It is also interesting to observe that the repair of back cover became an issue for more recent models.

Table 18: Repair service statistics for iPhone models[8]

Repair requests	iPhone X[103]	iPhone 6[104]
Display	98 (38.0%)	111 (48.5%)
Back cover	92 (35.7%)	2 (0.9%)
Display glass / Touchscreen	31 (12.0%)	22 (9.6%)
LCD Display	16 (6.2%)	16 (7%)
Battery	3 (1.2%)	39 (17%)
Others	18 (6.9%)	39 (17%)

Table 19: Repair service statistics for Samsung models

Repair requests	S9[105]	S6[106]
Display	186 (49.9%)	19 (13.7%)

[101] https://www.handyreparaturvergleich.de/ (accessed on 13 March 2019)
[102] https://vangerow.de/ (accessed on 13 March 2019)
[103] https://www.handyreparaturvergleich.de/apple-iphones-reparatur/defektes-apple-iphone-x-display-diagnose-reparieren-preisvergleich.html#welche-reparatur (accessed on 27 March 2019)
[104] https://www.handyreparaturvergleich.de/apple-iphones-reparatur/defektes-apple-iphone-6-display-diagnose-reparieren-preisvergleich.html#welche-reparatur (accessed on 27 March 2019)
[105] https://www.handyreparaturvergleich.de/samsung-smartphones-reparatur/defektes-samsung-galaxy-s9-display-diagnose-reparieren-preisvergleich.html#welche-reparatur (accessed on 27 March 2019)
[106] https://www.handyreparaturvergleich.de/samsung-smartphones-reparatur/defektes-samsung-galaxy-s6-display-diagnose-reparieren-preisvergleich.html#welche-reparatur (accessed on 27 March 2019)

Repair requests	S9[105]	S6[106]
Backcover	81 (21.7%)	2 (1.4%)
Display glass/ Touchscreen	70 (18.8%)	10 (7.2%)
LCD Display	20 (5.4%)	10 (7.2%)
Camera	5 (1.3%)	6 (4.3%)
Buttons	3 (0.8%)	17 (12.2%)
Ports/connectors	2 (0.5%)	6 (4.3%)
Battery	1 (0.3%)	61 (43.9%)
Others	5 (1.3%)	8 (5.8%)

The failure of the screen can have several modalities. For example, after a fall the smartphone no longer responds to inputs, remains completely black, has pixel errors or is scratched, cracked or splintered. In most of the cases, the screen cannot be repaired, but the entire unit must be replaced since the individual components (sensors, LCD display, touch screen) are firmly glued together and come as one unit[107]. The repair or replacement of the touchscreen is instead necessary if the display glass and the touchscreen have broken (scratched, cracked or splintered), no longer reacts, or only reacts with delay or with greater pressure.

With respect to batteries, their duration and performance over time can affect the lifetime of the smartphones, in particular when they are not replaceable by users. However, some manufacturers claim that trade-offs between longevity and reparability can occur. A manufacturer stated that batteries are now designed to last longer in terms of charging cycles so that replacement of batteries is less important for consumers. This could be supported by the information provided in Table 18 and Table 19, from which it can be observed that the battery repair service has dropped significantly from older models to more recent ones. For devices with removable batteries there could be repair and safety issues regarding counterfeit batteries, as well as dust and water damage. Additionally, battery replacement by professionals could increase recycling efficiency.

Om the other hand, research on smartphone battery ageing (Sustainably SMART 2018) confirms some essential factors for obsolescence of batteries and devices with embedded batteries (e.g. extreme ambient temperature; state of charge lower of 20% or higher than 80%). Provision of information for consumers could help to maximize battery life and lifespan of devices. Some manufacturers provide tips (e.g. Apple[108]) and tools (Figure 27) to maximize battery lifespan.

Figure 27: Battery Health tool in iPhone smartphone[109]

[107] https://www.handyreparaturvergleich.de/apple-iphones-reparatur/defektes-apple-iphone-x-display-diagnose-reparieren-preisvergleich.html (accessed on 9 April 2019)
[108] https://www.apple.com/batteries/maximizing-performance/ (accessed on 4 July 2018)
[109] https://support.apple.com/en-us/HT208387 (accessed on 14 March 2019)

Another important factor that can affect the functional lifetime of smartphones can be the end of the software supporting period offered by manufacturers.

In general, in case of smartphones using Android, the support period tends to vary between 2 and 3 years. This means that many smartphones do not run the most updated version of the OS. Even though the absence of OS updates does not generate any immediate failure, it can result in a loss of security and, at long term, it could affect the functionality of the applications installed on the smartphones (OCU 2017). Manufacturers that do not release updates for the last available Android versions can still provide security patches also for older versions of the OS. Table 20 below shows the relative number of devices running a given version of the Android OS.

Apples claims to provide OS update for a longer period of time, with more than 80% of the products using the last version of the iOS[110], i.e. iOS 12[111]. Models released up to 5 years ago (e.g. iPhone 5S) are still compatible with these OS updates.

Table 20: Percentage of devices running a given version of Android (October 2018)[112]

Version	Code name	Distribution
2.3.3	Gingerbread	0.2%
2.3.7		
4.03	Ice Cream Sandwich	0.3%
4.04		
4.1x	Jelly Bean	1.1.%
4.2x		1.5%
4.3		0. 4%
4.4	KitKat	7.6%
5	Lollipop	3.5%
5.1		14.4%
6	Marshmallow	21.3%
7	Nougat	18.1%
7.1		10.1%
8	Oreo	14.0%
8.1		7.5%

Another relevant aspect is the impact of the Operating System update on the smartphone performance. Recently, as result of an investigation launched in January by the Italian competition authority it was found that certain smartphone software updates had a negative effect on the performance of the devices, without informing adequately consumers or providing them any means of restoring the original functionality of the products. Moreover, a case was found for which no clear information was provided for "essential" characteristics of lithium batteries, including their average life expectancy and how to maintain and replace them[113].

[110] https://developer.apple.com/support/app-store/ (accessed on 14 March 2019)
[111] https://www.apple.com/ios/ios-12/ (accessed on 27 March 2019)
[112] https://developer.android.com/about/dashboards/ (accessed on 27 March 2019)
[113] https://www.theguardian.com/technology/2018/oct/24/apple-samsung-fined-for-slowing-down-phones (accessed on 27 March 2019)

Main limiting states of technical nature for smartphones are summarised in the table below (Table 21), also with a description of possible failure mechanisms. Such limiting states of smartphones can be handled through alternative measures analysed in the following sections.

Table 21: Main failures for smartphones

Part	Main failures	Failure mechanism
Screen:		
- Glass cover	Screen cracked, scratched, splintered	Accidental drops or other mechanical stresses (shocks, vibrations)
- Touch screen layer	Screen cracked, scratched, splintered	Accidental drops or other mechanical stresses (shocks, vibrations)
- Display	Black screen, broken/dead pixels (spots, stripes or similar), no background light	Accidental drops or other mechanical stresses (shocks, vibrations)
Back cover	Breakage	Accidental drops or other mechanical stresses (shocks, vibrations)
Battery	Loss of performance in terms of duration of battery cycles	Aging of the battery due to quality issues or use under stress conditions
	Battery not charging	EPS / battery connection failure
	Overheating	
Operating System	Malfunctioning/ loss of security and performance (e.g. device not switching on, error codes, apps crashes)	OS updates not provided by the manufacturer
Whole Product	Short circuits, disconnection of main parts (including buttons and connectors)	Stress conditions (e.g. exposure dust and water, shocks, vibration).

4.4.2 Durability analysis

The durability analysis aims at the identification of maintenance needs and possible measures to avoid or postpone faults, which address;

- The design of more durable smartphones and the availability of updates over time;
- External accessories to protect the device, as screen protectors and cases[114].

This is based on the analysis of degradation mechanisms and paths that may cause limiting states, i.e. failure modes of main functions and/or sub-functions[115] (Table 21).

[114] https://www.nytimes.com/2017/05/24/technology/personaltech/reality-check-what-does-and-doesnt-protect-your-smartphone.html (accessed on 9 March 2018)

Although strengthened glass panels are getting more and more durable, screens are still affected by a relatively high frequency of failures. The failure of the screen can have several modalities. For example, after a fall the smartphone no longer responds to inputs, remains completely black, has pixel errors or is scratched, cracked or splintered. Almost 3/4 of all screen damages are due to drops on corners or edges (Sustainably SMART 2017). Moreover, as pointed out by some testing organizations[116, 117], smartphones with larger glass surfaces are more exposed to impacts and damages.

Screen damages due to falls and contact with water are normally considered to be under the responsibility of consumers and are not covered by legal guarantees. Smartphones can be designed to withstand expected usage profiles and information about how to use them should be provided (Watson et al. 2017). Damages due to water contact seem to have become less relevant due to the development of smartphones featuring a waterproof design[118].

Resistance to common causes of failure as fall on a hard surface, immersion in water and ingress of dust can be measured via specific product testing. The following test methods (see section 1.2.4.5) have been already applied by manufacturers:

- Drop tests, to determine how resistant a handset is to physical damages;
- Water- and dust proof tests (IP rating).

Smartphones complying with an IP rating of 68 (water and dust proof), and drop tested onto a hard surface from a minimum of 1.2 metres (usually as part of support for the MIL-STD-810G) are available on the market and are classified as rugged smartphones[119] (Bullitt 2017). The inclusion of ergonomics and slip resistance considerations in the design of smartphones could also be beneficial for the fitness of use of the device[120].

Screen protectors and protective cases (also called bumper) are also effective ways to avoid limiting states due to falls or other mechanical stresses. The frequency of brakeage could be halved in case of protected smartphones (Wertgarantie 2017). Protective accessories are available in many designs from manufacturers or third party companies. Some protective cases even allow upgrading the functionalities of smartphones by adding additional battery capacity or additional lenses. However, rather than relying on the user to purchase protectors for inherently fragile devices, it could be more effective to provide extra-protective functions and/or accessories with the product. Screen protectors are pre-installed for some smartphone models (e.g. Samsung Galaxy S10[121]).

More durable design could be also incentivised by including failure due to accidental drops (e.g. free falls from up to 1.5 meters) and short term water contacts in the failures covered by legal guarantee.

Performance of batteries is also very important for the durability of smartphones, especially because new models have bigger screens, faster processors and apps that require more and more energy, and thus long lasting batteries. Longest life batteries currently used in smartphones have a capacity of

[115] IEC 60300-3-1 - Dependability management – Part 3-1: Application guide – Analysis techniques for dependability – Guide on methodology

[116] https://www.consumerreports.org/smartphones/iphone-x-review-test-results/ (accessed on 8 April 2019)

[117] https://www.cnet.com/news/apple-iphone-x-drop-test/ (accessed on 8 April 2019)

[118] https://www.cnet.com/news/how-does-waterproofing-work-apple-iphone-7-samsung-galaxy-s7-sony-xperia/ (accessed on 8 April 2019)

[119] A distinction has to be done between rugged smartphones and ultra-rugged smartphones, with the latter specifically designed for industrial uses or to survive extreme rugged testing. Ultra-rugged smartphones are usually considerably more expensive, and will often be engineered to be non-incendiary and intrinsically safe, making them suitable for use in hazardous environments

[120] https://smartphones.gadgethacks.com/how-to/4-most-durable-premium-smartphones-for-clumsy-people-0175454/#jump-comparisonchart (accessed on 23 March 2018)

[121] https://www.samsung.com/au/support/mobile-devices/galaxy-s10-in-box-items/ (accessed on 27 March 2019)

4000-5000 mAh[122], which in some cases can allow them to function as a power bank[123]. A long battery lifespan can reduce the chance of replacement of battery and device, with possible economic and environmental benefits (Science for Environment Policy 2018). The lifespan of batteries can be measured in two ways:

1. Calendar life: time during which the battery can be stored with minimal discharges until its capacity decreases below 80% of the initial one, and
2. Cycle life: number of times (cycles) a battery can be recharged and discharged before it becomes unsuitable for a given application. This is usually when it can only be charged up to 80% of initial capacity, given that the battery degrades quickly after this point.

The battery life can be tested according to IEC EN 61960[124]. Performance can be assessed as:

a. Remaining full charge capacity of the battery compared to the initial charge capacity, after x and y charge/discharge cycles (e.g. 300 and 500), or

b. Minimum number of full charge/discharge cycles achievable with more than 80% and 60% of the initial capacity.

Software tools can also contribute to optimise the battery lifetime. Pre-installed software can enable limiting the battery state of charge (SoC) when the smartphone is connected to the grid (e.g. overnight charge). Such functionality prevents that the battery is loaded at full charge.

Durability of smartphones is influenced also by the quality of other hardware parts:

- Fingerprint Sensor: a scratched or cracked sensor can for instance hinder the phone's ability to read fingerprints. The use of high-end materials can improve the overall reliability of the device[125].
- Camera lens: a cracked/scratched camera lens can affect the photo quality and compromise the device resistance to water and other contaminants. Sapphire crystal lens are reported to be harder than glass[126].
- Charging port: wear and tear could damage the charging port. Modular designs have been applied to facilitate its replacement[127]. Also symmetric ports reduce the risk of breaking the slot while forcing the cable into the wrong side (e.g. USB-C). However, the current trend towards wireless charging might eliminate or reduce the need for charging ports.

However, as described in section 4.4.1, unavailability of software/firmware updates can make smartphones obsolete even if their hardware parts are still fully functioning (Transform Together 2018). For an effective increase of the durability of smartphones it is thus needed to ensure the possibility of keeping software and firmware updated over time. From the other side, it has to be ensured that the Operating System updates do not negatively impact the smartphone performance and the reversibility of the software update.

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[122] https://www.tomsguide.com/us/smartphones-best-battery-life,review-2857.html (accessed on 22 March 2018)
[123] https://www.xataka.com/tecnologiazen/avances-en-baterias-moviles-cuando-llegara-el-sustituto-del-ion-litio (accessed on 22 March 2018)
[124] IEC 61960-3:2017 – Secondary cells and batteries containing alkaline or other non-acid electrolytes. Secondary lithium cells and batteries for portable applications. Prismatic and cylindrical lithium secondary cells, and batteries made from them
[125] https://smartphones.gadgethacks.com/how-to/4-most-durable-premium-smartphones-for-clumsy-people-0175454/#jump-comparisonchart (accessed on 23 March 2018)
[126] https://smartphones.gadgethacks.com/how-to/4-most-durable-premium-smartphones-for-clumsy-people-0175454/#jump-comparisonchart (accessed on 23 March 2018)
[127] https://smartphones.gadgethacks.com/how-to/4-most-durable-premium-smartphones-for-clumsy-people-0175454/#jump-comparisonchart (accessed on 23 March 2018)

A commitment on software support provision by manufacturers could increase the lifetime of smartphones. Google, for its own-brand smartphones is communicating the minimum update and support periods ensured for the models on the market. OS and software update (security) are ensured for three years for Pixel 2[128] and Pixel 3[129]. Devices with unsupported operating systems could moreover have limited-to-no resale value, which is a major barrier to reuse.

Durability metrics and related test methods are already applied by some smartphone's manufacturers in the design of their products to claim durability performance (not limited only to the market segment of rugged and ultra-rugged smartphones). A summary of the international standard methods applied is provided in Table 22. Longevity of smartphones could be potentially increased through these metrics, to demonstrate compliance with durability requirements and/or provide durability information.

Table 22: Possible measures to increase the durability of smartphones

Aspect	Measure	Assessment and verification
Mechanical stress resistance	- Resistance to accidental drops (e.g. 1.2-1.5 meters) and other stress tests (e.g. extreme temperatures, solar radiations) - Provision of protective accessories	- IEC 60068 Part 2-31: Tests – Test Ec: Rough handling shocks, primarily for equipment-type specimens (Freefall, procedure 1 - Free fall) - Visual check
Dust protection	- Protected from total dust ingress (IP6X)	- IEC 60529 - Degrees of protection provided by enclosures (IP Code)
Water protection	- Protected from immersion between 15 centimetres and 1 meter in depth (IPX7) or from long term immersion up to a specified pressure. (IPX8)	- IEC 60529 - Degrees of protection provided by enclosures (IP Code)
Battery longevity	- Minimum number of cycles with the battery properly functioning (e.g. 500 cycles at 80% of initial performance) - Availability of software for the battery management	- Testing the battery life according to the IEC EN 61960 - Declaration/ guarantee from manufacturer
Operating System, software and firmware	- No functionally obsolete capacity and OS at the moment of purchase - Availability of update support along the product lifetime - Information on impact of updates, reversibility of updates	- Declaration/ guarantee from manufacturer
Guarantee issue	- Inclusion of failures due to accidental drops and contact with water in the legal guarantee - Extended guarantees	- Declaration/ guarantee from manufacturer

[128] https://store.google.com/product/pixel_2_xl_specs?srp=/product/pixel_2_specs (accessed on 27 March 2019)
[129] https://store.google.com/product/pixel_3_specs (accessed on 27 March 2019)

User behaviour	- Information on correct use and maintenance of the device	- Provision of information from manufacturer

4.4.3 Reparability and upgradability analysis

The reparability and reusability analysis aims at the identification of measures that could improve the reparability and reusability of products, and thus overcoming a limiting state. The analysis is based on information on repair statistics, typical upgrades and technical, market and legal barriers[130], which is also reported in section 4.4.1.

Lack of spare parts and software/firmware updates (Watson et al. 2017), as well as their relative cost, can be an important barrier to repair. Some manufacturers raised the attention on the presence on the market of counterfeit parts/products, which could undermine the functionality of the device and the brand reputation, especially in case of bad repair.

Repair can be facilitated by the provision of information. Some manufacturers provide information of the web about the availability /cost of the repair services in different EU countries[131], as well as costs of spare parts[132, 133].

According to Watson et al. (2017), repair could be worthwhile even 3-5 years after sale; however, there is huge variation in the cost of repair since many devices do not have easily removable batteries or replaceable screens. Repair costs are in particular a barrier for screens. The repair of a screen can cost up to a 40% of the product price and the trend is towards more expensive repairs for more recent models[134].

Ease of disassembly of parts is considered as one of the main barriers to repair. Repair could be facilitated through the implementation of modular designs, the use of reversible fasteners are the commercial availability of repair tools.

Due to their priority for repair, effective modular designs should also consider the implementation of a non-permanent fixation of front glass and display module in screens (Schischke et al. 2016).

However, there is an apparent trend towards the increased use of adhesives, glues and of glass parts, which make more difficult to disassemble parts (Greenpeace 2017). According to some manufacturers, main reasons for using adhesive and glues include reduction/control of the mass and volume of devices, as well as reliability and durability considerations (e.g. water protection). Moreover, a modular design focused on the improvement of reparability/upgradability could require larger amounts of materials.

For example, in some recent models of smartphones, the removal of batteries requires the intervention of an experienced repairer. This means that the battery can directly affect the lifetime of the product[135]. Easy-to-replace batteries may require additional casing, which can mean thicker product designs and the use of more materials.

A global support platform for the repair of smartphones is provided by iFixit[136]. Instructions include the replacement of batteries, and screens. Reparability scores for smartphones are also calculated by

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[130] This can cover aspects as obsolescence, cost of repair operations, ease of disassembly of parts, availability of spare parts, updates and instructions
[131] https://support.apple.com/repair (accessed on 29 March 2019)
[132] https://www.parts4repair.com/xiaomi (accessed on 17 October 2018)
[133] https://www.sparesIg.com (accessed on 17 October 2018)
[134] Personal communication from stakeholders
[135] Personal communication from stakeholders
[136] https://www.ifixit.com/Device/Phone (accessed on 9 March 2018)

iFixit (2019), as reported in Annex II. iFixit analysed about 100 models. The worst 10% performing models in terms of reparability received a score between 1 and 3. These are characterized by:

- High difficulty to open the rear case and access to any parts;

- Intensive use of adhesive making any disassembly step complex and dangerous;

- Very difficult replacement of the battery (e.g. in case of soldered battery, buried beneath the mother board, or needing very complex disassembly process in terms of steps and time);

- High number of steps to remove the display.

Technical aspect influencing the repair and upgrade of products have been analysed by JRC (Cordella et al. 2019a). Aspects considered relevant for smartphones are analysed here, with the aim of providing a reference for the identification of best practices and/or minimum performance levels[137] for the whole product and its priority parts[138]. The following priority parts are considered in this study for smartphones:

1. Screen;
2. Back cover;
3. Battery;
4. OS.

4.4.3.1 Disassembly depth/sequence

The disassembly depth is the number of steps required to remove a part from a product. The analysis of disassembly depths is fundamental to assess the effort required to access and/or replace priority parts. The disassembly sequence is necessary to assess the disassembly depth. It is the order of steps[139] needed to remove a part from a product (which might include getting access to fasteners). The repair/upgrade operation can be facilitated by the availability of information about the steps needed to disassemble specific parts, as well as by design options where the number of disassembly steps is reduced. Some of this information may be relevant for some categories of repairers only, also because of safety reasons.

Indications about the steps necessary to disassembly parts of smartphones are provided by iFixit[140]. Based on the analysis of a sample of products[141], and with a focus on priority parts, it was found that disassembly steps range, depending on the model:

- From 2 to 46 for the battery (median value = 28);
- From 15 to 45 for the screen (median value = 30);
- From 1 to 103 for the back cover (median value = 14).

Such values could be used to set disassembly depth targets for priority parts of smartphones.

[137] Depending on the application a more or less ambition level could be considered (Cordella et al. 2018b)
[138] Based on Cordella et al. (2019a), priority parts are those parts that are more important for repair and/or upgrade operations.
[139] According to Commission Decision (EU) 2016/1371, a step consists of an operation that finishes with the removal of a part, and/or with a change of tool
[140] https://www.ifixit.com/Device/Phone (accessed on 9 March 2018)
[141] On 8 April 2019, analysed products include: 13 models from Apple (iPhone 6, iPhone 6 Plus, iPhone 6s, iPhone 6s Plus, iPhone SE, iPhone 7, iPhone 7 Plus, iPhone 8, iPhone 8 Plus, iPhone X, iPhone XS, iPhone XS max, iPhone XR), 5 models from Samsung (SIII, S5, S10, S10e, S10 Plus), 1 model from Huawei (P9)

4.4.3.2 Fasteners

Fasteners play an important role in the disassembly of a product. Fasteners are closely interlinked to the assessment of necessary tools and skills for repair, re-use or upgrade. The number and type of fasteners, as well as their visibility, may be used as a proxy for the time needed to repair or upgrade a product. However, their visibility (e.g. through labelling and marking) is not as important if repair manuals are available and if fasteners are physically accessible. For the assessment of fasteners, more important criteria are their reversibility and the re-usability.

The best design scenario for the repair of smartphones would be the use of reusable, or at least removable, fastening systems in the assembly of priority parts. On the other hand, the worst scenario for reparability sees the use of non-removable fastening systems such as glues.

4.4.3.3 Tools

Repair of smartphones can require a set of product-specific tools. Since most parts inside smartphones are sensitive to electrostatic discharges (ESD) or static electricity, it would be recommendable to use only ESD-safe tools and equipment. The list of tools and equipment includes[142]:

- Soldering Iron or Soldering Station, used to solder parts and components like capacitor, resistor, diode, transistor, regulator, speaker, microphone, display.
- Cleaning Sponge, used to clean tip of soldering iron while soldering.
- Hot Air Blower, also called SMD (Surface Mount Device) rework system and SMD repair system, regulating or managing temperature and flow or hot air, and used to remove and again solder ICs.
- PCB Holder / PCB Stand, used to hold the PCB of a mobile phone while soldering or repairing.
- Solder Wire and Flux, used to solder electronic components. Flux is applied before soldering to remove any oxide or contamination at the solder joints.
- Solder Paste, which is solder in melted semi-solid form looking like paste and used mainly for Reballing of ICs.
- Desoldering Wire, or Desolder wire, used to remove excess solder from track of PCB. Thinner or PCB Cleaner: Thinner or PCB cleaner is used to clean the PCB of a mobile phone. The most common PCB cleaner used in mobile phone repairing is IPA or Isopropyl Alcohol.
- Jumper Wire, which is a thin laminated or coated copper wire used to jumper from one point to another on the track of a mobile phone while repairing.
- Point Cutter, used for cutting wires.
- Precision Screwdriver, used to remove and tighten screws while assembling and dissembling a mobile phone. Precision screwdrivers of sizes T4, T5, T6 and four head are good for most mobile repairing operations.
- Tweezers, used to hold electronic components while soldering and desoldering.
- ESD-Safe Cleaning Brush, used for cleaning the PCB of a mobile phone while repairing.
- Multimeter, used to find faults, check track and components.
- Battery Booster, used to boost the power of battery of a mobile phone.

[142] http://www.smartphonetrainingcourses.com/repair-tool-kits/ (accessed on 9 March 2018)

- Ultrasonic Cleaner, used to clean PCB of a mobile phone and electronic components.
- BGA (Ball Grid Array) Kit, used to Reball and repair ball-type ICs.
- Magnifying Lamp, used to see the magnified view of the PCB of a mobile phone. Most magnifying lamps also have light. Magnifying lamps are available in different magnification such as 3x, 4x, 5x, 10x, 50x.
- Mobile Opener, used to open the housing or body of a mobile phone.
- DC Power Supply, Regulated DC (Direct Current) power supply, used to supply DC current to a mobile phone to switch on a mobile phone without battery.

Moreover, proprietary tools[143] are required for some products. For example, proprietary screws are used which require a special pentalobe screwdriver, which can make the removal of batteries a lengthy process. The replacement of screen can be done with precision screwdrivers and/or prying tools like spudgers (Wiens 2014).

Tools needed for repair/upgrade contribute to determine the complexity of the operation itself. Manufacturers can play a significant contribution in defining such complexity. The tools needed are in fact determined by the product design and are therefore an objective characteristic. In particular, the need of proprietary tools could limit the possibility to carry out a repair/upgrade, whilst repairs are inherently easier when commonly available tools are requested for such operations.

4.4.3.4 Disassembly time

Factors influencing the disassembly process (e.g. disassembly steps, fasteners, tools) could be combined all together through the calculation of disassembly times (Cordella et al. 2019a). Time can be important to determine the operational cost in case a service is paid, but it has also to be considered with other factors (e.g. the cost of spare parts).

Indications about the time necessary to disassembly parts of smartphones are provided by iFixit[144]. Based on the analysis of a sample of products[145], and with a focus on priority parts, it was found that minimum disassembly time ranges, depending on the model:

- From 1 to 120 min for the battery (median value = 30 min);
- From 20 to 120 min for the screen (median value = 40 min);
- From 1 to 180 min for the back cover (median value = 53 min).

Such values could be potentially used to set disassembly time targets for priority parts of smartphones. However, their calculation should be based on standard time units (Zandin 2003) and supported by appropriate methodological guidance, as done in eDiM (Peeters et al. 2018; Vanegas et al. 2016, 2018).

4.4.3.5 Type and availability of information

The provision of information is necessary to support the repair/upgrade operation and should recollect all the information mentioned in the other parameters (e.g. through user manuals). Information should

[143] Proprietary tools are tools that are not available for purchase by the general public or for which any exclusive intellectual property rights prevent their open use under fair, reasonable, and non-discriminatory terms
[144] https://www.ifixit.com/Device/Phone (accessed on 9 March 2018)
[145] On 8 April 2019, analysed products include: 13 models from Apple (iPhone 6, iPhone 6 Plus, iPhone 6s, iPhone 6s Plus, iPhone SE, iPhone 7, iPhone 7 Plus, iPhone 8, iPhone 8 Plus, iPhone X, iPhone XS, iPhone XS max, iPhone XR), 5 models from Samsung (SIII, S5, S10, S10e, S10 Plus), 1 model from Huawei (P9)

be both comprehensive and available to various target groups of repairers. If access to such information is provided broadly (e.g. to independent operators), it could be expected that both repair costs and effort to find suitable repair centres diminish since this could create a level-playing field between independent and authorised repair centres. A distinction can be made between information that should be provided to professional repairers and information for end users, as reported in Table 23.

Table 23: Information for professional repairers and end users

Information	Professional repairers	End users
Unequivocal identification of the device	X	X
Disassembly map or exploded view, including detailed step-by-step disassembly instructions for batteries and other priority parts and including information supporting the operation (e.g. tools needed, recommended torque for fasteners, diagnostic and error resetting codes)	X	
Technical manuals of instructions for repair, including safety issues, testing procedures for after repair and reference values for measurements	X	
List of necessary repair and test equipment	X	
Identification of errors, the meaning of the errors, and the action required, including identification of errors requiring professional assistance	X	X
Component and diagnosis information (such as minimum and maximum theoretical values for measurements)	X	
Wiring and connection diagrams and circuit board schematics of electronic parts (including the key (legend) with numbers and symbols explanations)	X	
Diagnostic fault and error codes (including manufacturer-specific codes, where applicable)	X	
Instructions for installation of relevant software and firmware including reset software	X	
Information on how to access data records of reported failure incidents stored on the product (where applicable).	X	
Correct installation, use, maintenance and upgrade of relevant hardware, software and firmware (including how to optimise the lifetime of the battery and ergonomic aspects)		X
Implications of self-repair or non-professional repair for the safety of the end-user and for the legal guarantee, and when applicable, also to the commercial guarantee		X
Skills needed and environmental conditions for the repair operations		X
How to access to professional repair (internet webpages, addresses, contact details)		X
Functional specification and compatibility of parts (as batteries and External Power Supplies) with other products	X	X
Period during which the spare parts are available	X	X
Price of spare parts	X	X

4.4.3.6 Spare parts

The availability of spare parts is a paramount parameter to ensure that a repair/upgrade process can take place. Spare parts availability can for example refer to:

i) Availability over a specific period of time;

ii) Availability to various target groups;

iii) Delivery time.

Priority parts should be made available as spare parts for 2-6 years after placing the last unit of the model on the market. These could also include approved-by-manufacturer compatible spare parts produced by third parties. The delivery time could be 2-15 working days.

Moreover, the list of spare parts, the procedure for ordering them and the related prices should be publicly available on the free access website of the manufacturer, importer or authorised representative.

Although not defined as priority parts, the use of standard interfaces could also be beneficial for the replacement of some parts:

- Micro USB can be specified according to IEC 62684:2018;
- USB type-C can be specified according to the IEC 62680-1-3 and IEC 63002 (Figure 28);
- External Power Supply (EPS) can be specified following the Recommendation of ITU-T L.1002 (10/16) (ITU-T 2016). The basic EPS configuration suggested by ITU-T L.1002 consists of an EPS with a detachable input cable and a detachable output cable to the ICT device (Figure 29). A detachable DC cable is required as the DC cable is generally the weakest point of the portable power supply and the main point of failure. Adapters which have captive cables, in case of failure of the latter, require all the rest of the equipment and in particular its active part, to be discarded, adding up unnecessary e-waste and cost for the users that could be a barrier for repair. Furthermore, the detachable cable enables more reuse and an increased lifetime of the power supply unit.

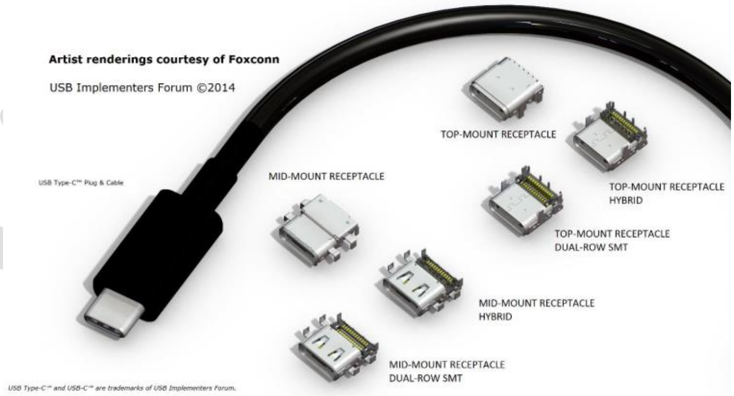

Figure 28: USB type-C cable and connectors (USB Implementers Forum 2016)

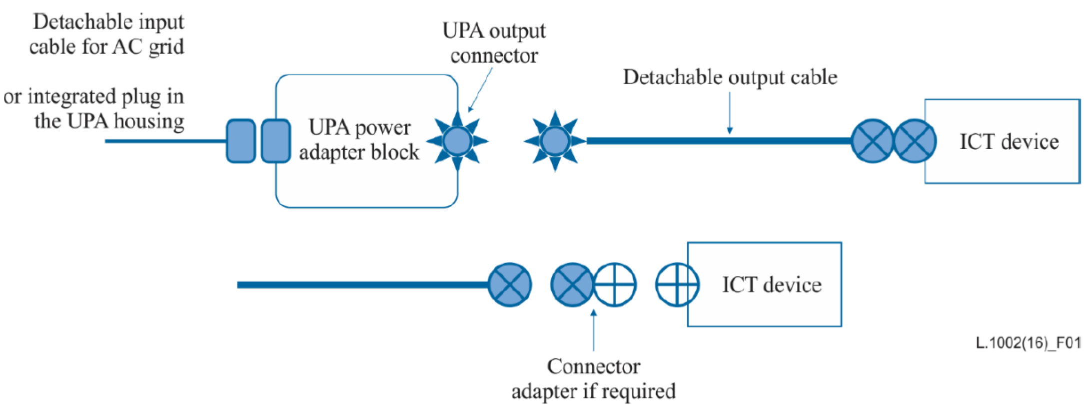

Figure 29: Basic Universal Power Adaptor (UPA) configurations and connection options (ITU-T 2016)

4.4.3.7 Software and firmware

Similarly with spare parts, the availability of software and firmware updates and/or support (including compatibility with open source programs) is a paramount parameter for smartphones. See section 4.4.2.

4.4.3.8 Data transfer and deletion

Data transfer and deletion is needed in repair/upgrade operations associated with the continued use or reuse of products (where privacy of personal data must be ensured) or the cleaning of memory space (e.g. for the repair of a smartphone). Secure data deletion/transfer tools should be pre-installed or made available (e.g. via installed or downloadable tools such as an application, a cloud-based service or instructions detailing a manual process). It is thus important that smartphones present such functions that facilitate reparability/reusability of the whole products without the risk of transfer of any sensitive and personal data in reused equipment.

Secure data deletion[146] tools should built-in (or as second option made available on request) and should permanently delete all user data without compromising the functionality of the device for further use. Simplified transfer of data from an old to a new product should also be made available via installed or downloadable tools such as applications, cloud-based services or instructions detailing a manual process.

4.4.3.9 Password reset and restoration of factory settings

Settings for password reset and restoration of factory settings is needed in repair/upgrade operations associated with the continued use or reuse of products (e.g. change of user in the same organisation). Password reset and restoration tools should be pre-installed or made available (e.g. via installed or downloadable tools such as an application, a cloud-based service or instructions detailing a manual process). In addition, the device should also include a software function that resets the device to its factory settings. This should come with detailed instructions.

4.4.3.10 Commercial guarantee

Commercial guarantees can be potentially a useful tool for controlling the risk of failure of products, and/or enabling the repair operation when needed. A "commercial guarantee" for the (entire) product could include a "commitment to free repair as first remedy" in case of failures and, where relevant, a "commitment to upgrade the product periodically". See also section 4.4.2.

4.4.3.11 Overview of possible measures to increase the reparability and upgradability of smartphones

An overview of possible measures to increase the reparability and upgradability of smartphones is provided in Table 24.

[146] According to the Commission Regulation (EU) 2019/424 of 15 March 2019 laying down ecodesign requirements for servers and data storage products "secure data deletion" means the effective erasure of all traces of existing data from a data storage device, overwriting the data completely in such a way that access to the original data, or parts of them, becomes infeasible for a given level of effort.

Such information could be also used as basis for the development of scoring system (Cordella et al. 2019a). In such case, a higher weight could be considered for:

- Functionally essential parts (screen, battery, operating system);
- Aspects relating to disassemblability and to availability of spare parts, updates and information.

Table 24: Possible measures to increase the reparability and upgradability of smartphones

Aspect	Measures	Assessment and Verification
Disassembly depth/sequence	Information about disassembly sequences to be made available Setting thresholds on disassembly steps for priority parts	A: A description supported by illustrations of the steps needed to disassemble parts is needed. The description has to show that the disassembly is reversible by including the steps needed for the reassembly of priority parts. V: Physical disassembly and recording of the operation are needed.
Fasteners and connectors	Reusable/removable fasteners to beused for the assembly of priority parts. Note: - Reusable: an original fastening system that can be completely re-used, or any elements of the fastening system that cannot be re-used are supplied with the new part for a repair, re-use or upgrade process; - Removable: an original fastening system that is not reusable, but can be removed without causing damage or leaving residue which precludes reassembly or reuse of the removed part.	A: A description supported by illustrations of the fasteners to be removed for the disassembly of parts is needed. V: Physical disassembly and inventory of fasteners are needed.
Tools	Disassembly of priority parts is possible without the use of proprietary tools.	A: Description of the repair/upgrade operations, including documentation of the tools to use, is needed. V: Physical disassembly and check of suitability of tools are needed.
Disassembly time	Setting thresholds on disassembly times for priority parts	A: Disassembly times quantified for parts and related data sources and calculation details are needed. In case additional research was needed to fill any data gap, supporting information has to be provided as well by the manufacturer. V: Physical disassembly, recording of the operation and check of calculations are needed.
Type and availability	Information for repair/upgrade of smartphones to be made available to professional repairers	A: Relevant information for maintenance, repair and upgrade needs to be compiled and made

Aspect	Measures	Assessment and Verification
of information	and final users Note: different information could be made available to different target groups	available to the target group of repairers. V: Check of actual availability.
Spare parts	Spare parts to be made available by manufacturers, importers or authorised representatives for a minimum period of time after placing the last unit of the model on the market. List of parts and prices to be available on-line, delivery within 2 working days after having received the order. Standard interface to be used for some parts.	A: Commitment by the manufacturer about the availability of spare parts over time, as well as provision of information about: - Delivery time - Recommended retail price of spare parts - Target groups - Interface used. V: Check of actual availability.
Software and firmware[147]	Software (at least for the Operating System) and firmware updates and support offered to end users for a duration of X years after placing the last unit of the model on the market, including the possibility to use open source Operating Systems or open source Virtual Machine software. Information about the impact of future updates on the original system characteristics (e.g. RAM, CPU) to be provided, and there has to be always the option to not install, to install or to uninstall the update.	A: Declaration about the duration of availability of software and firmware over time, as well as information about costs, and information about how updates will affect the original system characteristics. V: Check of actual availability, compatibility, and possibility to avoid/reverse the update.
Data transfer and deletion	Secure data transfer and deletion functionality to be made available. This can either: I) Be a feature built-in in the device; II) Be permitted without restrictions using freely accessible software or hardware solutions III) Be available on request from the OEM.	A: Information about the availability of secure data transfer and deletion functionality / service is needed. V: Check of actual availability.
Password reset and restoration of factory	To provide an option for resetting the password and restoring the factory setting. This can either:	A: Information about the availability of a feature / service for password reset and restoration of factory

[147] This has been considered also as durability measure

Aspect	Measures	Assessment and Verification
settings	I) Be integrated within the device; II) Be permitted without restrictions, using freely accessible software or hardware solutions III) Be available on request from the OEM.	settings is needed. V: Check of actual availability.
Commercial guarantee[148]	A "commercial guarantee" for the (entire) product to be offered by the guarantor, and including a "commitment to free repair as first remedy" in case of failures and a "commitment to upgrade the product periodically". Notes: - "Commercial guarantee" means any undertaking by the seller or a producer (the guarantor) to the consumer, in addition to his legal obligation relating to the guarantee of conformity, to reimburse the price paid or to replace, repair or service goods in any way if they do not meet the specifications or any other requirements not related to conformity set out in the guarantee statement or in the relevant advertising available at the time of, or before the conclusion of the contract. - The commercial guarantee must be related to the entire product (not only specific components), provided in the entire EU, be included in the sale price of the product, and the remedies proposed by the guarantor will not result in any costs for the consumer (e.g. it means that the repair is for free).	A: Guarantee contract is needed, with emphasis on "free repair first" clauses. V: Check of availability of guarantee, clauses statement and actual possibility of repair in case of failure.

[148] This has been considered also as durability measure

4.5 End of Life

After their useful life, products are disposed in order to remove and treat properly any source of hazard and to recover value embedded in components and/or materials. This is done in the recycling process. Recovery of materials and energy can also avoid the depletion of new resources. The effectiveness and efficiency of recycling can be facilitated through appropriate designs that can facilitate the recycling process, for instance improving depollution, dismantling, recyclability and recoverability of products, can have positive effects.

4.5.1 End of Life practices

The worldwide collection rates for small electronics are still low (Manhart et al. 2016). Although there are no global statistics available on this issue, data from various authors and regions of the world estimate that global collection rates for end-of-life mobile phones are below 50%, probably below 20% (Manhart et al. 2016). From a review of information reported in the literature:

- 20% of young Norwegian adults throw small electronics in the waste bin (Watson et al. 2017), while 89% of the mobile devices thrown away in the US in 2010 (141 million units) were disposed in landfill (Benton et al. 2015)[149];
- 28-125 million phones languish unused in the UK, meaning that for every phone in use, up to four sit in drawers unused (Benton et al. 2015). A similar situation occurs in Finland, where consumers typically have between two and five functioning mobile phones stored at home that are not in use (Watson et al. 2017), and North Rhine Westphalia, where 106 million of unused mobile phones and smartphones were stored in households in 2016[150].
- Collection rate in Europe for recycling, refurbishing and/or remanufacturing of smartphones was about 15% in Europe in 2012 (Ellen Macarthur Foundation 2012).

Disposal with household waste clearly has negative environmental impacts due to the missed recovery of the residual value of products and to the fact that most household waste management systems are not designed for treating the various chemicals embedded in EEE. However, also prolonged storage in households does have negative impacts since representing a missed reuse/ recycling opportunity.

4.5.2 Collection and end of life services

End-of-life smartphones are managed in Europe according to WEEE Directive. The end-of-life management of these devices is under the responsibility of producers and importers, who can manage their EEE either individually or through a Producer Responsibility Organisation (PRO) by transferring their obligation to the PRO by paying a fee, in accordance with the principle of the extended producer responsibility (EPR).

In Europe, large distributors of electrical and electronic equipment (EEE) are obliged since 2016 to take back such devices free of charge and to inform consumers about the availability of return facilities. Stationary/online shops with sales/shipment areas relating to EEE of at least 400 m^2 have to take back small WEEE (no external dimension more than 25 cm) like smartphones without the obligation to buy any new EEE (0:1 Take-back).

[149] The US landfill number is very likely not representative for the EU
[150] Personal communication by stakeholders involved in the development of this study

In terms of targets set by the WEEE Directive, 75% of small IT and telecommunication equipment must be recovered from August 2018, and 55% must be recycled/ prepared for reuse. Despite this commitment, a high share of broken or unused smartphones is not collected for recycling. Statistics from Eurostat show a strong discrepancy between EEE put on the EU market in the period 2010-2015 and the amount of WEEE collected, treated and recycled, with their collection considered being the main barrier.

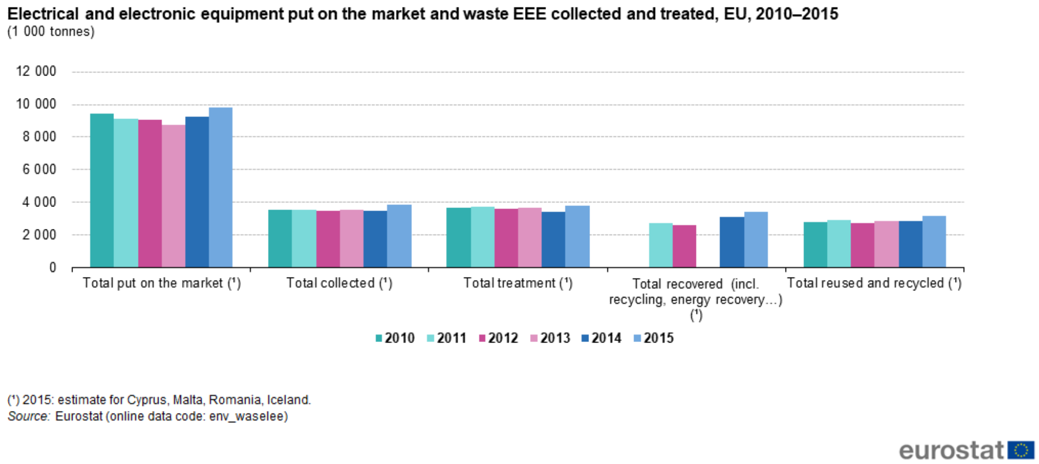

Figure 30: Electrical and Electronic Equipment put on the market and Waste EEE collected and treated in the EU in 2010-2015[151]

This problem of insufficient collection is particularly pronounced for small devices such as smartphones and tablets. Main reasons for low collection rates can be summarised as follows (Manhart et al. 2016; Martinho et al. 2017):

- Lack of information about the disposal of devices;
- Perceived value of unused devices;
- Data security issues.

In particular, collection efficiency could be improved by making consumers aware of the importance of recycling, and changing disposal habits of the society. This could require communication efforts and a broad availability of take back options (Tanskanen 2012).

Beside collection rates, the quality of the collected waste is also an important factor in the end-of-life management of smartphones. Collection and storage should ideally not expose devices to mechanical and physical stresses such as moisture. In addition, the level of sorting is an important factor for the subsequent reuse and recycling logistics. If smartphones are mixed with other product groups such as household appliances at the point of collection, the efforts for effective sorting can increase significantly, which can be economically unfavourable, especially in regions with high labour costs. Innovation in robotics and artificial intelligence can lead to the development of new sorting and data acquisition technologies for recycling.

[151] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=File:Figure_1_Electrical_and_electronic_equipment_(EEE)_put_on_the_market_and_waste_EEE_collected_and_treated,_EU,_2010%E2%80%932015.png&oldid=372559e (accessed on 2 April 2019)

Apart from manufacturers offering take-back systems (either for free or with a refund on a new purchase), remanufacture[152], recycle and re-sale of used phones and parts are of interest also for other market players (Watson et al. 2015). However, anti-theft and security software installed on smartphones can be a barrier for independent organisations and professionals since this software can only be removed by the original owner or by the manufacturer (Transform Together 2018).

4.5.3 Recycling process

The recycling process can be split into two main stages:

1. Pre-processing, encompassing all steps necessary to separate and sort parts and materials for safe disposal and recovery operations;
2. End-processing, encompassing all steps necessary to recover secondary materials from the processing of scraps (e.g. in smelters and refineries).

4.5.3.1 Pre-processing

Pre-processing operations typically start with depollution. The aim of this step is to comply with selective treatment (depollution) requirements, such as those laid out in Annex VII of the European WEEE Directive. With regards to smartphones, selective treatments involve the removal of:

- Battery;
- Printed circuit board;
- External electric cables (chargers).

Moreover, the WEEE Directive states that also BFR containing plastics have to be removed. Some manufacturers have voluntary committed to avoid the use of BFR (Jardim 2017). Some specific BFRs as polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE) are mandatory restricted in homogeneous materials (< 0.1% by mass) also according to the ROHS Directive.

Design features allowing easy access and removal of the components listed in annex VII of the WEEE Directive are essential to ensure optimal depollution of devices. Specifications for WEEE de-pollution are provided in CLC/TS 50625-3-1[153]. Disassembly instructions for relevant components are provided by Digital Europe on the Recycling Information Platform[154].

It is possible to disassemble and then reprocess an EoL battery to its original manufacturer specifications. This involves thoroughly inspection and cleaning of each component. Another option for spent lithium-ion batteries may be re-functionalisation of cathodes, e.g. by restoring chemically lithium content to cathodes (Science for Environment Policy 2018).

Some design principles could help overcome the difficulties associated with recycling lithium-ion technologies and encourage their re-use, as for instance: designs that allow easy separation of parts, use of reversible joining techniques, labelling of parts, use of a minimum number of materials and components, use of standard formats and materials, ease of removal

[152] See for instance: https://www.remade.com/ (accessed on 3 April 2019)

[153] CENELEC (2015) CLC/TS 50625-3-1: Collection, logistics & treatment requirements for WEEE - Part 3-1: Specification for de-pollution - General

[154] https://i4r-platform.eu/ (accessed on 3 April 2019)

of the battery from the device, minimised use of hazardous materials (Science for Environment Policy 2018).

It has been reported that batteries are typically removed, if technically feasible, in a realistic amount of time. Other parts cannot usually be separated as these are strongly tied together. No solution apparently exists to efficiently remove batteries as required prior to treatment when they are glued-together with smartphones.

After depollution, WEEE is broken down into parts and components either by:

- Mechanical processes (e.g. shredding);
- Manual operations (dismantling);
- A combination of the two.

The mixed scrap that is generated is then sorted into material output fractions (e.g. steel scrap, aluminium scrap, copper scrap, printed circuit boards, plastics) that are either passed on to end-processing units or to specialised companies that conduct more specific sorting (e.g. into various grades of aluminium- or steel-scrap).

Mechanical pre-processing steps (e.g. shredding) can lead to losses of metals that cannot be separated perfectly. Furthermore, mechanical stresses can also cause losses of metals in the form of dust (Manhart et al. 2016). Because of this, after the extraction of batteries, mobile phones and comparable devices are often delivered directly to end-processing units specialised in the recovery of copper and other precious metals.

The economic viability of WEEE recycling activities can only be ensured if a large number of appliances are treated in short time and with a satisfactory level of sorting. Processing of well sorted IT-equipment (e.g. smartphones only) can be more attractive from an economic point of view, and can increase the efficiency of recovery of parts and materials. In this way, devices can be screened to select those suitable for repair and reuse, whilst remaining devices can undergo a more thorough depollution where most batteries are removed for separate treatment.

Some European projects (Sustainably SMART[155] and ADIR[156]) are focusing on automated disassembly systems designed to manage and recover materials from smartphones. Apple has also developed automated disassembly systems as the LIAM-robot, custom built for the iPhone 6, and Daisy[157], an improved version of the Liam, that can take apart nine different versions of the iPhone. Daisy seems ensuring a higher granularity, allowing the recovery of Neodymium permanent magnets and tungsten vibration mechanism that are usually not recovered in the current recycling processes. It is however unclear whether robots as Daisy are already applied at industrial scale and at which degree the parts/ materials recovered close the loop in the re-manufacturing process.

4.5.3.2 End-processing

In terms of mass, smartphones are mainly composed of plastics and aluminium. However, the main contribution to the residual value of smartphones is due to the content of precious metals. The recovery of materials from WEEE is the main aim of end processing, although it presents some challenges (Akcil et al. 2015).

155 https://www.sustainably-smart.eu/ (accessed on 13 June 2018)
156 https://www.adir.eu/ (accessed on 13 June 2018)
157 https://www.apple.com/environment/resources/ (accessed on 1 February 2019)

Table 25**Error! Reference source not found.** provides an overview on various recycling options for smartphones and tablets (Manhart et al., 2016). There is no perfect recycling path. Nevertheless, the most typical scenario sees the removal of the battery, separate smelting of the device, and recovery of precious materials (Manhart et al. 2016).

Table 25: Major recycling options for smartphones and tablets and material recovery capacity (Manhart et al. 2016)

Material		**Option 1:** Battery is not removed, device fed into secondary Cu-smelter	**Option 2:** Battery is removed, handset fed into secondary Cu-smelter, battery into battery-smelter	**Option 3:** Device (incl. battery) is shredded and mechanically sorted into output fractions which are fed into Cu-, Fe- and Al-smelters
Aluminium	Al	No	No	Partly
Copper	Cu	Yes	Yes	Partly
Cobalt	Co	No	Yes	No
Magnesium	Mg	No	No	No
Tin	Sn	Yes	Yes	Partly
Iron (Steel)	Fe	No	No	Partly
Tungsten	W	No	No	No
Silver	Ag	Yes	Yes	Partly
Rare Earth Elements	REE	No	No	No
Gold	Au	Yes	Yes	Partly
Tantalum	Ta	No	No	No
Palladium	Pd	Yes	Yes	Partly
Indium	In	Partly	Partly	Partly
Gallium	Ga	No	No	No

No = no material recovery.
Partly = recovery of up to 80% of the embedded material
Yes = recovery of > 80% of the embedded material

The common recycling route for the recovery of metals in Europe is based on the pyro-metallurgical methods, basically based on smelting (Figure 31, red line) and adopted in different plants (e.g. Umicore in Belgium and Aurubis in Germany). Losses of precious metals can occur if this is associated with mechanical pre-treatments for the separation of steel and aluminium scraps. On the other hand, the practice of feeding smartphones directly into secondary Cu-smelters leads to losses of aluminium and iron as these metals move into the slag phase of the smelters. Plastics are instead reported to be burnt to fuel such smelters (Manhart et al. 2016).

Dedicated smelting processes are also available for recycling of batteries and recovery of cobalt that can be used for new rechargeable batteries (e.g. UHT furnace in Hoboken[158]). Different EU projects have been also investigating innovative routes to recover cobalt and other valuable materials included in the Lithium-ion batteries[159, 160]

Li-ion batteries cannot be landfilled as they leach substances that are toxic and explosive. However, recycling of Li-ion batteries is technologically challenging (Science for Environment Policy 2018) since:

158 https://csm.umicore.com/en/recycling/battery-recycling/our-recycling-process (accessed on 31 January 2019)
159 https://h2020-crocodile.eu/project-2/ (accessed on 31 January 2019)
160 http://www.colabats.eu/ (accessed on 31 January 2019)

- They contain a large number of blended materials, which makes recycling more complex than for simpler technologies like lead-acid.
- The array of chemical compositions for the electrodes adds a further complication, especially as the composition is not labelled for the recycler's information.
- The two main methods of recycling for lithium-ion batteries are energy intensive.

Recycling of waste lithium-ion batteries is generally aimed at recovering cobalt, nickel and copper due to their economic value. These materials are only partially recovered. Most other substances contained in the battery are not recovered, even if technically possible.

Lithium usually ends up in the slags of recycling processes which are used as construction materials. The declining use of cobalt in lithium-ion batteries could make recycling unattractive from an economic point of view.

Although most industrial applications for WEEE recycling are still restricted to physical and pyro-metallurgical processes, emerging techniques include (Akcil et al. 2015):

- Hydrometallurgical techniques (Figure 31, blue line), which focus on precious metals contained in PCBs. Hydro-based systems are able to process smaller quantities of recyclable material than smelting processes, thus needing a lower initial investment. The hydro-metallurgical process requires a series of pre-treatments on WEEE (collection, sorting and shredding of PCBs) and further separation of ferrous metals and aluminium. PCB granulates then undergo sulphuric acid leaching and solid/liquid separation. The leach liquor, which is rich in copper, is neutralised to recover copper in the solution. The residue obtained from sulphuric acid leaching goes to cyanide or thiourea leaching for the recovery of precious metals such as gold and silver (Rocchetti et al. 2013)
- Biotechnologies, which exploit the ability of microbes to accumulate metal ions for their vital functions. This could be used for the selective recovery of metals. However, the main barrier at the moment seems to be linked to the low speed of these techniques.

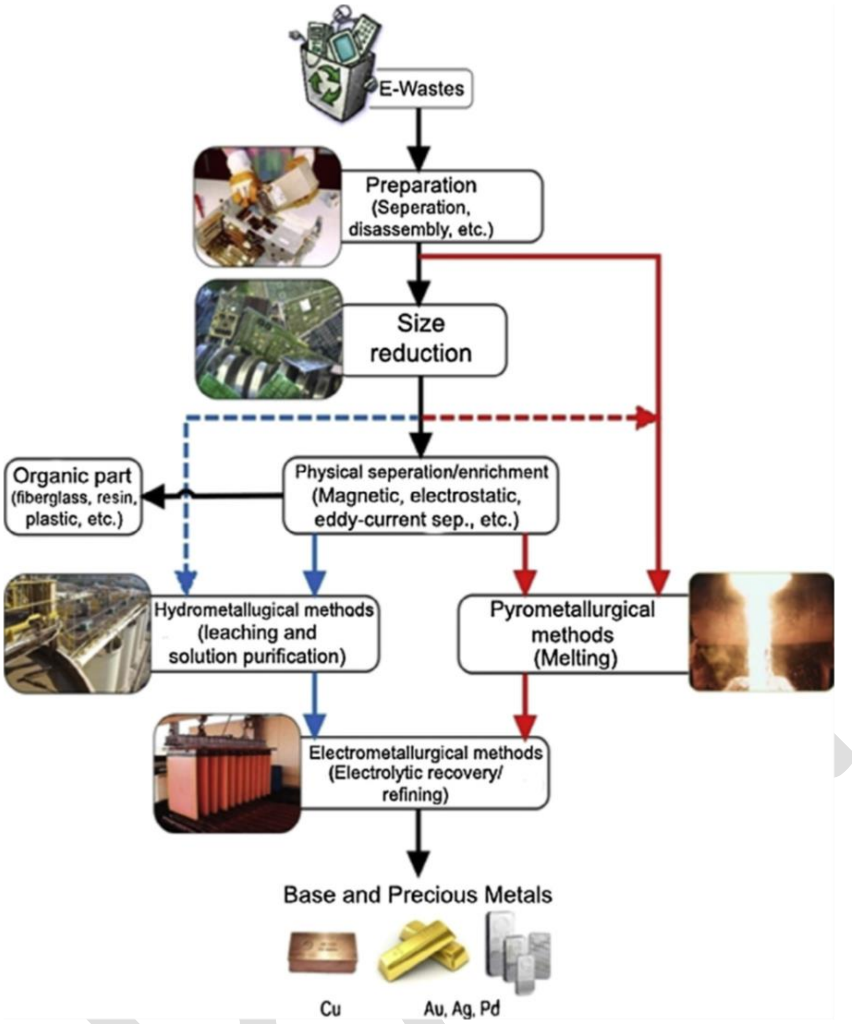

Figure 31: Typical end processing steps for the recovery of precious metals by pyro-metallurgical methods (in red) or hydro-metallurgical methods (in blue) from WEEEs (Akcil et al. 2015)

Several precious materials have a potentially high recyclability rate with the current EoL scenarios, as for instance: cobalt, copper, gold, silver, palladium, tin (Manhart et al. 2016).

Critical raw materials are other relevant elements for recycling, however they are not recovered effectively in the current EoL scenarios:

- Tungsten: recycling rates of tungsten are low/moderate in typical recycling plants (Fairphone 2017). However, pilot disassembly programmes are able to recover the vibration module and send it to a dedicated recycler for tungsten recovery[161];
- Rare Earth Elements (REE): less than 1% of REEs are currently recycled from postconsumer waste (Fairphone 2017). The REE4EU project[162] aims to develop and demonstrate the feasibility of an innovative Rare Earth Alloys (REA) recovery route from the recycle of permanent magnets (PM) and batteries;

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[161] https://www.apple.com/lae/environment/resources/ (accessed on 30 January 2019)
[162] http://www.ree4eu.eu/ (accessed on 23 October 2018)

- Gallium and Indium: less than 1% of gallium is estimated to be recycled from post-consumer waste. Gallium is sometimes substituted by Indium, which is however associated with similar supply and recycling problems (Fairphone 2017).

The Sustainably SMART[163] project is exploring the possibility to separate tantalum-rich, gallium-rich and tungsten-rich components from disassembled smartphones as these metals are currently lost in conventional electronics waste recycling processes.

A significant barrier for the recycling process is the critical volume required by end-processors of speciality metals, as the waste stream of smartphones is relatively small compared to the scale of recycling facilities (and also in comparison with other waste streams from the automotive, machining, building/infrastructure sectors). End-processors often do not accept volumes below 100 t which is a difficult quantity to accumulate for smartphones.

Moreover, although elements can be available at industrial recycling capacity (e.g. magnesium, tungsten, some rare earth elements, tantalum), pure input of materials is required. Different models of smartphones are instead made of different mixture of heterogeneous materials, which further complicate the recycling process. For example, cases are made of different materials, and metals are alloyed together. Roughly half of the metals in a cell phone are lost in a smelter during the recycling process[164].

Possible improvements mainly depend on the effective collection and separation of batteries, smartphones and their constituents. However, such effort could be not justified from an economic perspective due to the relatively small quantities of metals contained in smartphones and tablets. Some metals, like critical rare earth elements, are too difficult or too expensive to separate out for recycling.

4.5.4 Transport and risk of illegal export of WEEE

WEEE, including smartphones, can also end up, through informal routes, in countries which do not have appropriate recycling facilities. This can cause environmental pollution and health risks in these countries (Basel Action Network 2019). For instance, the presence of polyvinyl chloride (PVC) plastic and brominated flame retardants (BFRs) can contribute to the formation of dioxins, among other hazardous chemicals, when scrap is burned, especially if in an uncontrolled way.

Annex VI of the WEEE Directive 2012/19/EU states that in order to distinguish between EEE suitable for reuse and devices not suitable for reuse and legally classified as a waste (WEEE), where the holder of the object claims that they intend to ship or is shipping used EEE and not WEEE, Member States shall require the holder to have available the following to substantiate this claim:

- a copy of the invoice and contract relating to the sale and/or transfer of ownership of the EEE which states that the equipment is destined for direct re-use and that it is fully functional;

- evidence of evaluation or testing in the form of a copy of the records (certificate of testing, proof of functionality) on every item within the consignment and a protocol containing all record information;

[163] https://www.sustainably-smart.eu/ (accessed on 30 January 19)
[164] https://ifixit.org/recycling (accessed on 8 February 2019)

- a declaration made by the holder who arranges the transport of the EEE that none of the material or equipment within the consignment is waste as defined by Article 3(1) of Directive 2008/98/EC; and
- appropriate protection against damage during transportation, loading and unloading in particular through sufficient packaging and appropriate stacking of the load.

Further Technical Guidelines for the transboundary movements of WEEE and used EEE and for the differentiation between the definition of waste and non-waste are provided by the United Nations (UN 2015).

4.5.5 Possible measure relating to recycling

Recyclability and recoverability of materials at the end of life can be limited by the presence of specific substances, and by technological and design issues. Based on the analysis provided above, measures that could improve the material efficiency of smartphones in this area should in particular include:

1. The availability of take-back programmes for the collection smartphones and the proper information of consumers about the importance of giving back unused devices for recycling purposes
2. The ease of disassembly and marking of:

   - Parts listed in Annex VII of WEEE because of their hazardousness (battery and PCBs);

   - Parts that could be reused (e.g. displays);

   - Parts containing precious/critical materials.
3. The documentation of the sequence of dismantling operations needed to access the components listed above (including type and number of fastening techniques(s) to be unlocked and tool(s) required);
4. The provision of information on CRM, flame retardants used in plastic parts, as well as the marking of plastic parts.

4.6 Trade-offs between material efficiency aspects

Possible measures to improve the material efficiency of products should not be seen as a pool of separate alternatives but rather as a set of interconnected options which can affect and/or be influenced by other aspects (Cordella et al. 2019b). First of all, since smartphones are based on materials (as all products), there are inherently physical limits for the quantity and quality of materials used. Any strategy addressing directly the materials used in the product should ensure the fulfilment of technical specifications for product safety, performance and durability as well as analyse the related impacts. Moreover, actions that can potentially have a positive influence with respect to a specific material efficiency aspect could have negative consequences for other aspects (e.g. the use of glues for durability could compromise reparability, lean designs might reduce recyclability of the product).

Some manufactures claim that they prioritise durability and reliability in the design of their smartphones (e.g. robustness and water resistance), even though this could make more difficult for common users to repair the product, for instance due to embedded batteries and adhesives. Embedded batteries, which are more and more used, could be more difficult to replace. Nevertheless, it has been reported that their enclosure requires in general less plastic and metal materials to protect the battery cells. It has been also reported that innovative adhesives could make the repair of smartphones easier, at least for professionals.

Other manufacturers have been found to prioritise ease of repair and upgrade. In particular, the concept of modular smartphone has received lot of attention during the past years. Modular smartphones (e.g. Fairphone and Puzzlephone) offer the possibility to replace specific modules of the device, although they have not reached a large scale production. Actually, the only market case seems to be that of Fairphone 2[165]. Modular design comes with some challenges due to the larger mass and volume needed to house different parts in a way they ensure full flexibility of the device (Transform Together 2018). As an example, the modular design of Fairphone requires more materials due to the increased number of connectors and the sub-housing of modules (Proske et al. 2016). However, smartphones do not necessarily need to be fully modular. Research suggests that in order to achieve highest efficiency in terms of material recovery and cost savings, modularity should focus on printed circuit boards (PCBs), screens, shells and batteries (Souchet et al. 2017).

The analysis of material efficiency should be also supported by LCA considerations to understand which aspect can be more important from an environmental perspective and the magnitude of trade-offs (Cordella et al. 2019b).

[165] https://www.fairphone.com/en/upgrade-fairphone2-camera/ (accessed on 4 July 2018)

4.7 Networks, cloud offloading and data centres

The use of smartphones relies on mobile networks (voice and data) and data servers storing user (e.g. photos, videos) and provider data (e.g. music, maps, apps and their back-end data).

The monthly average consumption of mobile data has grown between 2012 and 2017 from 450 MB to up to 3.9 GB and 6.9 GB in Western Europe and North America, respectively. The monthly mobile data traffic per active smartphone in North America could reach 26 GB in 2022. Despite the increase in energy efficiency, the higher volumes of transferred data might cause a net increase in energy consumption of networks and of data centres (Transform Together 2018).

In Europe, data centres have been report to account for approx. 2% of the total energy consumption (Bertoldi et al. 2012). Furthermore, increased transmission speeds require continuous updates of the physical infrastructures (Transform Together 2018) with a continuous increase of the power needs foreseen for the next years (Figure 32).

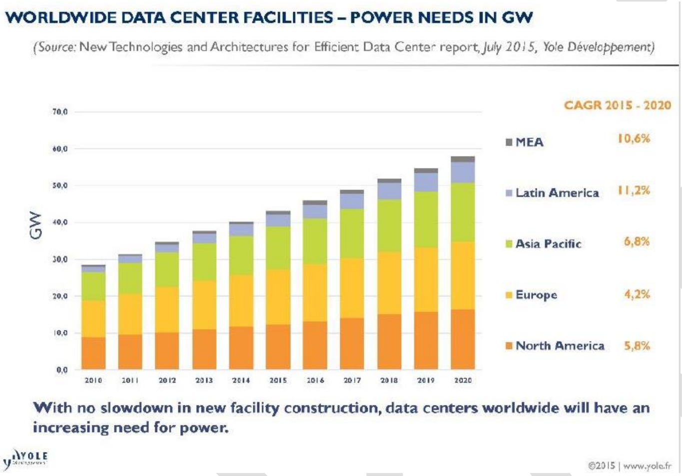

Figure 32: Global power demand of data centres[166]

Impacts from networks and data centres could be for instance reduced by:

- Developing active networks adjusting their-selves based on the activity of users and building zero-emission radio access networks (RAN) to increase energy-efficiency of telco networks, which also requires greater use of renewable energy and innovative energy-efficiency solutions such as liquid cooling of base stations (BTS) connected to local or district heating (Transform Together 2018);
- Designing apps that demand smaller amounts of data in order to function;
- Improving the energy efficiency of data centres and sourcing them with clean forms of energy. For example, it has been reported that 60-70% of the energy consumed in Apples' worldwide corporate offices, retail stores, and data centres come from renewable sources.

166 http://www.yole.fr/iso_upload/News/2015/PR_DataCenterTechnologies_SiPhotonics_YOLE_Oct2015.pdf (accessed on 3 April 2019)

5 MATERIAL EFFICIENCY HOT-SPOTS

5.1 Material efficiency concept

Material efficiency can be defined as the ratio between the performance output of a product, service or energy system and the input of materials required to provide such output. It is thus apparent that material efficiency can increase either by improving the performance or reducing the input of materials to provide a certain performance (Cordella et al. 2019b).

From a system perspective, material efficiency can be considered as a range of strategies relating to the use and management of resources throughout the life cycle of a product or service, and which aim to minimise material consumption, waste production, and their related environmental impacts (Allwood et al. 2011; Huysman et al. 2015), without affecting functionalities negatively.

Figure 33 shows alternative routes for products before their final disposal in landfill, which can contribute to improving their material efficiency. At the macro-scale level, material efficiency can mean moving from a linear model of production and consumption (i.e. from virgin material extraction, to short/single use of products, and final disposal in landfill) to a more circular model, where input of virgin materials can be reduced and landfill disposal is minimised, or at least kept controlled in a growing economy.

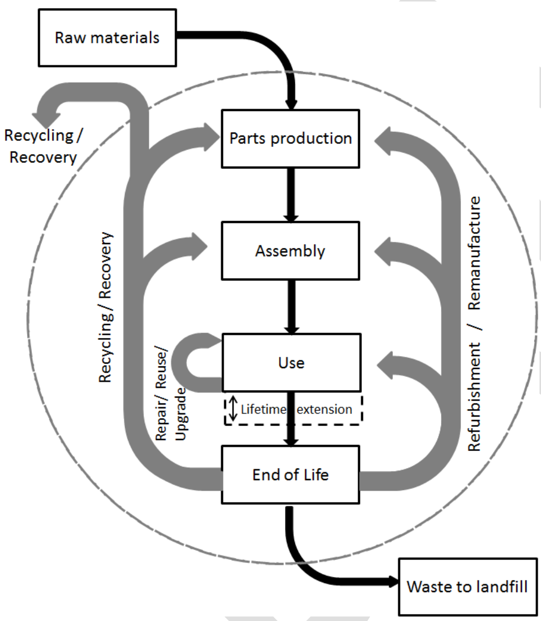

Figure 33: Material efficiency aspects in the life cycle of a product (Cordella et al. 2019b)

Material efficiency strategies can be quite well mirrored by the hierarchical approach set out by the Waste Framework Directive (Allwood et al. 2011; Bakker et al. 2014), as shown in Figure 34. The waste hierarchy aims at reducing the waste output and its disposal in landfill. Material efficiency goes beyond and promotes also the prevention of material consumption. Taking the example of waste management, a hierarchy of strategies can be drawn for material efficiency aspects at the product level (Cordella et al. 2019b):

1. Reduction of material consumption;
2. Value retention in product systems;
3. Recycling and recovery of materials.

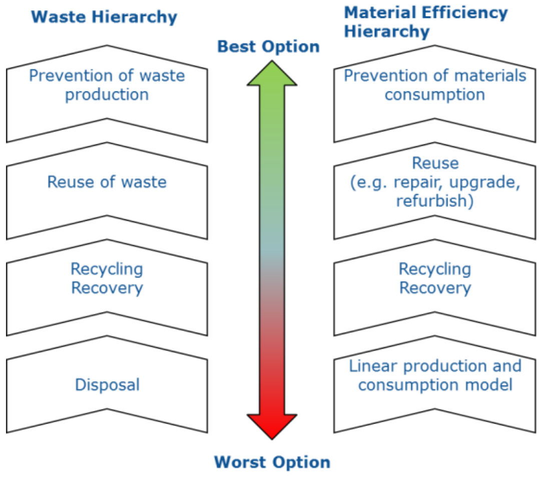

Figure 34: Analogy between waste and material efficiency hierarchies (Cordella et al. 2019b)

In general, material efficiency aspects could be more or less relevant for a product/ service depending on its specific characteristics. For example, depending on the relative magnitudes of impacts due to production, use phase and end of life, it could be either more convenient to prolong the use of energy-related products or to replace them with more efficient products (Alfieri et al. 2018a; Cordella et al 2018; Iraldo et al. 2017, Tecchio et al. 2016). An assessment of the relative importance of material efficiency aspects is thus needed, on a product-by-product basis, to understand which hotspots can potentially produce most tangible benefits and the magnitude of possible trade-offs.

5.2 Guidance for the LCA-supported analysis of hotspots

The analysis of material efficiency hotspots calls for the consideration of technical, environmental and economic information over the life cycle of products (see sections 1 to 4) and the further quantification of impacts. Life cycle assessment (LCA) (ISO 2006a; ISO 2006b) and Life cycle costing (LCC) are the general methodological references for the quantification of environmental and economic impacts of products and services along their life cycle. This can allow: i) determining main contributions in terms of stages, processes, parts and/or specific emissions and inputs, and ii) understanding which improvement options can be more beneficial and under which conditions, as well as if relevant trade-offs exist (Cordella et al. 2015; Cordella and Hidalgo 2016; Cordella et al. 2019b).

The scope of the analysis has to be defined with respect to:

1. Functional unit (FU) and reference flow;
2. Key performance indicators[167];

[167] For a comprehensive assessment of environmental impacts, the most ambitious level would be to use the indicators proposed in PEF, which would require carrying out a full LCA with the aid of commercially available databases (and software tools). The assessment can however be streamlined by referring to shorter lists of key indicators, and/or simplified tools. Ecoreport is a simplified LCA tool used in MEErP preparatory studies in study supporting Ecodesign/Energy Label. Although coming with a more moderate assessment effort, the current version of the Ecoreport lacks in terms of modelling flexibility, possibilities to harmonise with PEF, indicators addressing scarcity of resources

3. Reference product(s)/ types of products;
4. System Boundary and modelling approach[168].

Depending on the quality of the available information, the assessment can be based on existing studies (Cordella and Hidalgo 2016) and/or ad-hoc models which match, as close as possible, the stock/market conditions of the analysed product (Cordella et al. 2015).

5.3 LCA of smartphones

5.3.1 Goal and scope

The aim of this LCA application is to analyse material efficiency hot-spots relating to the average use of smartphones in the EU. Baseline and alternative scenarios potentially leading to an improvement of the material efficiency of smartphones are also defined and assessed. The assessment is assisted by an ad-hoc LCA model, developed based on the information available in the literature.

LCA studies for mobile phones published after 2010[169] were screened, based on elements provided by Cordella and Hidalgo (2016),to identify those which could constitute a potentially valuable resource for the analysis in terms of: scope of the analysis, data quality and representativeness, impact assessment metric, relevance and robustness of findings (Ercan 2013; Ercan et al. 2016; Manhart et al. 2016; Moberg et al. 2014;Proske et al. 2016; Prunel et al. 2014; Prunel et al. 2015; Suckling and Lee 2015). Additionally, LCA results for different models of smartphones have been shared by Apple, Huawei and Samsung.

5.3.2 Key Performance Indicators

LCA studies on smartphones (see for all: Ercan 2013; Ercan et al. 2016; Manhart et al. 2016; Moberg et al. 2014;Proske et al. 2016; Prunel et al. 2014; Prunel et al. 2015; Suckling and Lee 2015) have typically focused on the analysis of the Carbon Footprint (CF) of the product, i.e. the greenhouse gases (GHGs) emitted along the product life cycle, measured as $CO_{2,eq.}$ in terms of Global Warming Potential over 100 years (GWP_{100}).

The dominant contribution of materials and manufacturing processes to the CF of smartphones is described in several studies (Andrae 2016; Ercan 2013; Manhart 2016; Suckling and Lee 2015). When a broader set of indicators was used (Ercan et al. 2016; Moberg et al. 2014; Proske et al. 2016; Prunel et al 2015; Prunel et al 2016), materials and

(e.g. ADP). Reference impact categories could be identified based on the observation of Product Category Rules and relevant studies, as for instance described by Cordella and Hidalgo (2016). Since different hotspots are in general associated to different impact categories, it can be possible to narrow down further the list of impact categories. For example: 1) an environmental indicator where contribution to the impacts due to materials is dominant (e.g. 75-100% of the overall impact); 2) an environmental indicator where contribution to the impacts due to the use phase is dominant; 3) an environmental indicator where contribution to the impacts from both materials and use phase is significant (e.g. 30-50% each); 4) total cost of ownership (EUR).

[168] The modelling of the life cycle can include the application of assumptions and the further processing of foreground and LCI data for the calculation of the inputs and outputs associated to the key elements of the product's life cycle: Bill of Materials (BOM) and manufacturing processes, transports and distribution, expected time of use, maintenance and repair activities, EoL scenarios. A sensitivity analysis should be carried out when the uncertainty of assumptions and/or data is significant

[169] Considering that smartphones have been introduced on the market in 2007 (Arthur 2012) and that some years are needed before relevant LCA information is made available.

manufacturing processes were confirmed to be very relevant in determining the environmental profile of smartphones.

Although the quantitative assessment of the sustainability of products should be generally based on a comprehensive metric of indicators, this application is limited to the calculation of GWP100 and total cost of ownership for consumers (EUR) along the life cycle of smartphones. This is due to the fact that:

- Smartphones are per se a complex product system;
- GWP100 is a popular indicator representing a global environmental priority, which is also correlated to other indicators (Askham et al. 2012; Huijbregts et al. 2005);
- Economic considerations are important to complement GWP100;
- A broader metric would confirm the importance of consumption and disposal of materials, at least from a qualitative point of view.

5.3.3 Functional Unit and Reference Flow

This application refers to the average use of smartphones in the EU. The definition of a representative Functional Unit (FU) is complicated by the fact that smartphones integrate many functions at different levels of performance (potentially replacing the use of other products such as cameras and music players).

For comparative purposes, equivalency between smartphone systems must be ensured by selecting and defining relevant function(s) and functional unit(s). This would include the consideration of quantitative and qualitative aspects:

- What, when and how well: e.g. a smartphone produced in 2018, enabling 3G/4G speed and Wi-Fi access, equipped with a 5.9 inch display of 1440 × 2560 pixels, with 64 GB of storage memory and 4 GB of RAM, with a 20 Mega Pixel (MP) video-camera, and with a 4,000 mAh battery capacity;
- How much and how long: e.g. 1 hour calling, 1 hour web browsing, and 1 hour video watching per day, for a total of 4 years of use.

In practice, it is likely that conducting a coherent comparison between models is hindered by the different characteristics of such models.

The FU can be then converted in terms of Reference Flow, which is the amount of product(s) needed to deliver defined functions. The use of a phone for a certain number of years is the most commonly used reference flow (ETSI 2018). This simplification is considered useful for the analysis of the relevance of material efficiency hot-spots in the life cycle of a generic product. The analysis has been thus referred to the use of a smartphone for 4.5 years, based on the information reported in section 3.3. Further assumptions are defined in the next section.

5.3.4 Reference Product, System Boundaries and Scenarios

Smartphones on the market are multi-functionality products offering different levels of performance depending on the technologies used. The comparison of specific models of smartphones should be carried with an adequate level of granularity, so that products with similar characteristics are assessed within the same product category.

Since this application does not aim to compare specific models of smartphones, but rather produce general considerations for this product group, a virtual (non-existing) product made up of different technologies/materials is considered as reference for this assessment.

The System Boundaries include the evolution of the product from cradle-to-grave:

a. Production (i.e. extraction, processing and transportation of materials and parts and further assembly, including the product packaging);

b. Distribution (i.e. transportation of the product from manufacturing plants to regional hubs and final customers);

c. Use (by first/following owners, including system aspects);

d. End of Life (i.e. typical disposal scenarios, including transportation and recycling of the product).

Foreground data has been gathered from the literature; elementary input/output flows have been then calculated based on LCI datasets. Services and material goods to support the business are not considered (e.g. research and development activities, marketing).

5.3.4.1 Materials, manufacturing and assembly

Based on Section 4.2.1, an average smartphone is considered to have a display size of 75.53 cm^2 and a weight of 160 grams, including 39 g for the battery and excluding accessories and packaging. The weight of the smartphone has been estimated approximately as 29 g per display size inch (+/- 15%). Additional materials are necessary for packaging, documentation and accessories as head-set, USB-cable, charger. Packaging is typically made of fibre (e.g. cardboard) and, to a lower extent, plastic materials. A Bill of Materials has been estimated on the basis of the available information and reported in Table 26. The objective is to find a balance between comprehensiveness of materials, and simplicity for the modelling.

According to Proske et al. (2016), 4.698 kWh are needed for manufacturing one unit of smartphones. It has been estimated that this value could vary +/- 50%. Manufacturing has been considered to happen in China.

Table 26: Bill of Materials for a generic smartphone in the EU

Module	Part	Avg. weight (variation)	Transport
Housing	Plastic elements (PC) Metal frame and case: - Aluminium - Steel	9.5 g 22 g 6.5 g	T: 1000 km T: 1000 km
Screen/Display	LCD display (75.5 cm2)	30 g	F: 1000 km T: 100 km
Electronics	PCB (14 cm2) IC die area (3 cm2)	28 g 2 g	F: 1000 km T: 100 km F: 1000 km T: 100 km
Battery	Battery	39 g (19-48 g)	F: 1000 km T: 100 km
Audio-visual	Speakers and microphone Cameras	2 g 1.25 g (1-1.5 g)	F: 1000 km T: 100 km F: 1000 km T: 100 km

Others	Buttons	0.1 g	F: 1000 km T: 100 km
	Resistors	2 g	F: 1000 km T: 100 km
	Diodes	0.9 g	F: 1000 km T: 100 km
	Capacitors	0.7 g	F: 1000 km T: 100 km
	Inductors	0.2 g	F: 1000 km T: 100 km
	Transistors	0.1 g	F: 1000 km T: 100 km
	Filters	0.1 g	F: 1000 km T: 100 km
	Connections	0.25	F: 1000 km T: 100 km
	Vibration motor	1 g	F: 1000 km T: 100 km
	Other electro-mechanical components	14.5 g	F: 1000 km T: 100 km
Accessories	Charger	50 g (50-56 g)	F: 1000 km T: 100 km
	USB cable	20 g	F: 1000 km T: 100 km
	Headset	15 g	F: 1000 km T: 100 km
Packaging (primary, secondary and tertiary) and documentation	Paper	50 g	T: 100 km
	Cardboard	110 g	T: 100 km
	LDPE film	20 g	T: 100 km

Note:

- F: flight
- T: Truck

5.3.4.2 Distribution

The following means of transport are considered for the distribution of the product from China to the EU:

- 100 km by truck, in China;

- 8000 km by flight (distance from Beijing to Paris[170])
- 500 km by truck > 32t, in Europe
- 100 km by truck 16t, in Europe

5.3.4.3 Use

The use of smartphones mainly implies consumption of electricity in the battery recharge cycles. Actual consumption depends on user behaviour and on efficiency of battery/charger.

An electricity consumption of 4.9 kWh per year is calculated by Proske et al. (2016) considering a battery capacity of 2420 mAh, 3.8 V of voltage, 69% of recharge efficiency, and 365 charge cycle per year. According to Andrae (2016), energy consumption is 1.538 times the battery capacity and can vary between 2 and 6 kWh per year. Ercan et al. (2016) estimated that the annual electricity demand of a smartphones can range from 2.58 kWh, considering 1 recharge every 3 days, to 7.74 kWh, considering 1 recharge per day. The electricity consumption range is instead 3-6 kWh/year according to Manhart et al. (2016).

Based on the available information it is considered that the electricity consumption associated to the use of smartphones in the EU is 4 kWh/year, on average, and that this could be equal to 2 and 6 kWh/year in case of more moderate and intensive uses, respectively.

In terms of lifetime, it is considered that the average technical lifetime of a smartphone can be 4.5 year, while the time of use of the first user is 2 years, on average. This corresponds to the default scenario, additional scenarios are assessed, as described in Section 5.3.5.

5.3.4.4 End of Life

Re-elaborating the information from Ercan (2013):

- 49% of smartphones are kept unused at home, once they reach their end of life;
- 22% of smartphones find a 2^{nd} user, either as donation or through the 2^{nd} hand market;
- 29% of smartphones are collected and recycled/remanufactured.

In case of recycling/remanufacture, it is considered that waste smartphones have to be transported 1125 km by truck and 375 km by train (Proske et al. 2016).

5.3.4.5 System aspects

Apart from the consumption of electricity associated to the recharge of batteries, additional energy is consumed due to the infrastructures needed to transfer and store information.

Ercan et al. (2016) estimates the electricity consumption associated to network usage for representative, light and heavy users, as reported in Table 27.
According to Andrae (2016), the electricity consumption would be 1.16 kWh per GB of data used (1 kWh due to extra wireless networks; 0.1 kWh due to Wi-Fi/fixed backhaul; 0.06 kWh due to data centres). Considering an average consumption of 4 GB per month (see Section 3), or 48 GB per year, the annual consumption would be 55.7 kWh/year, which correspond to the

[170] https://www.distance.to/Paris/Beijing (Accessed on 4 April 2019)

heavy use of smartphones, according to Ercan et al. (2016). This value is considered to be representative for the current use of smartphones, due to the current trend towards an increased consumption of data. It could be considered that more moderate and intensive uses of smartphones can imply the consumption of +/- 50% of electricity per year.

Table 27: Consumption of electricity associated to network usage (adapted from Ercan et al. 2016)

	Light User	Representative User	Heavy User
Mobile network + Wi-Fi data traffic per year	5.5GB + 5.5 GB	11GB + 11 GB	30GB + 30 GB
Mobile network (kWh/year)	33.8	36.8	46.8
Wi-fi Operation (kWh/year)	1.8	3.6	9.9
Total (kWh/year)	35.6	40.4	56.7
Total (kWh/GB)	3.2	1.8	0.9

5.3.5 Scenarios of assessment

Building up on the information described above, a number of scenarios have been defined for the assessment of material efficiency aspects. Scenarios are reported in Table 28. Each scenarios address different material efficiency aspects and can be associated to the implementation of specific designs, technologies, behavioural practices.

Table 28: Scenarios considered for the assessment of material efficiency aspects in the life cycle of smartphones

Scenario	Reference lifetime	Use and EOL
1. Default (D0)	4.5 years	Smartphone replaced by a new device every 2 years. The old product is kept unused at home. New units (same device) bought and disposed as above to reach 4.5 years.
2. Durability 1 (D1)	4.5 year	Smartphone replaced by a new device every 3 years. The old product is kept unused at home. New units (same device) bought and disposed as above to reach 4.5 years.
3. Durability 2 (D2)	4.5 year	Smartphone replaced by a new device every 4.5 years (battery changed once). The old product is kept unused at home.
4. Durability 3 (D3)	4.5 year	Smartphone replaced by a new device every 6 years (battery changed twice). The old product is kept unused at home. Impacts allocated to 4.5 years of use.
5. Reparability 1 (R1)	4.5 years	Smartphone break down (display) after 1 year. The product is repaired and used for another year. At the end of life the product is kept unused at home. New units (same device) bought and disposed as above to reach 4.5 years.
6. Reparability 2 (R2)	4.5 years	Smartphone break down (display) after 2 years. The product is repaired, the battery is changed and the device is used for other 2 years. At the end of life the product is kept unused at home. New units (same device) bought and disposed as above to reach 4.5 years.

7. Re-use (RU)	4.5 years	Smartphone replaced by a new device every 2 years. The old product is used by a different user for other 2 years (only battery changed) and then kept unused at home. A credit for the avoided manufacture of a device is assigned for the re-use. New units (same device) bought and disposed as above to reach 4.5 years.
8. Recycle (RC)	4.5 year	Smartphone replaced by a new device every 2 years. The old product is sent to recycle; a credit is assigned for the recovery of parts/materials. New units (same device) bought and disposed as above to reach 4.5 years.
9. Remanufacture (RM)	4.5 year	Smartphone replaced by a new device every 2 years. The old product is sent to remanufacture; a credit is assigned for the recovery of parts/materials. New units (same device) bought and disposed as above to reach 4.5 years.

5.3.6 Life Cycle Costing and technical considerations relating to alternative scenarios

5.3.6.1 Calculation of the total cost of ownership for consumers along the life cycle of the product

Life Cycle Costs for end users, expressed in Euros, can be calculated according to equation below:

$$LCC = PP + \sum_{1}^{N} PWF * OE + EOL$$

Where:

- LCC: Life Cycle Costs for end-users;
- PP: Purchase price (including installation costs);
- OE: annual operating expenses for each year of use;
- EOL: End-of-life costs for end-users (i.e. costs for disposal);
- PWF: Present Worth Factor

PWF can be calculated as:

$$\mathrm{PWF} = 1 - \left(\frac{1+e}{1+d}\right) \cdot \left[1 - \left(\frac{1+e}{1+d}\right)^{N}\right] \qquad (d \neq e)$$

Where

- e is the aggregated annual growth rate of the operating expense ("escalation rate");
- d is the discount rate (= interest – inflation) in %;
- N is the product life in years.

To calculate the PWF the discount rate (d) and the escalation rate (e) of the operating expenses have to be defined. Assuming that d and e are the same, e.g. 4% (Boyano et al.

2017) , PWF is 1 to the power of the product life N. Moreover, end-users in Europe do not have separate costs for the disposal of smartphones. The formula can be thus simplified as:

$$\boldsymbol{LCC = PP + \sum_{1}^{N} OE}$$

5.3.6.2 Purchase price and electricity cost

From section 2.3.4, it is considered that the purchase price of an average smartphone in the EU is 320 EUR. The price could change to less than 130 EUR and more than 480 EUR for low and high-end products, respectively.

The only operative cost considered for the product is the consumption of electricity to recharge the battery of the smartphone: 0.208 EUR per kWh (Boyano et al. 2017).

5.3.6.3 Depreciation

The value of the device is 54% of the original price after 1 year, 32% of the original price after 2 years, 20% of the original price after 3 years. Lifespan and residual value of smartphones can vary depending on manufacturers and models. In particular, high-end smartphones have a higher residual value (Makov 2018)

5.3.6.4 Failures and repair costs

According to Bullitt (2017), 34% of the EU consumers has suffered a damage of their devices in a three-years period of observation. 24% of users in the UK have a screen breakage in a two-years period of observation[171]. Data from US reports even show higher frequency of failures[172].

The most frequent failure types, related to the screen, are usually not covered by legal guarantee, generating in case of failure a repair cost of 15-40% (25% as average) of the purchase price. The replacement of the battery can instead cost 5-10% of the purchase price.

Based on this data, average repair costs in the EU could be roughly estimated as 11% of the purchase price (25% of the purchase price for the repair of screens, multiplied by a frequency of failure of 34%).

5.3.6.5 Design for durability

More durable designs can be pursued through the following technical measures:

- IP68 protection level (dust and waterproof): it is mainly associated to current high-end devices[173] or to the specific market segment of rugged smartphones. However also some devices not belonging to the high-end class are reported to be IP68[174]. IP67

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[171] https://www.mintel.com/press-centre/technology-press-centre/smashing-times-24-of-uk-smartphone-owners-have-broken-their-screen-in-the-past-two-years (accessed on 5 April 2019)
[172] https://bgr.com/2018/11/20/smartphone-screen-repair-data/ (accessed on 5 April 2019)
[173] E.g. Galaxy S8 Plus, LG V30, LG G6, Sony Xperia XZ1, Sony Xperia XZ Premium and the Samsung Galaxy S7, iPhone XS and XS Max
[174] E.g. LG X venture, Samsung Galaxy A8, Xiaomi Pocophone F1claim - IP68 dust/water proof (up to 1.5m for 30 mins). LG X venture also claims to be compliant with MIL-STD 810G

protection levels (dust and waterproof) are claimed for more models on the market[175]. IP67 and 68 cannot be ensured in case of modular design[176]). Based on this information, no significant additional costs seem associated to the fulfilment of IP68 protection levels.

- Resistance to drops: drop tests results and compliance with related standards are usually reported for rugged smartphones[177]. However also some devices classified to have a medium price are claimed to have a high mechanical resistance[178]. Mechanical resistance can come with some trade-offs. For example, use of glass in the back cover and bezel-free smartphones are more fragile. Higher resistance could be ensured with different materials, smaller screen sizes and the use of bezels. Moreover, mechanical resistance can be improved through protective covers/bumpers. Model-specific certified bumpers are provided by some manufacturers[179]. Pre-installed protective layers are also provided for some models[180]. Based on this information, no significant additional costs seem associated to the fulfilment of a high mechanical resistance.
- Longer battery life: a manufacturer reports that their batteries are designed to retain up to 80% of its original capacity at 500 complete charge cycles[181] (equivalent to about 2 years). Since the cost of battery is relatively small compared to the total price of the products, no significant additional costs seem associated to the provision of long battery lives.
- Minimum guaranteed OS support period: this appears feasible, as claimed by a manufacturer[182], and without entailing significant additional costs.

A more durable design can have positive effects:

1. Extension of the technical lifetime, including reuse, from 4.5 years to 6 years;
1. Direct saving in maintenance/ repair;
2. Increase residual value (value retention) at the end of the first use.

On the other hand, a more durable design is normally associated to high-end products which present higher purchase prices, although this is also implemented in some products that are in the medium price range.

5.3.6.6 Design for reparability

An extension in the product lifetime and a reduction in maintenance/ repair costs can be achieved also through designs focused to increase the reparability of smartphones (especially

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[175] E.g. Huawei P20 Pro, Apple iPhone X , The Pixel 2 XL, Nokia 8 Sirocco, Sony Xperia XZ2 Compact, Motorola X4 4th Gen

[176] E.g. Fairphone, see: https://support.fairphone.com/hc/en-us/articles/115001535486-Is-the-Fairphone-2-dust-or-water-resistant- (accessed on 5 April 2019)

[177] https://www.toughgadget.com/best-rugged-smartphones-unlocked/ (accessed on 5 April 2019)

[178] e.g. LG X venture claims - IP68 dust/water proof (up to 1.5m for 30 mins) and MIL-STD 810G certified

[179] Samsung is providing protective covers certified to be compliant to drop tests according to the MIL-STD-810G-516.7(United States Military Standard Test - Shock), see: https://www.amazon.com/Samsung-Official-Protective-Standing-EF-RG965CBEGKR/dp/B07BNCLSVY (accessed on 5 April 2019)

[180] https://www.samsung.com/au/support/mobile-devices/galaxy-s10-in-box-items/ (accessed on 5 April 2019)

[181] https://www.apple.com/batteries/service-and-recycling/ (accessed on 5 April 2019)

[182] https://store.google.com/product/pixel_3_specs (accessed on 5 April 2019)

with respect to the replacement of batteries and screens). Such designs should cover at least: ease of disassembly of critical parts, availability of tools and spare parts, provision of repair information, as well as data erasure/transfer features and provision of software/firmware updates.

Reduction in repair costs can offset additional costs potentially associated to this design strategy. In case of modular designs (which are by definition easier to repair and upgrade) possible trade-offs with durability features can occur (e.g. waterproofing).

5.3.6.7 Design for recycling

Design strategies targeting the recycling process can produce economic benefits from a life cycle perspective.

Ease of dismantling of batteries, PCBs and screens could potentially increase their separate collection and recovery. Smartphones should be designed in a way that the access and removal of these components is possible with commercially available tools. Moreover, the sequence of dismantling operations should be provided to recyclers. In general, no additional costs seem associated to such measures. WEEE fees are considered to be integrated in the product purchase price.

Materials can also have an influence on price and feasibility/ profitability of the recycling process. However an analysis of their impact is quite difficult due to the broad heterogeneity of material design options and market value fluctuations. This also apply to the use of recycled materials, which can present uncertainty with respect to their availability and value over time, as well as unexpected side effects (e.g. diverting materials from one sector to another).

5.3.6.8 Lean Design

The inclusion of less accessories in the packaging could contribute to save materials and costs:

- Smartphones could be marketed without an external power supply;
- When a standard power supply is provided, this comes with detachable cables.

5.3.6.9 Environmental externalities

In order to internalise environmental costs, it is considered that each ton of CO2 emitted in the life cycle of the product has a societal cost of 90 EUR/tonne (current price in the EU market is around 23 EUR/tonne)[183,184].

5.4 Preliminary considerations

The assessment will be completed for the final report. Preliminary considerations to be checked by the study team are the following:

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[183] https://markets.businessinsider.com/commodities/co2-emissionsrechte (accessed on 5 April 2019)
[184] https://www.decluttr.com/blog/2017/04/05/how-quickly-does-your-phone-depreciate-in-value/ (accessed on 5 April 2019)

- Increasing durability (in terms of reliability of hardware and upgradability of software) and increasing reparability are core strategies to extend the technical lifetime of a smartphone and improve its material efficiency. This should be supported also by information provision. Moreover, consumers should be also triggered to use their products for a longer period of time. Factors as functionality, design, utility and value of the product.
- Ease of disassembly can have positive effects on both reparability and recyclability of smartphones. However, recyclability can only be assessed in relation to the applied recycling processes. With the current practice it seems possible to recycle only a small fraction of materials. Further innovation is needed to deal with small and highly integrated products at a commercial scale and to recover materials that are lost in today's recycling practices.

6 DEFINITION OF POSSIBLE DESIGN MEASURES FOR IMPROVING MATERIAL EFFICIENCY

This section aims to sum up the information gathered in the former sections and to define practical design measures that could help to improve the material efficiency of the product. The ambition is also to analyse relevance and technical feasibility of each measure, as well as to describe available methods for assessment and verification purposes.

An illustrative list of possible measures to improve the material efficiency of smartphones is reported in

Table 29. It should be underlined that this list does not have to be considered like a policy proposal but rather as examples of possible improvement options.

Table 29: Possible measures to improve the material efficiency of smartphones

Strategy (*)	Measure	Relevance	Feasibility	Assessment and verification
Reduction and/or optimisation the amount of materials used	1) Reduction of materials a. Provision of smartphones without EPS. b. To be complemented by measures for the interoperability of EPS: - Provision of information on the technical specifications of the accessories (voltage, power output and connector type of the EPS). - Compliance with IEC 62684:2018 or IEC 63002:2016	Many users have another charger that could be compatible and reused[185]. Impacts can be quantified via LCA/LCC	Technical feasible	Visual check of the product package, ports and documental review of the claimed specifications in the instruction manual provided with the product (voltage, power output and connector type)
	2) Use of recycled and/or renewable materials Use of recycled Aluminium, Copper, Tin and Tungsten	Environmental impacts for aluminium and copper. Socio-economic impacts for Tungsten (CRM and Conflict Material) and Tin (Conflict Material).	Apparently feasible for some manufacturers. Uncertainty about the recycled Tungsten supply chain. Risk of material diversion to be verified for aluminium and copper.	Chain of custody and mass balance methods
	3) Substances of concern Monitoring, restriction and provision of information on substances of concerns. (e.g.	Stimulating safer designs	Several manufacturers in the ICT sector have	IEC TR 62476:2010 provides guidance for the evaluation of

[185] https://support.fairphone.com/hc/en-us/articles/201065667-Why-don-t-you-offer-a-charger-with-Fairphone-2- (accessed on 10 April 2019)

Strategy (*)	Measure	Relevance	Feasibility	Assessment and verification
	halogens, Antimony, Phthalates, Arsenic compounds)	and processes	already implemented Substance Control systems	substances in EEE
Increase of durability	1) Protection from water and dust Compliance with the IP68 or IP67 levels of protection	Accidental ingress of water and dust is a relevant reason of product failure	There are models of smartphones on the market that are compliant with these requirements.	IEC 60529 - Degrees of protection provided by enclosures (IP Code)
	2) Resistance to accidental drops a. Compliance with specific drop tests and/or b. Provision (at the moment of purchase) of screen protectors and protective cases enabling the same level of protection.	Accidental drops are one of the main reasons of product failure.	a. There are models of smartphones that are compliant with these requirements. b. It has been demonstrated that protective accessories are effective.	a. MIL-STD-810G or IEC 60068 E.g. Part 2-31: Ec (Freefall, procedure 1) b. Visual check of the product package, ports and documental review of the claimed specifications in the instruction manual provided with the product.
	3) Battery life: a. Minimum number of cycles with the battery properly functioning (e.g. 500 cycles at 80% of initial performance) Alternative for a: the remaining full charge capacity of the battery compared to the initial charge capacity, after x and y charge/discharge cycles (e.g. 300 and 500) is higher than XX% b. Software is pre-installed to enable a limit on the battery state of charge (SoC) when the smartphone is connected to the grid (e.g. overnight charge). To be complemented with information about the	Battery aging is a common problem in smartphones	a/b. Already feasible for products on the market	a. Battery life testing according to IEC EN 61960. b. Provision of information from manufacturers

Strategy (*)	Measure	Relevance	Feasibility	Assessment and verification
	existence and the benefits of such functionality			
	4) Operating System, software and firmware a. Availability of update support (at least along the entire guarantee period), including information on impact and reversibility of updates b. The device is placed on the market with sufficient capacity and the last available OS model	Software issues have been found to be a limiting state even for products with a still functioning hardware.	Availability of updates is technically feasibile for products on the market.	Declaration/ guarantee from manufacturer
	5) Guarantee a. Inclusion of failures due to accidental drops and contact with water in the legal guarantee b. Extended guarantee Note: the guarantee could also include "commitment to free repair as first remedy" in case of failures and a "commitment to upgrade the product periodically	The inclusion of common failures in legal guarantees and/or the provision of extended guarantees could stimulate the design of more durable devices.	Already feasible for some products/countries	Declaration/ guarantee from manufacturer
	6) User behaviour Provision of information about the correct use and maintenance of the device	Behavioural patterns can be cause of early failures and/or replacement of devices	No barrier identified	Provision of information by manufacturer
Increase of reparability and upgradability	1) Disassemblability a. Batteries, screens and back covers removable in 28, 30 and 14 steps, respectively (a more ambitious level would be 2, 15 and 1 steps) b. Batteries, screens and back cover to be easily accessible and replaceable using universally	Priority parts should be easy-to-disassemble to facilitate the repair process (and reduce the related costs).	There is a broad heterogeneity in designs, with some devices being more reparable than others.	Provision of a manual with an exploded diagram of the device, and an illustration of how parts can be accessed and replaced, also with an indication of tools required

Strategy (*)	Measure	Relevance	Feasibility	Assessment and verification
	available tools. Non-removable fasteners are avoided. Alternatively to a and b: c. Batteries, screens and back covers removable in 30, 40 and 53 minutes, respectively (a more ambitious level would be 1, 20 and 1 minutes)			and associated difficulty (e.g. time needed).
	2) Provision of information Repair and maintenance information to be provided to - final users (at least with respect to priority parts) - professional repairers	Priority parts, and other parts, should be reparable in case of failure	No barrier identified	Check of the information provided
	3) Availability of spare parts a. Priority parts should be made available as spare parts for at least 4 years after placing the last unit of the model on the market (availability could be extended up to 6 years). These could also include approved-by-manufacturer compatible spare parts produced by third parties. The delivery time has to be 2 working days. b. Standardized interfaces are used for connectors and EPS	a. Spare parts are necessary for ensuring the repair/upgrade of devices b. Standardised interfaces could facilitate the replacement of parts (and reduce costs).	No barrier identified	Declaration and check
	4) Data transfer and deletion a. Secure data deletion tools should built-in (or as second option made available) to permanently delete all user data without compromising the functionality of the device. b. Simplified transfer of data from an old to a new product should be made available via installed or	These functions are important for data protection and privacy of users, and can facilitate the transfer/deletion of data in case of	No barrier identified	Declaration and check

Strategy (*)	Measure	Relevance	Feasibility	Assessment and verification
	downloadable tools such as applications, cloud-based services or instructions detailing a manual process.	repair/reuse.		
	5) Password reset and restoration of factory tools Password reset and restoration tools should be pre-installed or made available (e.g. via installed or downloadable tools such as an application, a cloud-based service or instructions detailing a manual process)	These functions are important for data protection and privacy of users, and can facilitate the transfer/deletion of data in case of repair/reuse	No barrier identified	Declaration and check
Improving the recycling of smartphones/parts/materials	1) Collection of products a. Take-back programmes are implemented for the collection smartphones b. Information of consumers about the importance of giving back unused devices for recycling purposes	Collection of old/broken devices is essential for recycling	No barrier identified	Check of provided information and effectiveness of the take back programme
	2) Disassembly and identification of parts: Smartphones to be designed so that the identification, the access to and the removal of the following parts is possible without the use of any tool which is not readily available for purchase: a. Parts of concern (batteries and PCB) b. Reusable parts (display) c. Parts containing precious/critical raw materials	Such parts have to be removed at the EOL for safe disposal and efficient recycling	Potentially feasible given the broad heterogeneity of products on the market	Documentation about the sequence of dismantling operations needed to access parts, including the type and the number of fastening techniques(s) to be unlocked and the tool(s) needed.
	3) Provision of information a. Content of CRM	a. CRM should be recovered as much as possible because of their	No barrier identified	a.

Strategy (*)	Measure	Relevance	Feasibility	Assessment and verification
	b. Content of flame retardant in plastic parts	socio-economic impacts. b. Flame retardants can hinder the recycling of plastics.		b.
	4) Marking of parts: Marking of plastic parts > 200 mm^2 in accordance to ISO 11469	Marking of plastics could improve their separation and recycling efficiency	At least for larger parts	ISO 11469

(*) *For illustrative purposes only. In case of potential consideration for policy implementation, such options should be properly assessed to understand their impact and side effects.*

7 QUESTIONS FOR STAKEHOLDERS

A list of questions for stakeholders is reported below. Stakeholders are invited to reply to experience-relevant questions and to support their views with supporting information.

Section 2
1) Can the price/cost information reported in section 2.3 be representative for the EU or would you apply any modifications?
Section 4 (and section 6)
2) Do you consider that the technical description for functions (4.1.2) and parts (4.1.3) is comprehensive? Do you have additional information to differentiate between technologies in terms of material efficiency aspects and costs?
3) Could you please provide additional information on disruptive innovations/ technological advances (e.g. foldable phones), and implications in terms of technologies, material efficiency aspects and costs?
4) Which technologies and functions could become obsoletes in short/medium time, under which conditions? *e.g. is IEC 62684 on ports and power supplies already obsolete and reference should be instead made only to IEC 63002?*
5) Which minimum levels of performance should be ensured to avoid the premature obsolescence of the device (e.g. memory capacity and OS version)?
6) We have found information on the size of smartphones reported either as cm2 (area) or inches (length). Is there an explanation and any agreed conversion factor?
7) Do you agree with the Bill of Materials reported in section 4.2?
8) Do you have considerations to add about the use of materials in smartphones?
9) Do you agree with the substances/parts of concern identified in section 4.2.4 and 4.5.3 or do you have any change/addition to propose?
10) Do you agree with the limiting states and barriers for durability/reparability identified in section 4.4? Do you have additional information (either quantitative or qualitative) to share?

11) Do you agree with the list of priority parts defined in section 4.4, or would you add other parts? Why?

12) Do you agree with the measures (and the related assessment and verification methods) that are described in the report to improve the material efficiency of smartphones? Do you have any deletions/modifications/additions to propose?

- *Reduction of the direct consumption of materials (4.2.5);*
- *Increase of the durability of the device (4.4.2);*
- *Increase of the reparability and upgradability of the device (4.4.3);*
- *Improvement of the recyclability of the device (4.5.5)*
- *System overview (6)*

13) With respect to the question above, how would you calibrate the ambition level for key measures to differentiate between:

- *MUST conditions: all products on the market should fulfil such characteristic;*
- *NICE TO HAVE conditions: front-runner products should fulfil such characteristic.*

14) With respect the questions above, and to the information reported in section 4.6, do you have any additional indications to provide about possible trade-offs associated to different material efficiency strategies?

Section 5

15) Do you agree with the main assumptions made for this LCA/LCC application? If not, what did you change and why?

16) A model of BOM to use for LCA/LCC is reported in section in section 5.3.4.1. The intention is to find a balance between comprehensiveness and complexity and focus on a representative number of key parts. Do you agree with the model and which simplifications/changes would you suggest?

17) What is the influence of battery performance/technology and user behaviour on the energy consumption of a smartphone during the use phase? Which factor is more important?

18) How the housing of a smartphone could change in terms of type and mass of materials?

19) How the weight of a screen/display and of a battery can vary depending on the size/technology?

20) Is the list of electronics complete and plausible or would you modify it?

21) Can other parts be modelled as electro-mechanics or as cluster(s) of generic parts? Which one(s)?
22) Are there technology relevant differentiations that you would suggest to analyse?
23) Do you have LCI datasets to recommend?
24) Do you agree with the scenario of assessment presented? Are there any additional scenarios that you would propose and why?
25) Do you agree with the technical and economic assumptions made for the assessment scenarios? Are there additional implications that you would like to point out?
25) How the LCA/LCC modelling could differentiate between recycle/remanufacture?

8 PRELIMINARY CONCLUSIONS

A methodological guidance for the analysis of material efficiency of products, based on technical, economic and environmental information as well as LCA/LCC considerations, has been presented in this report and applied to smartphones.

Apart for handling methodological aspects, the guidance is oriented to the tangible goal of defining possible requirements with which improving the material efficiency of products and contributing to a transition toward a more circular economy.

The application of the guidance to smartphones has allowed the identification of design practices which can support an improvement in the material efficiency of the product by:

- Reducing the direct consumption of materials;
- Increasing the durability, reparability and upgradability of the device;
- Improving the recyclability of the device.

Such measures also include considerations on critical raw materials and software, as well as the provision of information to users.

It is anticipated that durability could be one the most important aspect to tackle for smartphones. In this respect, apart from the hardware, also user behaviour and software can play an important role. However, the analysis has still to be completed with LCA/LCC calculations and further input form stakeholders.

Final results of the study can be used for integrating circular economy aspects in the design of smartphones, for feeding standardisation work and policy discussion on ICT products, as well as for supporting the revision of the Methodology for the Ecodesign of Energy-related Products (MEErP).

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ANNEX I – ECOLABELLING REQUIREMENTS FOR SMARTPHONES

The following tables summarises the requirements that smartphones have to fulfil to be labelled according to Blue Angel (Table 30), TCO (

Table 31) and EPEAT (Table 32).

Table 30: Requirements for the award of the Blue Angel to mobile-phones

Aspect	Requirement
3.1 Battery State-of-Charge Indicator	The mobile phone must have an integrated charge indicator indicating the current state of battery charge during use and charging. Also, the device must show in a clear manner that the charging has been completed.
3.2External Power Supply	The applicant shall provide a distribution channel for the mobile phone through which the mobile phone is marketed without an external power supply

3.3Secondary Batteries	
3.3.1Replaceability of the battery	The mobile phone shall be designed so as to allow the user to replace the rechargeable battery without special expert knowledge and without damaging the telephone.
3.3.2 Battery Capacity	The battery capacity shall be measured in accordance with paragraph 7.3.1 „Discharge performance at 20 °C (rated capacity)“ of EN 61960 standard „Secondary cells and batteries containing alkaline or other non-acid electrolytes - Secondary lithium cells and batteries for portable applications“, as amended (current version: DIN EN 61960:2012-04). The rated 9/24 DE-UZ 106 Edition July 2017 capacity (C) thus determined must be at least as high as the nominal capacity (N) indicated on the battery and in the product documents.
3.3.3 Battery Marking	The battery (or battery pack) must be marked in accordance with EN 61960 providing at least the following information: • nominal capacity (N), • nominal voltage, • type designation, • date of manufacture (may be coded). These specifications (except for the date of manufacture) shall also be given in the product documents. In case the date of manufacture is coded the product documents shall include instructions for decoding. In addition, the battery (or battery pack) shall be marked with an international recycling symbol as given in ISO 7000 (Graphical symbols for use on equipment) and specify the cell chemistry of the battery (e.g. Li-Ion, Ni-MH). This symbol shall be colour-coded in accordance with the recommendations of the Battery Association of Japan15 or the draft IEC 62902 standard
3.3.4 Durability of the Battery	The battery must achieve a minimum of 500 full charge cycles: full charge cycles ≥ 500. A full charge cycle is to be understood as the drain of a quantity of electricity (in ampere hours) from the battery to the amount of its nominal capacity (N) that has been stored in the battery by one or more charging processes. The minimum number of full charge cycles achievable shall be specified in the product documents. After 500 full charge cycles the battery must, in addition, have in a fully charged state, a remaining capacity (QRem) of at least 90 percent of the nominal capacity (N). QRem ≥ 90% * N Full charge cycles shall be calculated and remaining capacity shall be measured in accordance with the requirements set out in Appendix A.
3.3.5 Battery Safety	The batteries must meet the test requirements of EN 62133-2 "Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications – Part 2: Lithium systems", as amended.

3.4 Longevity 3.4.1 Warranty	The applicant undertakes to offer a free minimum 2-year warranty on the mobile phone, except for the batteries. In addition, the applicant shall offer a free minimum 1-warranty on the battery which covers a remaining capacity of at least 90%, provided that the phone is properly used and charged with the manufacturer's own or another suitable charging device. The product documents shall provide details of such warranties.
3.4.2 Availability of Spare Parts and Repair	The applicant undertakes to make sure that the availability of spare parts for device repair is guaranteed for at least 3 years from the time that production ceases. Spare parts shall be offered at reasonable prices by the manufacturer itself or a by third party. Spare parts are those parts which, typically, may fail or break down within the scope of the ordinary use of a product, especially batteries, displays and front glasses. The mobile phones shall be so designed as to enable qualified specialist workshops to replace such spare parts with reasonable effort. The product documents shall provide information on spare parts supply and repair services.
3.4.3 Software Updates	The device shall come with a free function to allow the user to update the operating system. The aim of these updates is, above all, the closing of security holes, as well as other software updates, if applicable. The applicant undertakes to offer security updates for the operating system of the mobile phone to be eco-labelled for at least 4 years from the time that production ceases.
3.4.4. Data Deletion	To allow reuse of the device it shall be designed so as to enable the user to completely and securely delete all personal data without the help of pay software. This can be accomplished by either physically removing the memory card or the use of free manufacturer-provided software. As an alternative to removing the data, it shall also be possible to encode the personal data on the data medium by means of software provided, thus allowing a secure deletion of the key. In addition, the device shall include a software function that resets the device to its factory settings. The product documents shall include detailed instructions on how to securely delete data and how to reset the device to its factory settings.
3.5 Take Back and Recycling 3.5.1 Take Back	The applicant shall operate its own take-back scheme for mobile phones to direct all collected devices to reuse or professional recycling. The applicant shall actively communicate this system to its customers. This take-back scheme can be based on collections at the branches, return campaigns, deposit systems or the like. A mere reference to the collection governed by the Elektro- and Elektronikgesetz (ElektroG) (Electrical and Electronic Equipment Act) would not be sufficient. The collection system can be organised by the applicant itself, by contracting partners and/or together with other manufacturers of mobile phones.
3.5.2 Recyclable Design	An efficient removal of the secondary batteries for recycling purpose shall be possible with no special knowledge being required (guidance value: in no more than 5 seconds). The battery chemicals must be prevented from leaking during the removal.

3.6 Material Requirements 3.6.1 Plastics used in Housings and Housing Parts 3.6 Use of Biocidal Silver	The plastics used in housings and housing parts must not contain, as constituent components, any substances with the following characteristics16: 1. Substances that have been identified as substances of very high concern according to Regulation (EC) No 1907/2006) (REACH6) and have been included in the list (so-called Candidate List) set up in accordance with REACH, Article 59(1).17. 2. Substances that have been classified according to the CLP Regulation18 in the following hazard categories or meet the criteria for such classification19: carcinogenic of category Carc. 1A or Carc. 1B mutagenic of category Muta. 1A or Muta. 1B reprotoxic of category Repr. 1A or Repr. 1B Halogenated polymers shall not be permitted in housings and housing parts. Nor may halogenated organic compounds be added as flame retardants. Nor shall any flame retardants be permitted which are classified under the CLP Regulation as carcinogenic of Category Carc. 2 or as hazardous to waters of Category Aquatic Chronic 1. The hazard statements (H-phrases) assigned to the hazard categories can be seen from Appendix 2: „Assignment of Hazard Categories and Hazard Statements“. The following shall be exempt from this requirement: • fluoroorganic additives (as, for example, anti-dripping agents) used to improve the physical properties of plastics, provided that they do not exceed 0.5 weight percent; • plastic parts weighing 10 grams or less, where - with regard to multiple part housings - the total weight of all parts made of the same plastic shall be the decisive factor in determining the mass. The use of biocidal silver on touchable surfaces shall not be permitted. .
3.7 Electromagnetic Radiation	Devices to be Blue Angel eco-labelled shall be designed so as to make sure that - when used at the ear - the specific absorption rate (SAR) induced by the radio-frequency electromagnetic radiation emitted does not exceed 0.5 watts per kg and - when used near the body - 1.0 watt per kg - locally averaged over 10 grams of tissue.
3.8 Additional Functions	The mobile phone must provide the technical tools needed to make phone calls without holding the mobile phone close to ear or mouth. To achieve this aim the mobile phone 1. must be equipped with an interface for connecting a headset (combination of headphones and microphone) and 2. offer a speakerphone function.

3.9 Social Corporate Responsibility 3.9.1 Due Diligence for Conflict Minerals	As regards the conflict minerals used in mobile phones, such as tin, tantalum, tungsten and their ores as well as gold the applicant shall perform its corporate due diligence by complying with the „OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas“[22,23]. The applicant shall present a list of the components that contain the predominant mass fraction in relation to the respective conflict mineral. The applicant shall name the supplier and the respective supply chain scheme or project for each component to ensure responsible sourcing of conflict minerals used in the mobile phone. In addition, the applicant shall support at least one of the initiatives listed in Appendix C which promotes responsible sourcing and trading of the above-mentioned minerals in line with OECD Guidance.
3.9.2 Working Conditions	Fundamental principles and universal human rights as stipulated by the applicable core labour standards of the International Labour Organisation[24] (ILO) must be observed during the final assembly of Blue Angel eco-labelled products. Employee rights and benefits shall apply to all forms of employment, including atypical forms of employment, such as part-time work, piecework, seasonal workers or home workers as well as to employees of subcontractors and those employed by subcontract. All workers shall receive a written employment contract that is in line with the legal provisions. The applicant shall ensure compliance with the following core labour standards: i) Conventions against child labour: - Minimum Age Convention, 1973 (No. 138) - Worst Forms of Child Labour Convention, 1999 (No. 182) ii) Conventions against forced and compulsory labour: - Forced Labour Convention, 1930 (No. 29) and the protocol of 2014 to the Forced Labour Convention - Abolition of Forced Labour Convention, 1957 (No. 105) iii) Freedom of association and the right to collective bargaining: - Freedom of Association and Protection of the Right to Organise Convention, 1948 (No. 87) - Right to Organise and Collective Bargaining Convention, 1949 (No. 98) - If the ILO core labour standards on freedom of association and collective bargaining are not or only insufficiently implemented due to national framework conditions the companies shall provide evidence of their efforts and achievements in supporting freely elected and true workers' representations by presenting relevant documentations in order to verify that concrete measures have been taken to allow independent observers to monitor elections and that measures have been taken to promote a constructive dialogue between workers/workers' representations and the management. iv) Conventions against discrimination: - Equal Remuneration Convention, 1951 (No. 100) - Discrimination (Employment and Occupation) Convention, 1958 (No. 111) In addition to the ILO core labour standards compliance with the following additional ILO conventions shall be ensured during the final assembly: v) Adequate hours of work and remuneration: - Hours of Work (Industry) Convention, 1919 (No. 1) Minimum Wage Fixing Convention, 1970 (No. 131) Living wages: The applicant shall make every effort that wages paid for a standard working week at least meet legal or industry standards and are always sufficient to meet the basic needs of personnel and provide some discretionary income. vi) Protection of health and safety: Occupational Safety and Health Convention, 1981 (No. 155) Chemicals Convention, 1990 (No. 170) (Convention concerning Safety in the use of Chemicals at Work).

3.10 Operating Instructions	The product documents included with the devices shall include both the technical specifications and the user information relating to environment and health. They shall be either installed on the mobile phone, easily accessible on the Internet or supplied as a data medium or in printed form together with the device. The product documents shall include and manufacturer's website shall allow easy access to the following basic user information: 1. Information on the significance and correct interpretation of the state-of-charge indicator (cf. para. 3.1). 2. Instructions to disconnect the charger from the mains upon completion of the charging process in order to reduce no-load losses. 3. Instructions that charging on non-used PCs should be avoided in order to reduce power consumption during charging. 4. Instructions for using a proper charging unit. 5. Information on how to extend the battery life. 6. Instructions for replacing the battery (cf. para. 3.3.1). 7. Specification of nominal capacity, nominal voltage and type designation of the battery as well as information on the recycling process (cf. para. 3.3.3) 8. Indication of the number of full-charge cycles achievable (cf. para. 3.3.4). 9. Information on the warranty periods for mobile phone and battery as well as on the warranty terms (cf. para. 3.4.1). 10. Information on the availability of spare parts and repair services (cf. para. 3.4.2). 11. Information on software updates (cf. para. 3.4.3). 12. Information on secure data deletion and the reset function to restore factory settings (cf. para. 3.4.4). 13. Information on environmental and resource significance of proper product disposal as well as information on the take-back scheme (cf. para. 3.5.1). 14. Information on an environmentally sound disposal at the end of use in accordance with the German Elektrogesetz (Electrical and Electronic Equipment Act) as well as instructions that the battery should not be disposed of as normal household waste but instead should be taken to a battery collection facility. 15. Specification and explanatory information on the SAR data (cf. para. 3.7). 16. Information on how to reduce health effects from radio waves when using the mobile phone, at least by recommending the use of headset or speakerphone function (cf. para. 3.8).
3.12 Outlook on Possible Future Requirements	A future revision of these Basic Criteria is expected to further toughen the requirements for social corporate responsibility. For this purpose, additional conflict-affected ores will probably be added to the list of conflict minerals (currently: tin, tantalum, tungsten and gold) and the criteria for social working conditions (currently: final assembly plants) will have to be met by additional plants along the supply chain (e.g. component suppliers). Also, the availability of spare parts is expected to be extended from 3 to 4 years.

1183

Table 31: Requirements and related background information for TCO Certified Smartphones.

Aspect	Background	Requirement
A.1.1. Information to End-Users	It is important that the purchaser of a product that has been certified in accordance with TCO Certified Smartphones receive information concerning the quality, features and capabilities of the product. This information is based on the viewpoint from the user's perspective that TCO Development represents.	An information document called 'TCO Certified Document' provided by TCO Development shall accompany the product to describe why these particular criteria have been chosen for the products within the TCO Certified program, and what is expected to be achieved by them.
A.2 Visual ergonomics	Good visual ergonomics is a very important aspect of quality that can also have a direct effect on the health, comfort and performance of the user. Good ergonomics, such as a high quality display image, can also influence our productivity and extend the usable life of a product. In this way, ergonomic design can also offer sustainability benefits.	
A.2.1 Luminance characteristics		
A.2.1.1 Luminance level	Luminance being emitted from a particular area is a measure of the luminous intensity per unit area of light travelling in a given direction and falls within a given solid angle. The unit of luminance is cd/m2. It shall be possible to set the luminance level according to the lighting conditions of the surroundings. Poor luminance can lead to low contrast and consequently affect legibility and colour discrimination and thus lead to misinterpretations. It shall be possible to set a sufficiently high luminance level with respect to the ambient lighting in order to present a comfortable viewing situation and to avoid eyestrain.	The following conditions shall be fulfilled: - The maximum white luminance shall be ≥ 200 cd/m2 at 80% image loading. - The minimum white luminance shall be ≤ 100 cd/m2 at 80% image loading

<table>
<tr><td>A.2.1.2 Luminance uniformity</td><td>Luminance uniformity is the capacity of the display to maintain the same luminance level over the whole active screen area. The luminance uniformity is defined as the ratio of maximum to minimum luminance within the fully active screen area.
Image quality is badly affected by non-uniform luminance. When poor luminance uniformity is visible, it can locally affect the contrast and consequently the legibility of information on the display. The areas of deviating luminance can have different sizes and cause varying contour sharpness.</td><td>Luminance variation across the active screen, the Lmax to Lmin ratio, shall be ≤ 1.20</td></tr>
<tr><td>A.2.1.3 Greyscale gamma curve</td><td>Greyscale gamma curve is the capability of the imaging device to maintain the original greyscale luminance of a greyscale pattern at all tested greyscale levels.
A TCO Certified Smartphone shall be delivered with a sufficiently accurate calibrated gamma curve in default pre-set since it makes it easier to distinguish between different light levels in the display image. A well-tuned greyscale is the basis for accurate detail rendering of any imaging device. The greyscale rendering is measured via a number of steps in a greyscale in the test image. Each greyscale step, regardless of grey level, shall have a relative luminance close to what is specified by common video standards sRGB and ITU Rec709 in order to give accurate rendering of the greyscale of the original image.</td><td>The different grey scale luminance levels shall be within the Max- and Min levels according to the table below, where 100% means the luminance level measured for white, RGB 255, 255, 255.
<table>
<tr><th>Grey level</th><th>L_{sRGB} %</th><th>L_{max} %</th><th>L_{min} %</th></tr>
<tr><td>255</td><td>100</td><td>100</td><td>100</td></tr>
<tr><td>225</td><td>75</td><td>80</td><td>71</td></tr>
<tr><td>195</td><td>55</td><td>62</td><td>48</td></tr>
<tr><td>165</td><td>38</td><td>47</td><td>30</td></tr>
<tr><td>135</td><td>24</td><td>33</td><td>18</td></tr>
<tr><td>105</td><td>14</td><td>22</td><td>9</td></tr>
<tr><td>75</td><td>7</td><td>13</td><td>4</td></tr>
<tr><td>45</td><td>3</td><td>6</td><td>1</td></tr>
</table></td></tr>
<tr><td>A.2.2 Screen colour characteristics</td><td></td><td></td></tr>
</table>

A.2.2.1 Correlated colour temperature, CCT variation	The correlated colour temperature (CCT) is the temperature of the Planckian radiator whose perceived colour most closely resembles that of a given stimulus at the same brightness and under specified viewing conditions. It is expressed in kelvin (K). The colour of a white area in nature could be neutral, warmer or colder dependent of e.g. the weather and lighting conditions. This is called the colour temperature of the white. The colour temperature of the display should be about the same as of the ambient lighting conditions. This makes it possible to more accurately evaluate the colour of an image on the display compared to real scenes or prints. Normal daylight has a correlated colour temperature in the range 5000 – 10000 K.	The default correlated colour temperature of the active display shall be in the range 5000K to 10000K.
A.2.2.2 Colour uniformity	The colour uniformity of a display is the capability to maintain the same colour in any part of the screen. The human visual system is very sensitive to changes in colour hue in white and grey areas. Since the white or grey colour hues are the background on which most colours are judged, the white or grey areas are the reference colours on the screen. Patches of colour variation on an active white or grey screen could reduce the contrast locally, be disturbing and affect the legibility, colour rendering and colour differentiation.	The maximum colour deviation between measured active areas on the screen that are intended to maintain the same colour shall be $\Delta u'v' \leq 0.012$

<table>
<tr><td>A.2.2.3 RGB settings</td><td>The RGB colour model is an additive colour model in which red, green, and blue light are added together in various ways to reproduce a broad array of colours.
Accurate colour rendering is important when realistic colour images or colour presentations are presented on the display. Poor colour rendering can lead to poor legibility and misinterpretation. The u' and v' chromaticity co-ordinates of the primary colours red (R), green (G) and blue (B) of the screen shall aim at values given in international IEC, EBU and ITU standards. The u' and v' chromaticity co-ordinates of the primary colours R, G and B form a triangle in the CIE 1976 uniform chromaticity scale diagram. The larger the area of the triangle, the wider the range of colours the screen is capable of presenting.
The colour characteristics of a display are based on the visual appearance of the display's primary colour stimuli, the R, G, B-stimuli.</td><td>The minimum colour triangle shall have the following coordinates:
<table>
<tr><td></td><td colspan="2">Red</td><td colspan="2">Green</td><td colspan="2">Blue</td></tr>
<tr><td>Co-ordinate</td><td>u'</td><td>v'</td><td>u'</td><td>v'</td><td>u'</td><td>v'</td></tr>
<tr><td>Requirement</td><td>≥ 0.375</td><td>≥ 0.503</td><td>≤ 0.160</td><td>≥ 0.548</td><td>≥ 0.135</td><td>≤ 0.305</td></tr>
</table></td></tr>
<tr><td>A.3 Workload ergonomics</td><td></td><td></td></tr>
<tr><td>A.3.1 Material Characteristics</td><td>Normal use is considered as the operation descriptions given in the product's user manual/guides.
Skin allergies, in the form of rash or inflammation, may happen when the skin comes in contact with substances that irritate the skin. It is medically termed as 'contact dermatitis'. Nickel is a well-known contact allergen and irritant, which may cause skin reactions upon exposure, including itching, irritation, inflammation or the appearance of rashes.</td><td>The Smartphone shall not release nickel from the surfaces that come in contact with user´s skin during normal use</td></tr>
<tr><td>A.3.2 Headset</td><td>A headset is headphones combined with a microphone, or one headphone with a microphone.
A headset provides hands-free smartphone communication. This has many benefits, especially in call centers and other telephone-intensive jobs and for anybody wishing to have both hands free during a telephone conversation. It also reduces the emissions from the smartphone towards the head as it can be placed further away from the head while making a call.</td><td>The Smartphone shall be delivered with a headset to be used for audio communication over the cellular network.</td></tr>
</table>

A.5 Electrical Safety		
A.5.1 Electrical Safety	Electrical safety concerns the electrical design of apparatus with respect to its electrical insulation and other arrangements that are intended to prevent accidents resulting from contact with live components, and the risk of fire or explosion as a result of electrical flash-over due to inadequate or faulty electrical insulation.	The Smartphone and the internal or external power supply/supplies shall be certified in accordance with EN/IEC 60 950 or EN/IEC 60065 or EN 62368-1.
A.6 Environment	This section details the environmental criteria in TCO Certified, which offer a unique, integrated balance of environmental issues in the manufacturing, use and end of life phases of the product. The environmental criteria are divided into the following sections: 1. Manufacturing – criteria focusing on the manufacturing phase and environmental management 2. Climate – energy consumption, one of the most important issues in the environmental impact of IT products. 3. Hazardous Substances – heavy metals, flame retardants, plastics. 4. Material resource efficiency – factors to extend the life of the product and influence better use of material resources. 5. End of life – factors to stimulate recycling and minimize the impact of e-waste. Potential environmental effects are evident at each stage of the product life cycle. The environmental criteria TCO Development has focused on in this document are those that we consider most relevant to the product group. They have also proved to be attainable in volume manufacturing and are verifiable. Future criteria updates will likely focus on the manufacturing phase, hazardous substances and climate issues. Compliance with these criteria is verified by sending the requested information to a verifier approved by TCO Development.	

A.6.1 Product description	The aim of this product description is to provide third party verified information about the product. The information is used by TCO Development to verify that the product complies with the criteria in TCO Certified. The information is also provided on the certificate to buyers so that it helps them calculate the sustainability impact of the products and the benefit of buying products that fulfil TCO Certified. Using the declared sustainability information a buyer can, for example, implement climate compensation or other sustainability-related measures connected to the sustainability impact of the product. This data is often used by organisations in their annual sustainability report or internal programs aimed at minimizing the environmental impact of IT. Recycled plastic is post-consumer recycled plastic, which has been used in products. Plastic parts are all product parts made out of plastic except panels, electronic components, cables, connectors, PWBs, insulating mylar sheets and labels. This is primarily due to insufficient available alternatives. This also means that the weight of these items is not included when calculating the total weight of the plastic in the product in this requirement. Marking plate /Marking label is the label that contains the product's electrical rating in terms of voltage, frequency, current and the manufacturer's name, trademark or identification mark together with the manufacturer's model or type reference. The label shall be in accordance with IEC 60 950:1 clause 1.7.1.	A product declaration shall be provided for the Smartphone. The following information shall be verified by the third party facility and is printed by TCO Development on the certificate.
A.6.2 Manufacturing		

A.6.2.1 Environmental management system certification	Manufacturing plant: Manufacturing facility where the final assembly of the TCO Certified product takes place. A certified environmental management system shows that the company has chosen to work in a systematic way with constant improvement of the environmental performance of the company and its products. A certified environmental management system includes external independent reviews.	Each manufacturing plant must be certified in accordance with ISO 14001, or EMAS registered. If the product is manufactured by a third party, it is this company that shall be certified or registered.
A.6.3 Climate		
A.6.3.1 Energy consumption	Energy is the single most important topic in the issue of climate change. Energy efficient equipment is an important and effective way to fight climate change. With an ever-increasing volume of IT equipment in use, the efficiency of each product is vital. To reduce energy consumption from the Smartphone the external power supply shall comply with the International Efficiency Marking Protocol for External Power Supplies.	The external power supply shall meet at least the International Efficiency Protocol requirement for level V.
A.6.4 Hazardous substances		
A.6.4.1 Cadmium (Cd), mercury (Hg), lead (Pb) and hexavalent chromium (CrVI)	The effects of cadmium, mercury, lead and hexavalent chromium are well documented as substances that are hazardous to both our health and the environment. Electronic devices contain hazardous substances like heavy metals and brominated flame retardants. This causes problems both in the use phase (additives can leak from the plastic and accumulate in dust, harming both our health and the environment) and at end-of-life, where uncontrolled recycling can cause the release of toxins such as dioxins and furans. This criterion is harmonized with EU RoHS2 Directive (2011/65/EU), except that TCO Certified does not allow mercury in the display panel backlight. As TCO Certified is a global label this also affects products sold outside the EU.	The Smartphone shall not contain cadmium, mercury, lead and hexavalent chromium.

A.6.4.2 Halogenated substances	Halogenated flame retardants and plasticizers are often persistent, can bio-accumulate in living organisms and have been detected in both humans and the environment. These substances are problematic in the manufacturing and end of life phases where workers or the environment can be exposed. They can also migrate from the products during the use phase with unknown health effects as a result. Plastic parts are parts made mainly of plastics, e.g. the housing. Parts containing other materials in any significant amounts, e.g. cables with metal conductors, are not included in the definition. Printed wiring board laminate is a printed board that provides point-to-point connections but not printed components in a predetermined configuration on a common base. Halogens are a group of five chemically related non-metallic elements in the Periodic Table; fluorine, chlorine, bromine, iodine and astatine. Polybrominated biphenyls (PBB) and Polybrominated diphenyl ethers (PBDE) are restricted in the RoHS directive (2002/95/EC) due to the hazardous properties of these substances. Hexabromocyclododecane (HBCDD) has been identified as a Substance of Very High Concern in accordance with EU REACH criteria due to PBT (persistent, bio accumulative, toxic) properties.	1. Plastic parts weighing more than 5 grams shall not contain flame retardants or plasticizers that contain halogenated substances. Note: This applies to plastic parts in all assemblies and sub-assemblies. Exempted are printed wiring board laminates, electronic components and all kinds of cable insulation. 2. The Smartphone shall not contain PBB, PBDE and HBCDD. Note: This applies to components, parts and raw materials in all assemblies and sub-assemblies of the product e.g. batteries, paint, surface treatment, plastics and electronic components.

A.6.4.3 Non-halogenated substances	The purpose of this mandate is to increase the knowledge of substances with regards to their human and environmental impacts and to drive a shift towards less hazardous alternatives. These substances may be problematic in the manufacturing and end of life phase where workers or the environment can get exposed and can also migrate from the products during the use phase with unknown health effects as a result. The mandate uses the hazard assessment and decision logic framework called GreenScreen™ for Safer Chemicals developed by the non-profit organization Clean Production Action (CPA). The GreenScreen methodology can be used for identifying substances of high concern and safer alternatives. The GreenScreen criteria are in line with international standards and regulations including the Globally Harmonized System of Classification and Labelling of Chemicals (GHS), OECD testing protocols and the European REACH Regulation. The U.S. EPA's Design for Environment (DfE) Alternatives Assessment is also an important influence on the GreenScreen™ for Safer Chemicals. Plastic parts are parts made mainly of plastics, e.g. the housing. Parts containing other materials in any significant amounts, e.g. cables with metal conductors, are not included in the definition. Printed wiring board laminate is a printed board that provides point-to-point connections but not printed components in a predetermined configuration on a common base. Licenced Profilers are organisations approved by CPA with the capacity to provide GreenScreen assessments. Accepted substances are considered the most sustainable alternatives which are possible for the industry to use, also taking into consideration aspects such as availability and functionality. Accepted substances are found on the TCO Development website under 'Accepted Substances list'.	Non halogenated flame retardants used in plastic parts that weigh more than 5 grams shall be on the publically available Accepted Substance List for TCO Certified. This means that the substance has been assessed by a licensed profiler according to GreenScreen™ and been assigned a benchmark score ≥ 2 The following acceptance decisions apply to substances given Benchmarks 4, 3, 2, 1 or designated U (undefined): 4: Accepted – (Few concerns) 3: Accepted – (Slight concern) 2: Accepted – (Moderate concern) 1: Not accepted - (High concern) U: Not accepted - (Unspecified) All substances of a flame retardant mixture shall be accounted for. Non-accepted components shall not exceed concentration levels of 0.1% by weight of the flame retardant. Exempted are printed wiring board laminates, electronic components and all kinds of cable insulation. A grace period for the above may be granted, see B.6.4.3 for rules TCO Development will conduct spot-checks and require full disclosure of the flame retardants, including CAS number, used in the product to verify that the obligations according to this mandate are fulfilled.

A.6.4.4 Halogenated plastics	PVC is by far the most common halogen containing plastic. There are however other plastics that contain halogens in the plastic itself. Halogens are problematic from both a health and environmental perspective throughout the product life cycle and should be phased out. Plastic parts are parts made mainly of plastics, e.g. the housing. Parts containing other materials in any significant amounts, e.g. cables with metal conductors, are not included in the definition. Printed wiring board laminate is a printed board that provides point-to-point connections but not printed components in a predetermined configuration on a common base. Halogens are a group of five chemically related non-metallic elements in the Periodic Table; fluorine, chlorine, bromine, iodine and astatine.	Plastic parts in the Smartphone weighing more than 5 grams shall not contain intentionally added halogens as a part of the polymer. Note: Printed wiring board laminates, and all kinds of internal and external cable insulation are not considered to be part of plastic parts and are therefore not included in the mandate.
A.6.4.5 Phthalates	Phthalates are substances mainly used as plasticizers. The substances restricted in the mandate are listed as Substances of Very High Concern and are included in REACH Annex XIV classified as toxic to reproduction. These substances are problematic from both a health and environmental perspective throughout the product life cycle and should be phased out.	The Smartphone shall not contain Bis (2-ethylhexyl) phthalate (DEHP), Butyl benzyl phthalate (BBP), Dibutyl phthalate (DBP), and Diisobutyl phthalate (DIBP). No parts of the product are exempted. Also diisononyl phthalate (DINP, CAS no. 28553-12-0), diisodecyl phthalate (DIDP, CAS no. 26761-40-0) and di-n-octyl phthalate (DNOP, CAS no. 117-84-0)
A.6.4.6 Hazardous substances in product packaging	Packaging constitutes a well-known environmental problem and is regulated in many countries worldwide. Packaging material has a short lifetime and generates large volumes of waste. There are three main areas of concern, content of hazardous substances, use of resources and transport volume.	The packaging material shall not contain lead (Pb), cadmium (Cd), mercury (Hg) or hexavalent chromium (Cr6). Plastic packaging material shall not contain organically bound halogens.

A.6.4.7 Batteries	The widespread use of batteries has given rise to many environmental concerns, such as toxic metal pollution, as they may contain very high amounts of lead, cadmium and mercury. Used batteries also contribute to electronic waste. In the United States, the Mercury-Containing and Rechargeable Battery Management Act of 1996 banned the sale of mercury-containing batteries, enacted uniform labeling requirements for rechargeable batteries, and required that rechargeable batteries be easily removable. The Battery Directive of the European Union has similar requirements, in addition to requiring increased recycling of batteries. Note that restrictions on hazardous substances in batteries are covered by A.6.4.1 Hazardous substances	Batteries shall be rechargeable and when necessary, replaceable by the end user or a qualified professional.
A.6.5 Material Resource Efficiency		

A.6.5.1 Lifetime extension	A longer product lifetime makes a significant positive contribution to more efficient resource use as well as the reduction of air and water pollution. A pre-condition for prolonged lifetime is that the product is of high quality, which is supported by good warranties. Another requirement is the availability of spare parts for a number of years once the product is taken out of production. During this period, products should, if possible, be repaired and not replaced. Brand owner: The company or organization owning or controlling the Brand Name. Brand Name: The name or sign, including but not limited to a trademark or company name, used to identify, amongst users and customers, the manufacturer or seller of a product. Product Warranty is a period where the Brand owner offers to repair or replace broken products during a period of time at no charge. Spare parts are those parts that have the potential to fail during normal use of the product. Product parts whose life cycle usually exceeds the average usual life of the product need not be provisioned as spare parts. When the cost for replacing a broken part (e.g. panel) exceeds the cost of replacing the whole product, then that part need not be considered as a spare part under this mandate.	1. The brand owner shall provide a product warranty for at least one year on all markets where the product is sold. 2. The brand owner shall guarantee the availability of spare parts for at least three years from the time that production ceases. Instructions on how to replace these parts shall be available to professionals upon request.
A.6.6 End of life		

A.6.6.1 Material coding of plastics	Prolonging the life of IT-products by reuse is the best way to minimize their environmental impact. But when this is no longer possible, it is important to facilitate material recycling of the products. Material coding of plastics aims at making the recycling of plastics easier so that the plastic can be used in new IT equipment. Plastic parts are parts made mainly of plastics, e.g. the housing. Parts containing other materials in any significant amounts, e.g. cables with metal conductors, are not included in the definition. Printed wiring board laminate is a printed board that provides point-to-point connections but not printed components in a predetermined configuration on a common base.	Plastic parts weighing more than 5 grams shall be material coded in accordance with ISO 11469 and ISO 1043-1, -2, -3, -4. Exempted are printed wiring board laminates.

A.6.6.2 Take back system	The amount of electronic waste in the world today is enormous and a growing environmental problem. It is important that manufacturers provide mechanisms to take back their equipment at end-of-life under the principle of individual producer responsibility wherein each manufacturer must be financially responsible for managing its own branded products at end-of-life. Currently much electronic waste is being exported to developing countries where it is managed unsustainably and disproportionately burdens those regions with this global environmental problem. The Basel Convention and its decisions govern the export of many types of electronic waste, however it is not properly implemented in all countries. With this mandate TCO Development aims to influence the expansion of better electronic waste management practices to more countries. Brand owner is the company that owns the brand name visible on the product. Take back system is a system that makes sure that the customer can return used products to be recycled. The system can be with or without a fee. Environmentally acceptable recycling methods are: • Product and component reuse • Material recycling with secured handling of hazardous chemicals and heavy metals • Pollution-controlled energy recovery of parts of the product	The brand owner (or its representative, associated company or affiliate) shall offer their customers the option to return used products for environmentally acceptable recycling methods in at least one market where the product is sold and where electronics take back regulation is not in practice at the date of application.
A.6.6.3 Preparation for recycling of product packaging material	Packaging constitutes a well-known environmental problem and is regulated in many countries worldwide. Packaging material has a short lifetime and generates large volumes of waste. There are three main areas of concern; hazardous substance content, use of resources and transport volume. Brand owner is the company that owns the brand name visible on the product.	Non-reusable packaging components weighing more than 5 grams shall be possible to separate into single material types without the use of tools. Exempted is reusable packaging.

A.7 Socially responsible manufacturing	Shorter product cycles and growing demand for new technologies put increasing pressure on industry and its complex supply chain to deliver new devices faster and at a low cost. The result is often inadequate working conditions at manufacturing facilities, long working hours, low wages and a lack of health and safety measures. TCO Development aims for greater brand engagement throughout the supply chain by setting criteria and verification routines that create strict social policies toward suppliers, as well as factory audit structures and an open dialog within the IT industry.	

A.7.1 Supply chain responsibility	It is TCO Development's opinion that codes of conduct and factory audits are currently the tools that are most practical to help the majority of brands to work with socially responsible manufacturing in a structured way. It is also TCO Development's opinion that these tools are improving the situation incrementally as long as they are used in the correct and committed way by the brand. The contribution of TCO Certified is: • TCO Certified defines a minimum level of the Brand owner's code of conduct. • TCO Certified is a control system to ensure that the brand takes the responsibility and works in a structured way in accordance with their code of conduct. • TCO Certified creates an incentive for Brand owners to work proactively. Brand owner: The company or organization owning or controlling the brand name. First tier manufacturing facility: Manufacturing plant where the final assembly of the TCO Certified product is taking place. Corrective action plan: A list of actions and an associated timetable detailing the remedial process to address a specific problem.	By signing this mandate the Brand owner agrees to the (1. Commitment) and agrees to conduct the (2. Structured work). Additionally TCO Development requires that the Brand owner show (3. Proof) of the commitment and the structured work by allowing random inspections, by sharing audit reports and corrective action plans and by providing other documented proof described below. 1. Commitment: The Brand owner shall have a code of conduct that is considered consistent with the following in the manufacturing of TCO Certified products: • ILO eight core conventions: 29, 87*, 98*, 100, 105, 111, 138 and 182. • UN Convention on the Rights of the Child, Article 32. • Relevant local and national Health & Safety and Labour laws effective in the country of manufacture. *In situations with legal restrictions on the right to freedom of association and collective bargaining, non-management workers must be permitted to freely elect their own worker representative(s) (ILO Convention 135 and Recommendation 143). 2. Structured work: • The Brand owner shall ensure that routines are in place to implement and monitor their code of conduct in the manufacturing of TCO Certified products. • In the final assembly factories the Brand owner shall ensure the implementation of their code of conduct through factory audits. • In the final assembly factories and in the rest of the supply chain the Brand owner shall ensure that a corrective action plan is developed and fulfilled within reasonable time for all violations against their code of conduct that the Brand owner is made aware of. 3. Proof: • TCO Development may conduct/commission random factory inspections (spot-checks) at any final assembly factory manufacturing TCO Certified products for the Brand owner and may require full audit reports during the certification period in order to assess social commitment and advancement. • TCO Development may also require seeing corrective action plans and auditing reports from factories further down the supply chain to ensure that corrective actions have been successfully implemented. • TCO Development additionally requires the documentation below to be verified by a third party approved verifier.

A.7.2 Senior Management Representative	It is beneficial to all parties that an open and transparent dialogue between TCO Development and the Brand owner exists for the monitoring of compliance with the criteria or when issues concerning working conditions at manufacturing facilities require clarification. A contact person responsible for the organization's efforts to enforce the socially responsible manufacturing criteria needs to be consistently available for dialogue with TCO Development throughout the validity of the certificate.	The Brand owner shall have an appointed Senior Management Representative (SMR) who, irrespective of other responsibilities, has the authority to ensure that the social criteria in the manufacturing of TCO Certified products are met and who reports directly to top management. • The contact details of the SMR shall be submitted and the SMR shall be available for dialogue in English with TCO Development throughout the validity of all the Brand owners' certificates. • To ensure that the SMR has the necessary authority and is working in a structured and proactive way implementing the code of conduct, a review of the SMR shall be done every year according to B.7.2.2.
A.7.3 Conflict minerals	The exploitation and trade of the natural resources Tantalum, Tin, Tungsten and Gold (3T+G) from conflict-affected areas is commonly regarded as a major source of conflict financing. TCO Development supports the underlying goal of the EU conflict minerals measures and those contained in the Dodd Frank Act 1502, but believe it is also vital to support in-region responsible sourcing programs in order to help suppliers meet these due diligence requirements, maintain trade and develop mining that directly benefits the people whose livelihoods depend on a legitimate trade. TCO Development now requires all Brand owners who use TCO Certified to address the issue of conflict minerals in their certified products in a progressive and proactive way. Conflict minerals: Tantalum, Tin, Tungsten and Gold = 3T+G DRC: Democratic Republic of the Congo	The Brand owner shall have a public conflict minerals policy and also indicate all the initiatives they are using/funding. It is TCO Developments opinion that the OECD Due Diligence Guidance for Responsible Supply Cain of Conflict-Affected or High-risk Areas is the most ambitious approach in the list. At least one of the following options shall be marked: • A Due Diligence process based on the OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected or High-risk Areas • iTSCi (International Tin Research Institute (ITRI) Tin Supply Chain Initiative). • CFTI (Conflict-free Tin Initiative). • PPA (The Public-Private Alliance for Responsible Minerals Trade). • Other relevant DRC in-region initiative • CFSI (EICC/GeSi Conflict-Free Sourcing Initiative).

Table 32: EPEAT requirements for Mobile Phones.

Area	Requirement
7. Supply Chain Management of Materials	R 7.1.1 Compliance with the European Union REACH Regulation
	O 7.2.1 Reduction of European Union REACH Candidate SVHC Substances
	O 7.3.1 Substitutions assessment
	O 7.4.1 Requesting substance inventory
	O 7.4.2 Receiving substance inventory
8. Sustainable Materials Use	R 8.1.1 Declaration of post-consumer recycled and biobased plastics content
	O 8.1.2 Post-consumer recycled plastic and biobased plastic content in the mobile phone
	O 8.1.3 Post-consumer recycled plastic and biobased plastic content in accessories
9. Substances of Concern	R 9.1.1 Compliance with the European Union RoHS Directive
	R 9.2.1 Restrictions of extractable nickel
	O 9.2.2 Restrictions of DEHP, DBP, and BBP product
	O 9.2.3 Restriction of bromine and chlorine
	R 9.2.4 Restriction of cadmium and mercury in the mobile phone battery cell
	R 9.2.5 Restriction of substances in textile and leather
10. Energy Use Requirements	R 10.1.1 Battery charger systems
	O 10.1.2 Reduction of energy consumption of battery charging systems
	R 10.1.3 External power supply energy efficiency
	O 10.1.4 Reduced maintenance mode power
11. End of Life Management	R 11.1.1 Take-back program
	R 11.2.1 Primary recyclers third party certified
	R 11.3.1 Battery removability/replacement by qualified repair service providers or authorized repair providers
	O 11.3.2 Battery removability/replacement instructions
	O 11.3.3 Battery removability/replacement without use of tools
	R 11.4.1 Ease of disassembling mobile phone
	O 11.4.2 Further ease of disassembling mobile phone
	R 11.5.1 Feature to erase user data from mobile phone
	R 11.6.1 Repair and refurbishment
	O 11.6.2 Further repair and refurbishment
	R 11.7.1 Availability of replacement parts
	R 11.8.1 Notification regarding and the identification of materials and components requiring selective treatment
12. Packaging	O 12.1.1 Use of recyclable fiber based packaging materials

	R 12.2.1 Separability and labelling of plastics in packaging
	O 12.3.1 Use of post-consumer recycled plastic packaging
	R 12.4.1 Expanded polystyrene packaging (EPS) restriction
	R 12.5.1 Recycled content in fiber packaging
	O 12.6.1 Environmentally preferable paper/paperboard in POS packaging
	O 12.6.2 Environmentally preferable paper/paperboard for printed content
	R 12.7.1 Restriction of chlorine in packaging materials
	R 12.8.1 Heavy metal restriction in packaging
	O 12.9.1 Improve packaging efficiency
13. Corporate Sustainability	R 13.1.1 Corporate sustainability (CS) reporting
	O 13.2.1 Corporate sustainability (CS) reporting in the supply chain
	O 13.3.1 Third party assurance of corporate sustainability (CS) reporting
14. Life Cycle Assessment	O 14.1.1 Conducting a life cycle assessment
	O 14.2.1 Product LCA third-party verification of making LCA publicly available
15. Supply Chain Impacts	O 15.1.1 Supplier responsibility
	R 15.2.1 Final assembly facilities environmental management system
	O 15.2.2 Supplier production facilities environmental management system
	R 15.3.1 Conflict minerals public disclosure
	O 15.4.1 Reduce fluorinated gas emissions resulting from flat panel display manufacturing

ANNEX II – REPARABILITY SCORES FOR SMARTPHONES BY IFIXIT

Reparability Scores for smartphones available on the market as published by iFixit (2019).

Table 33: Reparability Scores for smartphones available on the market (iFixit 2019)

Model (Year)	Characteristics	Score
Fairphone 2 (2015)	+ The most commonly failing components, battery and display, can be replaced without tools. + Internal modules are secured with Phillips #0 screws and simple spring connectors. + Individual modules can be opened, and many components can be individually replaced.	10
Motorola Droid Bionic 2011	+ No tools are necessary for changing the SIM and microSD + The battery can be removed in seconds. +The phone is held together with a limited number of screws and plastic clips. Adhesive is minimally used in its construction	9
Motorola Atrix 4G 2011	+The LCD is separable from the glass front panel, making them independently replaceable. + The phone is held together with a limited number of screws and plastic clips. Adhesive is minimally used in its construction. + The battery can be removed in seconds..	9
Xiaomi Redmi Note 3 2015	+ Despite no external screws, the rear case is fairly easy to remove. + Battery is easy to access and remove. − Display assembly is a single fused component, that requires disassembling the entire phone to replace.	9
LG G5 2016	+ The user-removable, slide-out battery is a huge boon to phone lifespan. + No glue and few screws make for a relatively simple opening procedure. − The fused display assembly will need to be replaced if the LCD or glass breaks, increasing costs.	8
LG G4 2015	+ Rear panel and battery can be removed with no tools. +Many components are modular and can be replaced independently. − Fused display assembly—glass and LCD will need to be replaced together if one or the other breaks.	8
Google Nexus 5 2013	+ Very modular design allows independent replacement of several wear-prone components—like the headphone jack and speakers. + Only very mild adhesive holds the battery in place, making it fairly easy to safely remove and replace. − The glass and LCD are fused to the display frame. Fixing broken glass will be either expensive or very difficult.	8
Samsung Galaxy S4 2013	+ The battery can be replaced in seconds, without any tools. + Very easy to open for access to internal components. − The glass is fused to both the display and the display frame, increasing repair costs.	8
Blackberry Z10 2013	+The battery can be replaced without any tools. +Motherboard and display come out with little difficulty and are held in place with little adhesive Smaller components (headphone jack, camera) are modular and can be replaced individually, but have somewhat strong adhesive holding them in place.	8
Samsung Galaxy Note II 2012	+Battery is easy to replace. +Very easy to open for access to internal components. −Components adhered to the back of a fused display assembly.	8
Samsung Galaxy S III 2012	+The battery can be replaced without any tools. +Very easy to open and access internal components. The glass is fused to both the display and the display frame, increasing repair costs.	8
Samsung Galaxy Note 2011	+Battery is easy to replace +Very easy to open for access to internal components. −Components adhered to the back of a fused display assembly.	8
Samsung Galaxy S II 2011	+Battery is easy to replace. +Very easy to open for access to internal components. −Components adhered to the back of a fused display assembly.	8

Nokia N8 2010	+The battery, although considered by Nokia not to be user-serviceable, can be easily removed. +The AMOLED display easily comes apart from the glass, which means that you can replace the glass and the display independently. −Removing the cameras is near-impossible, and requires tedious, potentially detrimental steps..	8
Moto Z 2017	+Pull-tab on battery, easy to access once you have the device open. +Modular assembly allows independent replacement of many components −Charging port soldered to the motherboard means a common repair will be very expensive.	7
Vivo X7 Plus 201	+Battery is fairly easily accessible and removable. +Parts could be more modular, especially mechanical/high wear components. −The single unit display assembly is annoying to reach, and will be a costly part.	7
Oppo R9m 2017	+Battery is fairly easily accessible and removable. +Most components are extremely modular making for cheaper repairs. −The opening procedure is extremely tough, clips are very stiff and likely to be broken.	7
OnePlus 5 2017	+There are no proprietary screws. +The OnePlus 5's display is held on by easy to dispatch reusable plastic clips. −The display and glass are fused and the home button is integrated into the display assembly making repair of all three of these parts more complicated and expensive.	7
Wiko Pulp 4G Phone 201	+Replacing the battery is easy as pie with the swappable back cover. +This phone doesn't use excessive glue nor proprietary screws—we found only Phillips throughout the entirety. −Unfortunately, the components on the daughterboard are soldered on, making a repair on an individual component difficult.	
Meizu MX6 2016	+The display assembly is the first component out, simplifying screen repairs. +Modular components with spring contacts, large screws, and thoughtful cabling all make repair cheaper and easier. −The MX6 uses Pentalobe security screws on the exterior, requiring a specialty screwdriver to open the phone before any repair.	7
Google Pixel 2016	+The battery is secured with removable adhesive tabs, making replacement simple. +Many components are modular and can be replaced independently. −The fused display is thin and unsupported, and must be removed to access any other component.	7
Google Pixel XL 2016	+Many components are modular and can easily be replaced once the display assembly is removed. +The battery has a removal tab and is adhered by a modest amount of adhesive, making its removal painless. −The opening procedure requires prying up a thin, poorly-supported display assembly making it difficult to open the phone without damage.	7
Apple iPhone 7 Plus 2016	+The battery is straightforward to access. Removing it requires specialty screwdrivers and knowledge of the adhesive removal technique, but is not difficult. +The solid state home button eliminates a common point of failure. −With the addition of tri-point screws, many iPhone 7 Plus repairs will require up to four different types of drivers.	7
Apple iPhone 7 2016	+The battery is straightforward to access. Removing it requires specialty screwdrivers and knowledge of the adhesive removal technique, but is not difficult. +The solid state home button eliminates a common point of failure. −With the addition of tri-point screws, many iPhone 7 repairs will require up to four different types of drivers.	7
Huawei P9 2016	+Modular components with spring contacts, thoughtful cabling, and minimal adhesive all make repair cheaper and easier. +The battery is straightforward to access. Removing it requires knowledge of the adhesive removal technique, but is not difficult. −The display assembly is a fused unit, and replacement requires near complete disassembly of the phone.	7
Nexus 5x 2015	+Many components are modular and can be replaced independently. +Standard Phillips screws means a driver is easy to find. −Fused display assembly—glass and LCD will need to be replaced together if one or the other breaks.	7

Apple iPhone 6 Plus 2015	+The display assembly continues to be the first component out, simplifying screen repairs. +The battery is straightforward to access. Removing it requires a proprietary +Pentalobe screwdriver and knowledge of the adhesive removal technique, but is not difficult. −The iPhone 6s Plus still uses proprietary Pentalobe screws on the exterior, requiring a specialty screwdriver to remove.	7
iPhone 6s 2015	+The display assembly continues to be the first component out, simplifying screen repairs. +The battery is straightforward to access. Removing it requires a proprietary pentalobe screwdriver and knowledge of the adhesive removal technique, but is not difficult. −The iPhone 6s still uses proprietary Pentalobe screws on the exterior, requiring a specialty screwdriver to remove.	7
OnePlus 2 2015	+A single (non-proprietary) screw head decreases cost of tools for repairs. +Many components are modular and can be replaced independently. −The LCD and digitizer glass are fused together and must be replaced as a single part; heat is required to remove it from the midframe.	7
Google Nexus 6 2014	+Pressure contacts and cable connectors make the modular components (cameras, buttons, headphone jack) easy to replace. +The Nexus 6 uses a single kind of screw, although it's a fairly uncommon size (T3). −Several components (vibrator, SIM slot, speaker, USB port) are soldered directly to the motherboard and will be more difficult to replace than if they were connected by cable.	7
iPhone 6 Plus 2014	+Continuing the trend from the iPhone 5 series, the display assembly comes out of the phone first, simplifying screen repairs. +The battery is straightforward to access. Removing it requires a proprietary pentalobe screwdriver and knowledge of the adhesive removal technique, but is not difficult. −The iPhone 6 Plus still uses proprietary Pentalobe screws on the exterior, requiring a specialty screwdriver to remove.	7
iPhone 6 2014	+Continuing the trend from the iPhone 5 series, the display assembly comes out of the phone first, simplifying screen repairs. +The battery is straightforward to access. Removing it requires a proprietary pentalobe screwdriver and knowledge of the adhesive removal technique, but is not difficult. The iPhone 6 still uses proprietary Pentalobe screws on the exterior, requiring a specialty screwdriver to remove.	7
Fairphone 1.0 2014	+The battery can be replaced without any tools. +It's very easy to open and access the internal components. −Several smaller components are soldered to the motherboard, increasing repair difficulty (front-facing camera, vibrator motor, LED flash, and headphone jack).	7
Motorola Moto X 1st Generation 2013	+Pressure contacts and cable connectors make the modular components (cameras, buttons, headphone jack and speakers) easy to replace. +The Moto X uses a single kind of screw, although it's a fairly uncommon size (T3). Sticky adhesive on the back cover is annoying and will slow opening the phone.	
Samsung Galaxy Nexus 2011	+Battery replacement is incredibly simple thanks to the removable rear panel. +Minimal adhesive makes removal of the motherboard and other components a snap. −Removing the rear case to access the motherboard and other internals requires a lot of careful prying and guitar-picking.	7
Nexus S 2010	+Battery is very easily replaceable -- just remove the back cover to swap it out. +The motherboard comes out easily once you're inside, as it's held in place by regular screws and connectors. −Front panel is attached with adhesive instead of screws, so it's harder to take off than on the iPhone.	7
iPhone 3G 2009	+LCD and front glass are not fused and can be replaced individually. +Standard Phillips screws used throughout. Battery is buried under the logic board, making it difficult to replace.	7
iPhone 3GS 2009	+LCD and front glass are not fused and can be replaced individually. +Standard Phillips screws used throughout. −Battery is buried under the logic board, making it difficult to replace.	7

iPhone XR 2018	+The display-first opening procedure and easy access to the battery remain design priorities. +A broken display can be replaced with minimal hardware removal, and with a little care you can preserve Face ID. − Glass on front and back doubles the crackability—and broken back glass requires an entire chassis replacement.	6
iPhone XS 2018	+Critical display and battery repairs remain a priority in the iPhone's design. +A broken display can be replaced without removing the biometric Face ID hardware. − Glass on front and back doubles the likelihood of drop damage—and if the back glass breaks, you'll be removing every component and replacing the entire chassis.	6
Google Pixel 2 XL 2017	+Many components are modular and can be replaced once the display assembly is removed. +All of the screws are common Phillips #00 screws, and there are only 9 of them. The battery's loss of pull-tab adhesive, plus tightly walled-in placement, makes it much harder to remove.	6
Google Pixel 2 2017	+Front panel is fairly easy to remove and replace +Standard screws used throughout. Cable placement makes battery removal more difficult than necessary.	6
iPhone 8 Plus 2017	+The display and battery are straightforward to access—with the proper knowledge and tools. +Wireless charging means less wear on the all-purpose Lightning port, a common point of failure. − Despite alleged durability, the back glass is breakable and next to impossible to replace when cracked.	6
iPhone 8 2017	+The two most commonly replaced components, display and battery, remain straightforward to access with the proper knowledge and tools. +The addition of wireless charging means less strain on your Lightning port, a common point of failure. − The durability of the glass back remains to be seen—but replacements are likely to be very difficult.	6
Sony Xperia X Compact 2017	+Modular design allows for replacement of many individual components. Battery is fairly easy to access and remove, but requires removal of the delicate NFC antenna to replace. − Adhesive used throughout will need to be replaced during reassembly, and may never be as waterproof again.	6
Xiaomi Mi 5 2017	+The motherboard and battery can be replaced independently and easily. +Most components are modular and can be replaced independently. − The display is difficult to replace, requiring complete disassembly and purchasing consumables.	6
AsusZenfone 3 Max 2017	+Battery is easily accessible and removable. Parts could be more modular, especially mechanical/high wear components. − The opening procedure is extremely tough, clips are stiff and likely to be broken, and the SIM slot bends easily.	6
Vivo X7 2017	+Battery is fairly easily accessible and removable. Parts could be more modular, especially mechanical/high wear components. −The opening procedure is extremely tough, clips are very stiff and likely to be broken.	6
Huawei Mate 8 2017	+Many components are modular and can be individually replaced. Opening the phone requires only a Torx screwdriver and a prying tool (No adhesive holding it together). − A tamper evident sticker must be removed when disconnecting the battery.	6
Lenovo K5 Note 2017	+Battery is replaceable with just a couple of tools. +A single Phillips 00 driver takes care of all the screws. − Replacing the display assembly requires removing every other component from the device first.	6
Shift 5.1	+Cover and battery are easy to remove and can be swapped without using tools. +No excessive glue and no proprietary screws are used, only Phillips #000. − Lots of components and connectors are soldered to the motherboard. They could be soldered by hand if needed but this makes repairs more difficult.	6
iPhone SE 2016	+The display assembly is the first component out of the phone, simplifying screen replacements. +The battery is fairly easy to access, even though it's not technically "user replaceable." − The Touch ID cable could be easily ripped out of its socket if a user is not careful when opening the phone.	6

iPhone 5c 2013	+Just like in the iPhone 5, the display assembly is the first component out of the phone, simplifying screen replacements. +The battery is still fairly easy to access, even though it's not technically "user replaceable." − Adhesive on the antenna connectors hinder disassembly.	6
iPhone 5s 2013	+Just like in the iPhone 5, the display assembly is the first component out of the phone, simplifying screen replacements. +The battery is still fairly easy to access, even though it's not technically "user replaceable." −The fingerprint sensor cable could be easily ripped out of its socket if a user is not careful while opening the phone.	6
iPhone 4S 2011	+The iPhone 4S is still held together primarily with screws and limited adhesive. +The rear panel and battery are both easy to remove and replace (provided you have the correct screwdriver). Apple is again using Pentalobe screws to secure the rear panel and keep people out	6
SamsungGalaxy S 4G2011	+Removing the rear panel to replace the microSD/SIM cards and the battery requires no tools. +Attaching components like the headphone jack to separate cables makes their replacement less costly than replacing the entire motherboard. −The front panel is adhered to the AMOLED display, so they must be replaced as one expensive unit.	6
Motorola Droid 3 2011	+There were no security screws in the entire device. +The battery was not soldered to anything and was easy to replace. There is a lot of adhesive holding things together, making disassembly and reassembly difficult.	6
iPhone 4 Verizon 2011	+The iPhone 4 is held together primarily with [lots of] screws, sans tabs, and limited adhesive. +The rear panel and battery are both easy to remove and replace (provided you have the right screwdriver). −Apple is using Pentalobe screws to secure the rear panel and keep people out.	6
OnePlus 6 2018	− Display replacement, the most common repair, is not prioritized in the design and will take a lot of work. − Front and back glass means twice the risk of cracks—without even the benefit of wireless charging. +The battery can be accessed almost the moment you open the phone, and is only lightly adhered in place. Plus, there's a convenient pull tab.	5
Huawei Mate 9 2017	− Replacing a broken display, one of the most common repairs, will be one of the most difficult ones on this phablet. The battery is trapped behind some flex cables and is glued tightly into place, but still can be swapped out when its power starts to fade away. Most of the components—like both camera units, the loudspeaker, and the USB +board—can be replaced. Even the proximity sensor and the NFC antenna are modular.	5
LG G6 2017	−Front and back glass doubles the crackability, and strong adhesive on both makes it tough to begin any repair. −Components adhered to the back of a fused display assembly. +Many components are modular and can be replaced independently.	5
Samsung Galaxy Alpha 2014	−The display assembly is held in with a significant amount of adhesive and requires very careful prying and a considerable amount of heat to remove without cracking the thin glass or cutting cables. −Replacing anything other than the battery requires first removing the display, risking extra damage on the way to a repair. +The battery is incredibly easy to remove and replace.	5
Samsung Galaxy S5 Mini 2014	− Replacing anything other than the battery requires first removing the display, risking extra damage on the way to a repair. − The display is now one of the first components out, making its replacement a little faster. However, it is held in with a significant amount of adhesive and requires very careful and persistent prying, as well as a considerable amount of heat to remove without cracking the glass or cutting cables. + The battery is incredibly easy to remove and replace.	5

OnePlus One 2014	− Replacing anything other than the battery requires first removing the display, risking extra damage on the way to a repair. The display is now one of the first components out, making replacements a little faster. However, it is held in with a significant amount of adhesive and requires very careful and persistent prying and a considerable amount of heat to remove without cracking the glass or cutting cables. +The battery is incredibly easy to remove and replace.	
HTC Surround 2011	− Unable to access the internal MicroSDHC card without voiding the warranty. − It is very difficult to access the front panel and LCD for replacement. Relatively easy to remove the rear case to replace the battery.	5
Huawei Mate 20 Pro 2018	− Glued-down front and back glass means greater risk of breakage while making repairs difficult to start. − Screen repairs require a lot of disassembly while battling tough adhesive. Many components are modular and can be replaced independently.	4
Google Pixel 3 2018	− Display repairs are much more difficult than previous models, requiring complete disassembly of the phone. − To service any component, you'll have to painstakingly un-glue (and later re-glue) the glass rear panel. +The only screws are standard T3 Torx fasteners.	4
Google Pixel 3 XL 2018	− Display repairs are much more difficult than previous models, requiring complete disassembly of the phone. −To service any component, you'll have to painstakingly un-glue (and later re-glue) the glass rear panel. +The only screws are standard T3 Torx fasteners.	4
LG G7 Thin Q 2018	− Front and back glass make for double the crackability, and strong adhesive on both makes it tough to access the internals for any repair. − Screen repair, the most common type repair, is not prioritized, requiring an almost complete disassembly while battling tough adhesive. +Lots of components are modular and can be replaced independently	4
Huawei P20 Pro 2018	− Double the risk for breakage with glass front and back. − Replacing the screen requires going through at least two layers of adhesive and some disassembly. +Many components are modular and can be replaced independently.	4
SamsungGalaxy S9 2018	− Glued-down glass both front and back means greater risk of breakage, and makes repairs difficult to start. − Screen repairs require a lot of disassembly while battling tough adhesive. +Many components are modular and can be replaced independently.	4
SamsungGalaxy S9 Plus 2018	− Glued-down glass both front and back means greater risk of breakage, and makes repairs difficult to start. − Screen repairs require a lot of disassembly while battling tough adhesive. +Many components are modular and can be replaced independently	4
Huawei Mate 10 Pro 2017	− A damaged front camera means switching the whole display including the frame, or damaging the display while trying to remove it. − And replacing the display—the most common repair—means taking out almost every component. +Despite the IP67-rated seals, the back cover is fairly easy to open.	4
Samsung Galaxy Note 2017	− All repairs require removing the glass rear panel, which is challenging due to the large amount of adhesive. − Replacing the display requires removing the glass rear panel and the display, both of which are fragile and secured with strong adhesive. +Many components, including all of those that experience wear, are modular and can be replaced independently.	4
Samsung Galaxy Note Fan Edition 2017	− Front and back glass make for double the crackability, and strong adhesive on the rear glass makes it very difficult to gain entry into the device. − Because of the curved screen, replacing the front glass without destroying the display is probably impossible. +Many components are modular and can be replaced independently.	4
Samsung Galaxy S8 2017	− Front and back glass make for double the crackability, and strong adhesive on both makes it tough to access the internals for any repair. − Because of the curved screen, replacing the front glass without destroying the display is extremely difficult. +Lots of components are modular and can be replaced independently.	4

Samsung Galaxy S8 Plus 2017	− Front and back glass make for double the crackability, and strong adhesive on both makes it tough to access the internals for any repair. − Because of the curved screen, replacing the front glass without destroying the display is extremely difficult. +Many components are modular and can be replaced independently.	4
Samsung Galaxy Note7 2016	− Front and back glass make for double the crackability, and strong adhesive on the rear glass makes it very difficult to gain entry into the device. − Because of the curved screen, replacing the front glass without destroying the display is probably impossible. +Many components are modular and can be replaced independently.	4
Samsung Galaxy S6 2015	− Front and back glass make for double the crackability, and strong adhesive on the rear glass makes it very difficult to gain entry into the device. − Replacing the glass without destroying the display is probably impossible. Many components are modular and can be replaced independently.	4
Motorola Droid 4 2012	− Keyboard contacts are located on the motherboard, making keyboard replacement costly and difficult. − Tons of glue adheres the glue that is securing the glue to the glue that holds the phone together. +The lack of security or proprietary screws is a welcome sight.	4
Motorola Droid RAZR 2011	− The front panel is adhered to the AMOLED display, so they must be replaced as one expensive unit. − All plastic frames and casing proved to be incredibly tedious to remove, and felt like they would break at any moment. Once the battery and motherboard are within reach, replacement is easy—no soldering required.	4
Samsung Galaxy S10 2019	− Battery replacement is possible, but still unnecessarily difficult. − Glued-down glass both front and back means greater risk of breakage, and makes repairs difficult to start. +A single Phillips driver takes care of all the screws.	4
Samsung Galaxy S7 Edge 2016	−The display needs to be removed (and likely destroyed) if you want to replace the USB port. −Front and back glass make for double the crackability, and strong adhesive on the rear glass makes it very difficult to gain entry into the device. +Many components are modular and can be replaced independently.	3
Samsung Galaxy S7 2016	−The display needs to be removed (and likely destroyed) if you want to replace the USB port. −Front and back glass make for double the crackability, and strong adhesive on the rear glass makes it very difficult to gain entry into the device. +Many components are modular and can be replaced independently.	3
Samsung Galaxy S6 Edge 2015	−Front and back glass make for double the crackability, and strong adhesive on the rear glass makes it very difficult to gain entry into the device. −The battery is very tightly adhered to the back of the display, and buried beneath the midframe and motherboard. + components are modular and can be replaced independently.	3
Amazon Fire 2014	−Tons of cables and connectors make disassembly tedious and reassembly difficult. −The four Dynamic Perspective cameras are encased in glue. Replacement will mean heat and cutting. +External, non-proprietary screws means no adhesive holding the device together, and an easier time getting in.	3
Nexus 6P 2015	−It's very difficult—although not impossible—to open the device without damaging the glass camera cover. Because of the unibody design, this makes every component extremely difficult to replace. −The display assembly cannot be replaced without tunneling through the entire phone. This makes one of the most common repairs, a damaged screen, difficult to accomplish. −Tough adhesive holds the rear cover panels and battery in place.	2
HTC One M9 2015	−The battery is buried beneath the motherboard and adhered to the midframe, hindering its replacement. −The display assembly cannot be replaced without tunneling through the entire phone. This makes one of most common repairs—a damaged screen—very difficult to accomplish. −Intense adhesives make many components difficult, and even dangerous, to remove and replace.	2

HTC One M8 2014	−It's very difficult—although no longer impossible—to open the device without damaging the rear case. This makes every component extremely difficult to replace. −The battery is buried beneath the motherboard and adhered to the midframe, hindering its replacement. −The display assembly cannot be replaced without tunneling through the entire phone. This makes one of most common repairs, a damaged screen, very difficult to accomplish.	2
iPhone 1st Generation 2009	−Hidden clips make it nearly impossible to open rear case without damaging it. −Soldered battery is very difficult to replace. +Standard Phillips screws used throughout.	2
Essential Phone 2017	−The USB-C port is soldered to the motherboard, and with no headphone jack it'll be subject to extra wear. −Nearly invisible seams and copious adhesive means any attempt at repair is likely to inflict as much damage as it fixes. −Did we mention we had to freeze it?	1
HTC One 2013	−Very, very difficult (possibly impossible?) to open the device without damaging the rear case. This makes every component extremely difficult to replace. −The battery is buried beneath the motherboard and adhered to the midframe, hindering its replacement. −The display assembly cannot be replaced without removing the rear case—this will make the most common repair, a damaged screen, nearly impossible.	1