European Commission

JRC TECHNICAL REPORT

Methods for the Assessment of the Reparability and Upgradability of Energy-related Products: Application to TVs

Final report

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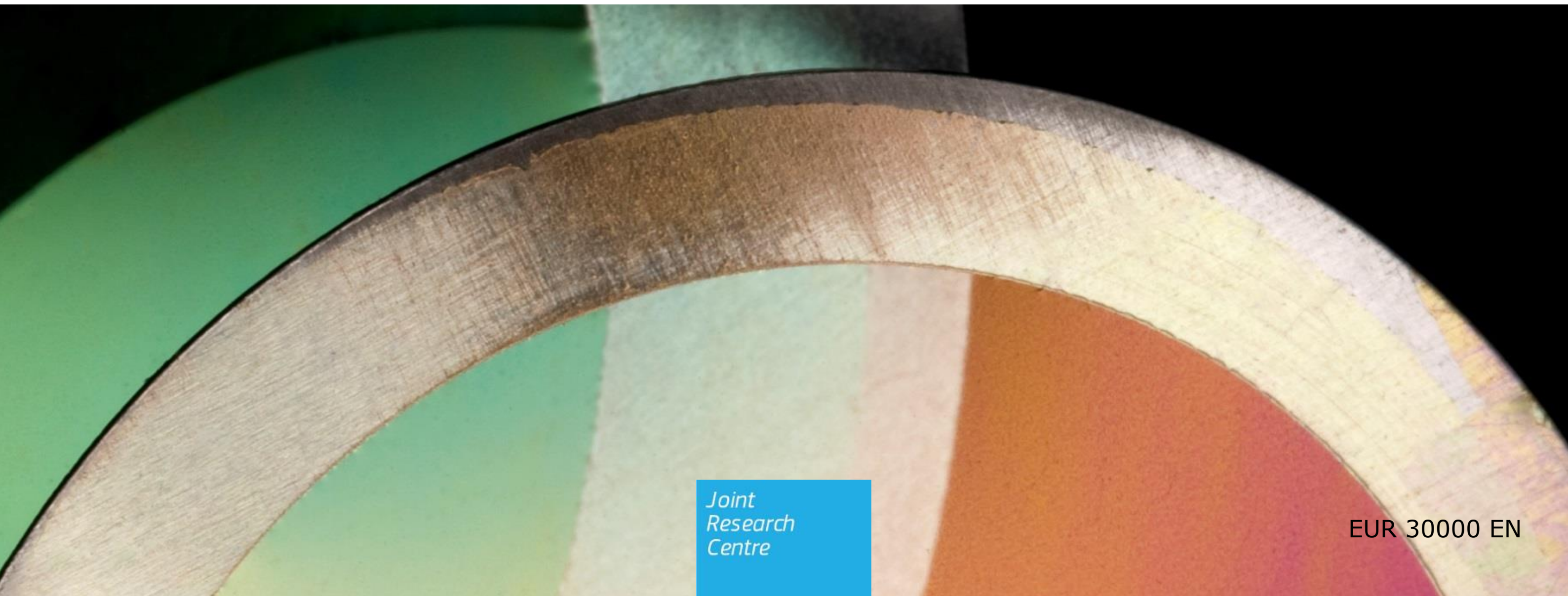
2019



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JRC116105

EUR 30000 EN

PDF ISBN 978-92-76-11254-9 ISSN 1831-9424 doi:10.2760/501525

Luxembourg: Publications Office of the European Union, 2019

How to cite this report: Sanfelix Forner, J., Cordella, M. and Alfieri, F., *Methods for the Assessment of the Reparability and Upgradability of Energy-related Products: Application to TVs*, EUR 30000 EN, Publications Office of the European Union, Luxembourg, 2019, ISBN 978-92-76-11254-9 (online), doi:10.2760/501525 (online), JRC116105.

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LIST OF ACRONYMS

CCFL	Cold Cathode Fluorescent Lamp
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CLP	Classification, Labelling and Packaging Regulation
CRT	Cathode Ray Tube
DVD	Digital Versatile Disc
DVI	Digital Visual Interface
eDiM	Ease of Disassembly Metric
EoL	End of Life
ErP	Energy-related Product
GPSD	General Product Safety Directive
GWP	Global Warming Potential
HD	High Definition
HDD	Hard Drive Disk
HDMI	High Definition Multimedia Interface
ICT	Information and Communications Technologies
IR	Infrared Receiver
LCA	Life Cycle Assessment
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LVDS	Low Voltage Differential Signaling
MOIP	Multimedia Over Internet Protocol
NGO	Non-Governmental Organisation
OLED	Organic Light Emitting Diode
PCB	Printed Circuit Board
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals Regulation
RoHS	Restriction of Hazardous Substances Directive
SDI	Serial Digital Interface
SEK	Swedish Crown
SMPS	Switch Mode Power Supply
TV	Television
TWG	Technical Working Group
USB	Universal Serial Bus
TEG	Technical Working Group
VAT	Value Added Tax
VCR	Videocassette Recorder

SUMMARY

Improving the material efficiency of products is important to reduce their environmental impacts. In particular, an improvement of the reparability and upgradability of products can be beneficial to the environment and to the economy by limiting the early replacement of products and thus saving resources. However, the 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, has compiled multi-level approaches for assessing the reparability and upgradability of products. This report describes such approaches and their application to TVs, with the overarching goal of improving the knowledge about the assessment of the reparability and upgradability of energy related products (ErP). The document is built on in-house research and on input received from stakeholders during two written consultations which took place in April 2018 and in April 2019.

The following approaches have been considered, based on the preliminary identification of priority parts:

- Quantitative methods, including Life Cycle Assessment (LCA) and calculation of disassembly steps/times, which are more complex in terms of data and calculation needs;
- Qualitative methods, which aim to provide lists of pass/fail requirements influencing the repair and upgrade of TVs;
- Quali-quantitative methods, which fall in between the previous methods in terms of complexity and aim to develop scoring criteria with which to rank a product.

Key findings for TVs are the following:

- The most relevant parts for repair and upgrade of TVs are the main board, T-con board, sound board, power board, inverter board, IPS/EPS, speakers and backlights (lamps/LEDs).
- Manufacturing of circuit boards is the major contributor to the environmental impacts of a TV. In case of failure of these parts, repairing a TV (instead of replacing it with a new product) can be convenient only if the repaired product is used for a considerably longer period of time (about 35-40% longer than an expected lifetime of 10 years). For other parts which present lower environmental impacts, like the speakers, repair can be considered as an environmentally convenient alternative after a marginal increase of the time of use.
- The analysis of disassembly steps and times seems to indicate that there is little variance for these parameters among different products; other parameters like availability and cost of spare parts could be more relevant in determining the likelihood of repairing or not the product.

Given the similarities of TVs with other types of electronic displays, for which the main difference is the absence of a tuner card, it is in expected that the outcomes of this study could be in general extended to a large extent also to other electronic displays. Nevertheless, similarities and differences with TV displays should be carefully assessed on a product basis before translating specific results to other types of display.

The study can support standardisation work on material efficiency of TVs and other Energy-related Products (e.g. the ongoing CEN/CENELEC JTC10 standardisation process) as well as the possible methodological refinement and applications of the Repair Score System developed by JRC. The information gathered even constitutes a reference for policy making and designers (e.g. the revision of the EU Ecolabel requirements for TVs or the potential development of a reparability label).

1 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 can be important to reduce their environmental impacts. In particular, an improvement of the reparability and upgradability of products[1] can have the potential of bringing added value to the environment and to the economy by limiting the early replacement of products and thus saving resources (Deloitte 2016). However, the 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 ecodesign", which is working on the development of general standards on material efficiency aspects for Energy-related Products (ErP).

In this context, the Joint Research Centre has compiled multi-level approaches for assessing the reparability and upgradability of products (Cordella et al. 2018a):

- Calculation of quantitative indicators (quantitative assessment);
- Definition of checklists of qualitative attributes (qualitative assessment);
- Rating and aggregation of parameters into indices (quali-quantitative assessment).

This report describes considerations about how such approach could be applied to TVs, with the main aim to improve the knowledge about the assessment of the reparability and upgradability of ErP. The work, entrusted by DG ENV, has a research orientation which does not mean to interfere with ongoing policy processes. Results could however feed into work on actions contained in the Circular Economy Action Plan related to product policy[2] and the Ecodesign task force for ICT products[3].

The report is structured in the following chapters:

1. Product group characterisation (i.e. scoping and definitions and relevant information on legislation and testing methods, market, user behaviour and technologies);
2. Assessment of reparability and upgradability (i.e. identification of relevant aspects and priority parts, quantitative, qualitative and quali-quantitative assessment of TVs);
3. Questions for stakeholders;
4. Conclusions;

Annex I: Background information about failures for TVs;

Annex II: Additional information about possible methods to assess reparability of products.

The document also built on two written consultations (April/May 2018 and April 2019) organised to get technical input and feedback from a Technical Working Group (TWG) of experts consisting of manufacturers, retailers, repairers, academia, environmental and consumer NGOs, as well as Member States.

[1] Reparability and upgradability are here defined, respectively, as the ability to restore the functionality of a product after the occurrence of a fault, and the ability to enhance the functionality of a product, independently on the occurrence of a fault. Both can refer to one or more parts of a product. Since similar processes apply to repair and upgrade, the same service conditions and design strategies can influence both reparability and upgradability of a product

[2] COM(2015) 614

[3] COM(2016) 773

2 PRODUCT GROUP CHARACTERIZATION

2.1 Scoping and definitions

The following definitions are provided in the revised ecodesign regulation for electronic displays[4]:

1. "Television" means an electronic display designed primarily for the display and reception of audiovisual signals and which consists of an electronic display and one or more tuners/receivers.
2. "Electronic display" means a display screen and associated electronics that, as its primary function, displays visual information from wired or wireless sources.
3. "Tuner/receiver" means an electronic circuit that detects television broadcast signal, such as terrestrial digital or satellite, but not internet unicast, and facilitates the selection of a TV channel from a group of broadcast channels.

The provided definitions are those used to define the scope of this study, which will focus on the most representative technologies on the market.

Given the similarities of TVs with other products under the scope of the revised Ecodesign regulation (e.g. computer monitors), the present study will briefly analyse to what extent the conclusions drawn for TVs could apply to other products of the same family.

An important aspect to classify TVs is their screen resolution, which depending on the number of pixels can be standard definition, high-definition (HD), full HD, ultra HD (4k and 8k). The screen resolution of TVs improves as technology progresses, for example, ultra HD 10k is currently under development. Table 1 shows the most common resolutions available on the market.

Table 1 Classification of TVs according to the image resolution

Name	Resolution (pixels)
Standard definition	704x480
HD	1280x720
Full HD	1920x1080
Ultra HD (4k)	3840x2160
Ultra HD (8k)	7680x2160

[4] http://ec.europa.eu/transparency/regcomitology/index.cfm?do=search.documentdetail&Dos_ID=16995&ds_id=59740&version=2&page=1 (accessed on 11 June 2019)

2.2 Legislation and testing methods

2.2.1 Mandatory legislation

This section describes mandatory legislation which can influence repair and/or upgrade of TVs. Legislation of other aspects (like REACH, CLP, F-gases, RoHS) has not been considered in this study.

2.2.1.1 Ecodesign and Energy Labelling

TVs are covered by the Ecodesign Regulations No. 642/2009 and No. 801/2013. Such regulations have been recently revised[5] in terms of energy requirements and to integrate material efficiency aspects (Cordella et al. 2018a; Cordella et al. 2019a). Moreover, the scope of the two regulations has been extended to other types of displays (see Section 1.1).

According to the new Ecodesign Regulation No. 2021/2019, from 1 March 2021 manufacturers have to ensure that joining, fastening or sealing techniques do not prevent the removal, using commonly available tools, of the components indicated in point 1 of Annex VII of Directive 2012/19/EU on WEEE or in Article 11 of Directive 2006/66/EC on batteries and accumulators and waste batteries and accumulators (when present).

To facilitate end of life processes, manufacturers also have to make available the dismantling information needed to access any of the products components referred to in point 1 of Annex VII of Directive 2012/19/EU on a free-access website, including the sequence of dismantling steps, tools or technologies needed to access the targeted components.

To facilitate repair operations, manufacturers or importers have to indicate how professional repairers can register to have access to repair information. To this aim, it may be requested that professional repairers demonstrate that: (i) they comply with the applicable regulations for repairers of electrical and electronic equipment in the Member State where they operate; (ii) they are covered by relevant insurance including liability.

In relation to design for repair and reuse, the new regulation requires availability of spare parts:

- For professional repairers: internal power supply, connectors to connect external equipment (cable, antenna, USB, DVD and Blue-Ray), capacitors, batteries and accumulators, DVD/Blue-Ray module (if applicable), and HD/SSD module (if applicable); and
- For end-users and professional repairers: external power supply and remote control.

Spare parts have to be available for a minimum period of seven years after placing the last unit of the model on the market and have to be delivered within 15 working days after having received the order. Moreover, these parts have to be replaced with the use of commonly available tools and without permanent damage to the appliance.

Other requirements include:

- The availability of firmware updates for at least 8 years after placing the last unit on the market;
- Information on the minimum guaranteed availability of software and firmware updates;

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[5] http://ec.europa.eu/transparency/regcomitology/index.cfm?do=search.documentdetail&Dos_ID=16995&ds_id=59740&version=2&page=1 (accessed on 11 June 2019)

- The public availability of the list of spare parts and the procedure for ordering them.

Ecodesign measures on TVs are complemented by the Energy Label, which has been also recently updated[6].

2.2.1.2 Reparability

To promote circular economy and boost the repair sector, a few EU member states have implemented VAT reductions on repair services of bicycles, clothing, textiles and leather goods. The list of countries includes Ireland, Luxemburg, Malta, Netherlands, Poland, Slovenia, Finland and Sweden. Other actions taken by governments to incentivise repair are listed in Table 2. Moreover, the European Parliament has asked the EC in July 2017 to consider a "voluntary European label" covering, in particular, the product's durability, eco-design features, upgradeability in line with technical progress and reparability[7].

Table 2 Strategies with tax reduction to incentivise repair

Country	Strategy[8]
Sweden	50% labour costs for repairs of large household appliances are tax deductible up to a maximum of 25 000 SEK/year, or 50 000 SEK/person, over the age of 65. This is for repairs performed by professionals in the place of use of the device (e.g. households).
Austria	Proposal put forward by the Federal Chancellor in January 2017 to make repair cheaper by reimbursement of 50% of the labour costs of repair. The maximum amount would be 600 EUR per year per private person and year. Applicable for bikes, shoes, clothes, leather goods, electric household appliances. The city of Graz already introduced this system in November 2016 with maximum support of 100 EUR per household and year.
Spain	In Spain there is the Patronage law that allows tax reductions to companies and individuals who donate money from assets to charities. It also includes the donation of used goods, without differentiating them from new ones.

Another relevant piece of legislation is the French decree 2014-1482 published in December 2014[9], which puts new requirements on retailers to inform consumers about the durability of products and the availability of spare parts, under the threat of fine of 15 000 EUR. Manufacturers, in turn, 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 to 24 months. Planned obsolescence is also legal offence punishable by 300 000 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".

[6] https://webgate.ec.europa.eu/regdel/#/delegatedActs/982 (accessed on 11 June 2019)
[7] http://www.europarl.europa.eu/news/en/press-room/20170629IPR78633/making-consumer-products-more-durable-and-easier-to-repair (accessed on 19 March 2018)
[8] http://www.rreuse.org/position-paper-on-reduced-taxation-to-support-re-use-and-repair/ (accessed on 10 March 2018)
[9] Decree No. 2014-1482 of 9 December 2014 concerning Disclosure Requirements and Supply of Spare Parts https://www.legifrance.gouv.fr/affichTexte.do?cidTexte=JORFTEXT000029881868&categorieLien=id (accessed on 6 August 2019)

2.2.1.3 General Product Safety Directive 2001/95/EC

The General Product Safety Directive (GPSD) 2001/95/EC aims at ensuring 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 already for the safety of toys, electrical and electronic goods, cosmetics, chemicals and other specific product groups[10]. The GPSD does not cover pharmaceuticals, medical devices or food, which fall under separate legislation.

The GPSD establishes obligations to both businesses and Member States' authorities:

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. They check whether products available on the market are safe, ensure product safety legislation and rules are applied by manufacturers and business chains and apply sanctions when necessary. Member States should also send information about dangerous products found on the market to the Rapid Alert System for non-food dangerous products (RAPEX). This is a cooperation tool enabling rapid communication between EU, EEA authorities about dangerous products to be able to trace them everywhere on the European market. Third countries like China and international institutions are also involved.

Market surveillance authorities cooperate closely with customs, which play a major role in protecting consumers from any imported unsafe products coming from outside the EU.

2.2.1.4 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. The Directive introduced 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. The Directive is currently revised. In the Commission proposal for a revised Directive, the burden of proof shifts to the consumer only after 2 years.

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

[10] https://ec.europa.eu/info/business-economy-euro/product-safety-and-requirements/consumer-product-safety/standards-and-risks-specific-products_en (accessed on 21 March 2018)

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.

2.2.2 Standards and testing procedures

Although several standards have been developed for testing the energy performance of TVs[11] [12] [13] [14] [15], only few of them address aspects of relevance for the assessment of the reparability and upgradability of TVs, the most relevant ones included in Table 3.

Table 3 Standards of relevance for assessing the reparability and upgradability of TVs

Standard	Title / Scope
IEEE 1680.3:2012	IEEE Standard for Environmental Assessment of Televisions
ONR 192102:2014	Sustainability label for electric and electronic appliances designed for easy repair (white and brown goods)
FprEN 45554 (December 2019)[16]	General methods for the assessment of the ability to repair, reuse and upgrade energy related products. (Note: the publication of this standard is expected in 2020)

The IEE 1680.3:2012 standard includes a specific chapter on product longevity (life cycle extension), where it requires to the manufacturers to provide: a) upgradeable firmware; b) information about how and where the TV can be serviced, and c) a resolution process for products that fail within one year. These three criteria are also included in the EPEAT ecolabel scheme, as described in Table 6 of the following section.

The ONR 192102:2014 includes a list of criteria to facilitate the repair of products. The criteria are separated into product design criteria (25 requirements of which 9 are mandatory) and service documentation criteria (14 requirements of which 7 are mandatory). For each list of criteria the non-mandatory requirements give points to the assessed product when fulfilled (5 or 10 points). At the end of the assessment the product is rated according to the final score obtained as it appears in Table 4.

The prEN 45554:2018 standard about repair, reuse and upgrade of ErP is part of CEN/CENELEC JTC10, currently working on the preparation of generic standards for the assessment of material efficiency aspects of ErP. In the case of prEN 45554, the standard includes a series of parameters influencing the ability of an ErP to be repaired, reused or upgraded, as well as methods to assess such parameters individually. It is expected that the final standard will be published in 2020.

[11] Energy Conservation Program: Test Procedures for Television Sets - Uniform Test Method for Measuring the Energy Consumption of Television Sets
[12] EN 50301:2001 - Methods of measurement for the power consumption of audio, video and related equipment
[13] IEC 62087:2011 - Methods of measurement for the power consumption of audio, video and related equipment
[14] IEC 62301:2011 - Household electrical appliances - Measurement of standby power
[15] JEITA Test Standard - Measurement method for energy consumption efficiency of television receivers
[16] https://www.cenelec.eu/dyn/www/f?p=104:7:1493784429841701::::FSP_ORG_ID,FSP_LANG_ID:2240017,25 (accessed on 13 December 2019)

Table 4 Assessment scores and quality levels of the ONR 192102:2014

Points	Quality level	Assessment
45-69	5	Good
70-94	6	
95-119	7	Very good
120-144	8	
145-174	9	Excellent
175-205	10	

2.2.3 Environmental labelling

Several environmental labelling schemes exist worldwide for TVs. These schemes include pass/fail criteria over the entire life cycle of the product with the aim of targeting environmentally superior products and setting the reference for improving the overall environmental performance of the product group. An overview of environmental labelling schemes for TVs is provided in Table 5.

Table 5 Environmental labels for TVs

Scheme	Title	Version	Effective	Valid until
EU Ecolabel	EU Ecolabel for TVs[17]	-	November 2009	31 December 2019
Blue Angel	Television sets[18]	-	July 2012	31 December 2017
Nordic Swan	Nordic Ecolabelling of TV and Projector[19]	5.5	20 June 2013	30 June 2020
TCO Development	TCO Certified Displays[20]	7	November 2015	Not specified
	TCO Certified Edge Display	8	October 2018	Not specified
EPEAT	Televisions[21]	-	Not specified	Not specified
US Energy star	Television specification	7.0	October 2015	Not specified
Green Mark (Taiwan)	Televisions	Second revision	November 2013	Not specified

Environmental labelling schemes have been analysed to identify any criteria addressing repair and upgrade aspects. Table 6 includes the results of the analysis. It is apparent that reparability and/or upgradeability aspects are not covered systematically in all schemes. The majority of them request the availability of spare parts for a certain period of time after ceasing the production of the TV. In the

[17] COMMISSION DECISION of 12 March 2009 establishing the revised ecological criteria for the award of the Community Eco-label to televisions
[18] https://www.blauer-engel.de/en/products/electric-devices/fernsehgeraete (accessed on 19 March 2018)
[19] http://www.nordic-ecolabel.org/product-groups/group/?productGroupCode=071 (accessed on 19 March 2018)
[20] http://tcocertified.com/files/2015/11/TCO-Certified-Displays-7.0.pdf (accessed on 19 March 2018)
[21] https://www.epeat.net/resources/criteria-2/#tabs-1=televisions (accessed on 19 March 2018)

Blue Angel criteria for TVs, for example, spare parts are defined as the parts of the TVs that may break down within the scope of the ordinary use of the product. However, it should be pointed out that no scheme provides a specific list of these parts.

The criteria of EPEAT is based on the standard IEE 1680.3 described in the previous section and the manufacturers interested in obtaining the EPEAT certificate of their product may order a copy of the standard.

Table 6 Reparability and upgradability aspects covered in environmental labels for TVs

Label / Aspect	Instructions	Durability / life time extension
EU Ecolabel	Information for professionals about easy dismantle for the purpose of repair and replacement of worn parts and upgrading older or obsolete parts	Availability of compatible electronic replacement parts should be guaranteed for 7 years from that time the production ceases
Blue Angel	-	Availability of replacement parts shall be guaranteed for 5 years from that time the production ceases
Nordic Swan	Information for professionals about easy dismantle for the purpose of repair and replacement of worn parts	Availability of compatible replacement parts shall be guaranteed for 7 years from that time the production ceases
TCO certified diplays /edge displays	Instructions for professionals available upon request	Availability of replacement parts shall be guaranteed for at least 3 years from that time the production ceases
EPEAT	-	Upgradeable firmware; Service information readily available; Early failure resolution process

Note: Environmental labels not addressing reparability and reparability aspects are not reported in the table above.

2.3 Market information

This section intends to provide a summary description of the market of TVs, as well as indications about costs, which can be used to understand the economic impact of relevant aspects associated to the repair and upgrade of products.

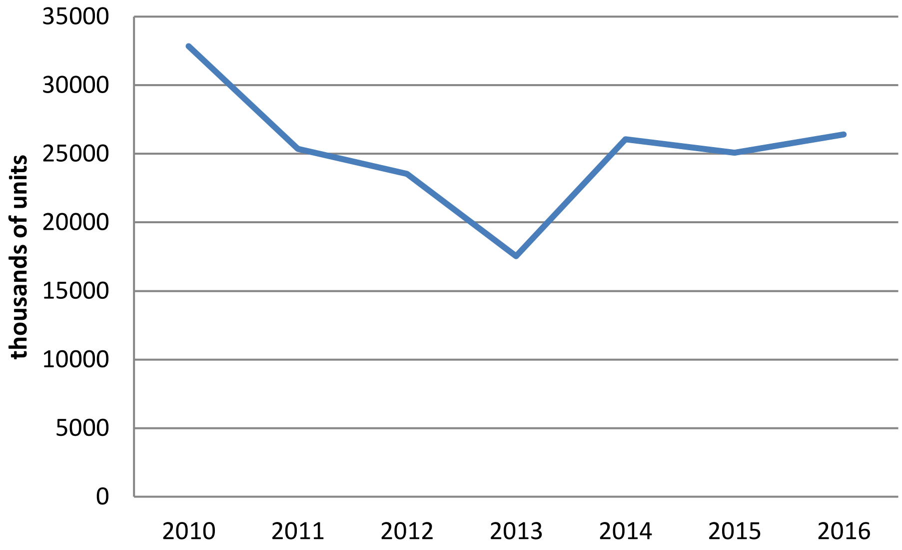
2.3.1 Market sales and trade

Figure 1 includes the number of TVs produced in the EU-28 member states for the period 2010 to 2016. Within the EU-28 member states, Poland is the main producer with about 65% of the total units in 2016, followed by Slovakia (28%) and Czech Republic (5%)[22].

[22] PRODCOM database, http://ec.europa.eu/eurostat/web/prodcom/data/database (accessed on 20 March 2018). Note: The PRODCOM code used for TVs is 26.40.20.90 "Other television receivers, whether or not combined with radio-broadcast receivers or sound or video recording or reproduction apparatus n.e.c.")

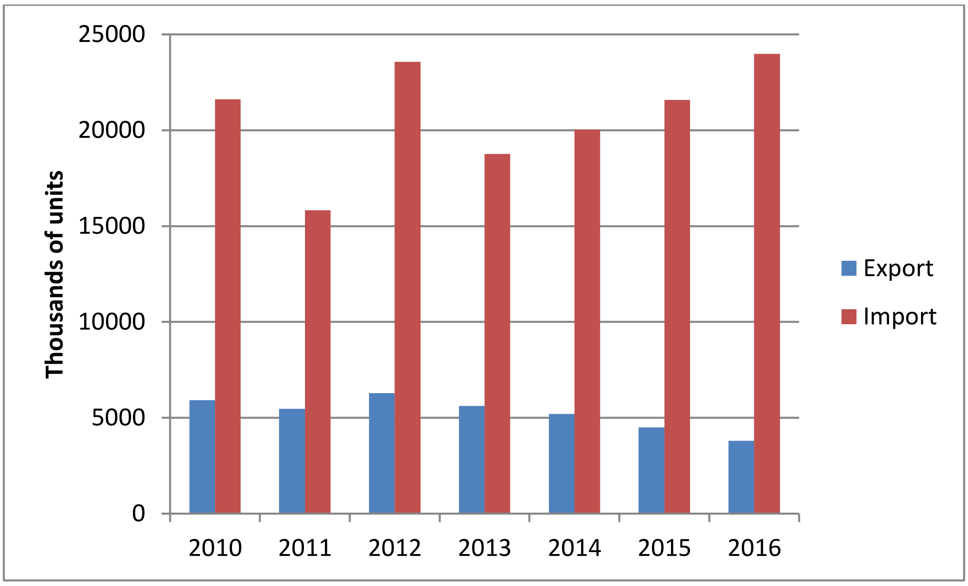
Figure 2 shows imports and exports of TVs for the EU28 during the period of time 2010 to 2016. Net size of imports is of the same order of magnitude of internal production in the EU. The number of imported units has had a gradual increase from 2013 to 2016, up to reach the levels of 2012. On the other hand, the number of exports shows a gradual decrease from 2012 to 2016.

Figure 1 Production of TVs in EU-28[23]



[23] PRODCOM database, http://ec.europa.eu/eurostat/web/prodcom/data/database (accessed on 20 March 2018). Note: The PRODCOM code used for TVs is 26.40.20.90 "Other television receivers, whether or not combined with radio-broadcast receivers or sound or video recording or reproduction apparatus n.e.c.")

Figure 2 EU28 imports and exports of TVs [24]



2.3.2 Market share of technologies

Several types of TVs can be found in the market, the dominant technology is LCD (liquid crystal display), as CRT (cathode ray tube) technology has been gradually replaced by flat TVs. Table 7 includes a description of TV technologies that can be found on the market.

Table 7 Description of the different technologies for TVs[25]

Technology	Description
CRT	With CRT TV the image is generated by shooting electrons through a tube onto a screen, exciting the particles on it. CRT TV formats have been on the fall since the early 2000's with the introduction of far thinner LCD screens.
LCD with CCFL* backlight	A liquid crystal display is a special flat panel that can block light, or allow it to pass. The panel is formed by segments with a block filled with liquid crystals. By increasing or reducing the electrical current, the colour and transparency of the blocks can be modified. In order to generate the image an external light (CCFL*) source is needed.

[24] PRODCOM database, http://ec.europa.eu/eurostat/web/prodcom/data/database (accessed on 20 March 2018). Note: The PRODCOM code used for TVs is 26.40.20.90 "Other television receivers, whether or not combined with radio-broadcast receivers or sound or video recording or reproduction apparatus n.e.c.")
[25] https://www.ebuyer.com/blog/2014/03/tv-types-explained-plasma-lcd-led-oled/ (accessed on 22 March 2018)

LCD with LED backlight	LED TVs are an updated version of the LCD generation, indeed the technology is similar but instead of using a backlight fluorescent bulb they use an array of LEDs. This makes them more efficient and allows smaller sizes, meaning the TV can be narrower. LED have further: *Direct LED:* These displays are backlit by an array of LEDs directly behind the screen. This enables focused lighting areas – meaning specific cells of brightness and darkness can be displayed more effectively. *Edge-lit LED:* Lights are set around the television frame. Edge-lit models reflect light into the centre of the monitor, and are the thinnest, lightest models available. Since they have fewer lights in the centre of the screen. *Quantum dot*: A film consisting of billions of nanocrystals, from different types of crystals, is placed in front of the LED backlight. These nanostructures respond to incoming light and emit monochromatic light with a sharply defined spectrum, allowing purer colour reproduction. This technology offers higher light density and broader colour spectrum.
PLASMA	Plasma screens are composed of two sheets of glass with a mixture of gases in between the layers. In the manufacturing process these gases are injected and sealed in plasma form. The gases react and cause illumination in the pixels across the screen when charged with electricity. Plasma is used in the super-sized 80-inch+ screens as the plasma screens are easier, and more cost effective, to produce in larger formats.
OLED	OLED uses organic (carbon-based) materials to create light when supplied directly by an electric current, and do not require a backlight to illuminate the set area. OLED screens can be very thin and flexible thanks to that. Since the individual areas are lit up directly, the colours and contrasts are of better quality.

**CCFL - Cold Cathode Fluorescent Lamp*

Data from 2013 about the shipment of TV technologies suggested an increased penetration of LCD at the expenses of CRT and plasma TVs, which are gradually disappearing from the market (see Figure 3). In the long term, the TV replacement cycle seems shifting from the flat panel replacement of CRTs to flat panel upgrades, especially as new features become more affordable (Osmani et al. 2013). LCD TVs represent the majority of the market, plasma has never had a significant share and OLED has a low share at the moment, although it is growing and predicted to be significant[26].

[26] https://www.flatpanelshd.com/flatforums/viewtopic.php?f=2&t=8453 (accessed on 21 March 2018)

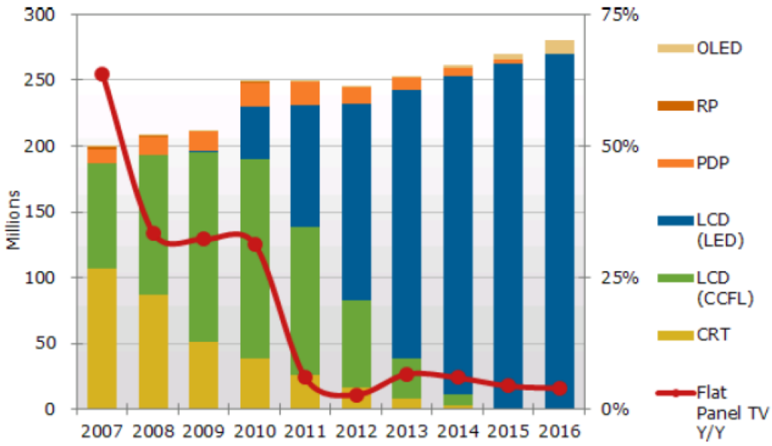


Figure 3 Worldwide TV shipments by technology (Source: Osmani et al. 2013, forecasts from 2013 made by DisplaySearch)

Figure 4 shows a technology share prediction for TVs above 1000 USD. As shown in Figure 4, 4k OLED TVs could replace 4k LCD in the coming years, although the new generation of 8k LCD could also take part of the corresponding market share. According to a TV manufacturer involved in the development of this study, the market of OLED and LCD TVs is well established in the high-end market, and it cannot be expected that one replaces the other.

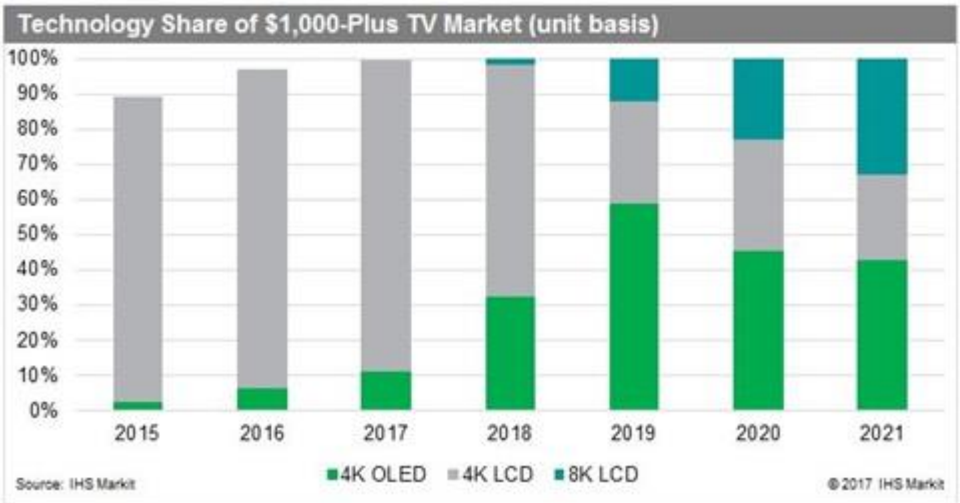


Figure 4 Technology share of $1000-plus TV Market (unit basis)[27]

Figure 5 shows the share of shipments worldwide by main brands, it has to be noted that it includes only LCD TVs.

TV manufacturers involved in the development of this study have indicated that LCD is the dominant technology in the market and that it can be expected that this will be also in the coming years for the

27 http://news.ihsmarkit.com/press-release/oled-tv-expected-grow-more-50-percent-1000-plus-market-2019 (accessed on 20 March 2018)

low-medium market, due to the maturity of this technology. Manufacturers see OLED and eventually micro-LED as relevant for high end markets but without indication of how this relevance will be in the coming years. Quantum dot enriched LCD could also cover an important share of the high-end market in the future.

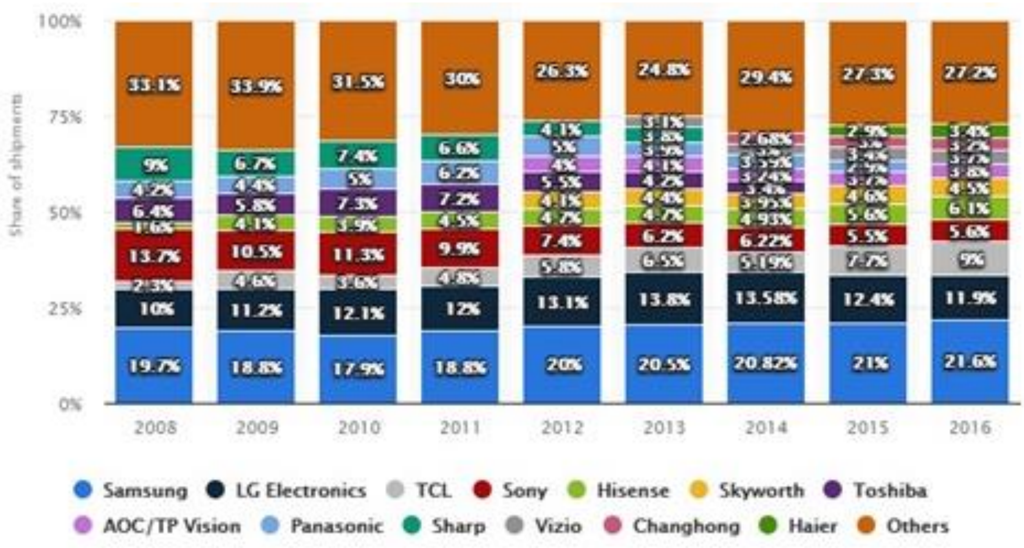


Figure 5 Share of shipments LCD TVs worldwide by main brands[28]

The market share of smart TVs is instead very difficult to quantify at the moment. While some manufacturers indicate that this is about 40% (by units) others estimate it at about 80%, depending on the size of the TV. No matter the share, the demand for this kind of TV is increasing. Some manufacturers expect that smart TVs will have 100% of market share in the near future.

2.3.3 Key actors in the repair market

The TV repair market is mainly covered by professional repairers, normally certified by the brand manufacturers and located at the point of sale, but not necessarily. The do-it-yourself repair seems to be rather low as the repair normally requires electronic knowledge by the user. The availability of disassembly information seems to be as well limited to professionals and in some cases it requires a fee to access it. This aspect influences the cost of the repair operation making it more expensive.

The repair cost is one of the most important factors taken into consideration when deciding whether to repair or not a TV. Repair costs vary depending on the country, especially due to labour costs. With the current trend towards larger sizes of TVs, the repair is requested to take place on-site, which significantly increases the cost of the repair. For instance, in the case of models above 55 inches, the repair might require the intervention of two technicians. According to a TV manufacturer involved in the development of this study, 80% of the repairs performed during the warranty period took place at the users' house.

The cost of the spare part also plays an important role in the repair decision. According to a TV manufacturer involved in the development of this study, the cost of the different parts forming a TV

[28] https://www.statista.com/statistics/267095/global-market-share-of-lcd-tv-manufacturers/ (accessed on 1 March 2018)

ranges between 3% (e.g. power supply or peripherical electronics) and 80% (screen) of the total manufacturing cost of the product, with the screen being the most expensive part (see Table 8). The cost of spare parts would be more or less similar to that of the original parts used in the product.

Some manufacturers reported to have a take back system in place to collect end of life TVs, and from which they refurbish some of the parts, which are then offered at a lower price to reduce the costs of the repair.

Table 8 Relative contributions to the total cost of materials for a flat TV

Part	Relative contributions to the total cost of materials for a flat TV (%)
Screen (e.g. LCD cell, optical sheets, Backlight unit, T-con board, mechanics)	75 - 80
Signal board	7 - 10
Power Supply	3 - 5
Peripheral electronics (Wi-Fi/Bluetooth module, IR receiver board, Keyboard, etc.)	3 - 5
Others	3 - 5

Websites like iFixit.com[29] provide guides and solutions to repair household electronics. In the case of TVs, the website compiles questions from the users regarding different failure modes and descriptions on how to fix them. As an illustrative example, Figure 6 shows a screenshot of the information than can be found. When available, the website provides information about where to purchase the parts needed for replacement and/or tools required. For some TV models the website includes a trouble shooting for general, audio and video problems, one example is showed in the right side of Figure 6, where the list of problems included in the troubleshooting appears.

For the repairs where technical expertise is not required, some manufacturers offer support to customers through contact centres. These types of self-repair are safe and can be performed by the user, as for instance repairs of remote controllers, stand base, adaptors, batteries, power cord.

[29] https://www.ifixit.com/ (accessed on 20 March 2018)

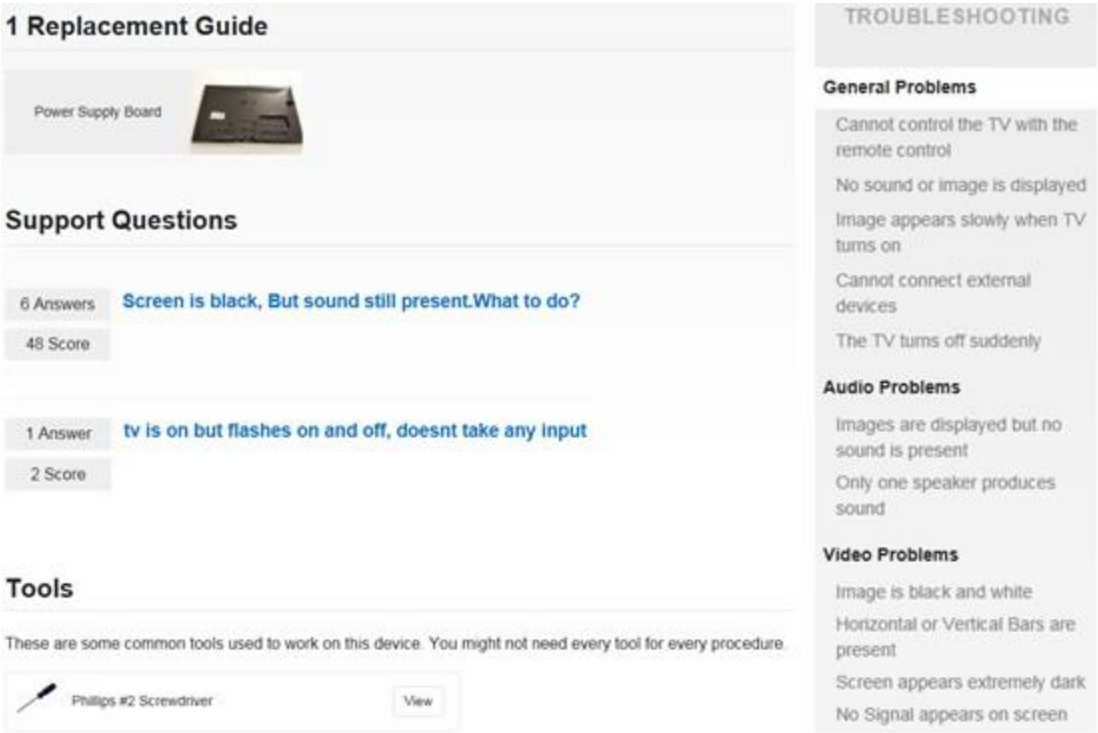


Figure 6 Example of information available in www.iFixit.com[30]

2.4 User behaviour: product's lifetime and replacement

This section intends to provide a summary description about the experience of users with TVs, in particular with respect to repair and upgrade considerations.

The research performed by Bakker et al. (2014) sets the lifespan of a TV as 10 years (from TV acquisition until EoL in the Netherlands with data from 2007-2009). However, according to the input received from TV manufacturers involved in the development of this study, the TV replacement by users in the EU can range from 5 to 10 years.

The TV replacement cycle has apparently decreased on a global scale from 8.4 to 6.9 years, compared to the previous 10-15 year average, when the main replacement was from CRT-to-CRT technology (Osmani et al. 2013). Reasons for this trend could have been the declining of prices, a wider variety of sizes, and the desire for the latest technologies.

Regarding the replacement of TVs, the most important driver in nearly all countries seems to be a desire to trade up in size, followed by wanting to own a flat panel TV with improved picture quality (Osmani et al. 2013). Price related factors are also important in TV replacement decisions. The existing TV being outdated or broken seems also a strong driver for TV replacement, but not one of the top reasons. However, the availability of new advanced features such as internet connectivity and video streaming services in general seems to consumers a nice feature to have but not a principle reason to upgrade a TV. When the replaced TV is still functioning users normally bring it to another room or sell it for second use.

[30] https://www.ifixit.com/Device/LG_32CS560 (accessed on 20 March 2018)

2.5 Product and system aspects

This section intends to provide a technical description of TVs, with the aim of supporting the further analysis of reparability and upgradability aspects.

2.5.1 Design and innovation

Product design of TVs is closely related with market demands. The current trend is towards thinner displays, which may have an impact on the ease of repair, since more compact designs require other types of connectors (e.g. snap-fits or flat connectors) which have to be handled with care by professionals. In addition, the smart functionality of the TV, which is as well growing in demand, requires more complex electronics that may increase the difficulty of repair as well as the level of knowledge required.

The design cycle of a TV can vary between 1.5 and 2 years, depending on the level of innovation involved. New TV models are typically offered on a yearly basis, but the actual process for each model can start up-to 2 years in advance. The manufacturing process itself can be rather short (typically few months) compared to the overall manufacturing cycle, i.e. from conception of the product to its placing on the market.

2.5.2 Functions

As described in section 1.1, the main purpose of a TV is to display broadcast television images (i.e. to receive audio-visual signals). The television functions as a graphical interface between the received signal and the user.

Additional functions of TVs can include:

- Streaming services, apps and internet browsing (for smart TVs),
- Recorder of Digital Video Broadcast (DVB) (normally by attaching an external USB memory),
- Video output for external sources like DVD, Blue Ray players, game-consoles.

The main difference between TVs and other products of the same family (displays) is the possibility to decode broadcast signals (signal board), but there are as well other differences related to picture settings. For example, TVs are intended to be seen by several people at a certain distance and with moving images, while monitors of computers are intended to be seen by a single person with a maximum distance of one meter and with steady images. The environment where the display is planned to be used also has an influence on the design (e.g. medical displays). Although some similarities may exist, these aspects need to be taken into considerations when analysing different types of displays and before extrapolating characteristics of computer displays to commercial TVs.

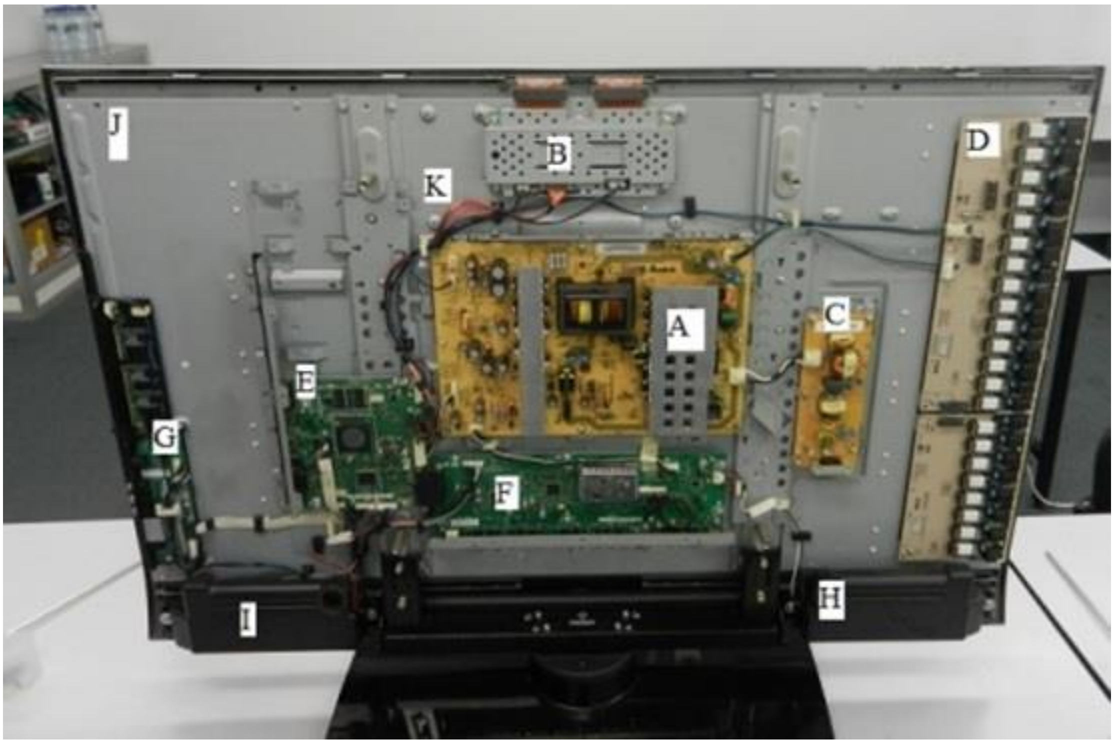
2.5.3 Parts

Table 9 provides the list of typical parts included in an LCD computer display (Socolof et al. 2005). These can be considered similar to those of an LCD TV, with the exception of the tuner card which is present only in TVs.

Table 9 Typical parts of an LCD display (Socolof et al. 2005)

Function	Part
Image display	Liquid crystals
	Thin-film transistors
	Electrodes
	Colour filters
	Polarizers
	Orientation film
	Backlight
Glass structure	Front panel
	Back panel
Electronics	LCD controller PCB
	Backlight PCB
	Column and row driver PCBs
	Other PCBs (e.g. power PCB and sound PCB)
Casing	Plastic casing and stand
	Plastic frame and stand

Figure 7 provides a graphical representation of how key parts of an LCD TV can be arranged, while Figure 8 shows the parts of an OLED TV. Variations exist among manufacturers, and these are more significant for OLED TVs. As it can be appreciated, the circuits are different for LCD and OLED TVs, although they have similar parts (main board, T-con board, speakers, etc.). Parts like WIFI board and MOIP are characteristics of a smart TV. Manufacturers are reducing the amount of boards by integrating them (for example, the T-con is often integrated in the main board). Another important part that is not included in the two representations is the remote control.

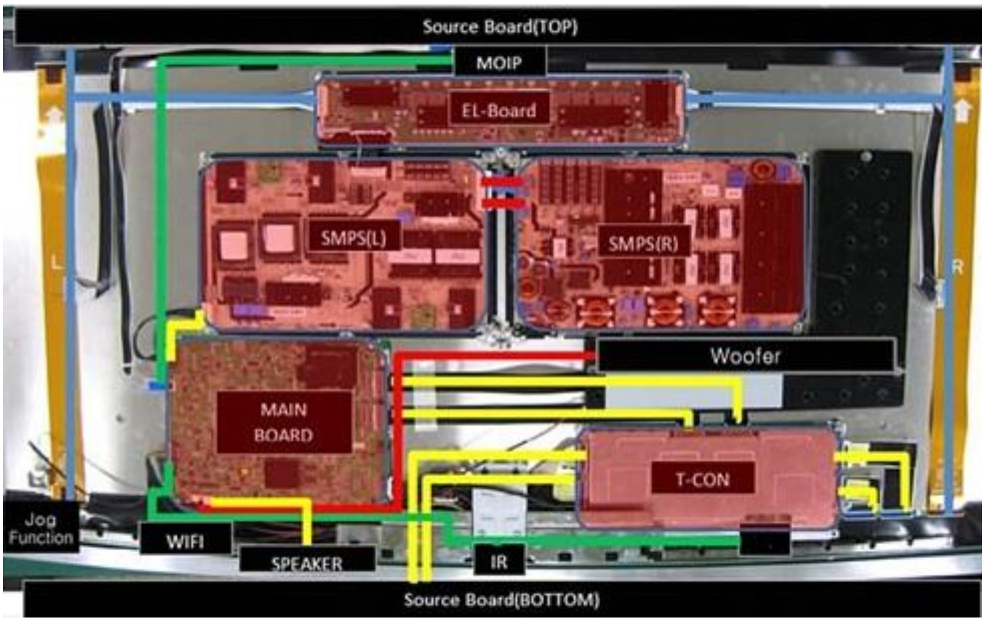


A: Power Board
B: T-con Board
C: EMI Filter board (sometimes is built into the Power Board)
D: Inverter Board (sometimes is built into the Power board and called as I/P board)
E: Main Board
F: Jackpack

G: Side Key Panel/Power Control/Remote Receiver Unit (IR/LED control)
H: Left Speaker
I: Right Speaker
J: Display module
K: Low-voltage differential signaling (LVDS) cable

Figure 7 Parts of an LCD TV[31]

[31] http://www.electronicrepairguide.com/lcd-tv-repair-basic.html (accessed on 21 March 2018)



MOIP: Multimedia over Internet Protocol

SMPS: Switch mode power supply, left (L) and right (R)

IR: Infra-red receiver

Figure 8 Parts of an OLED TV[32]

A BOM has been found for a LCD-TV of 20.1" with an integral cold cathode fluorescent lamp as backlight system (Ardente and Mathieux 2012).

Table 10 BOM of an LCD-TV (Ardente and Mathieux 2012)

Component		Material	Mass (g)
Frames / covers	Back cover	ABS	920
	Main front cover	ABS	340
	Support	ABS	250
	Secondary front covers	PC	15
		Plastic unspecified	98
	Main metal frame	Iron/steel	1580
	Metal frame (#2)	Iron/steel	261
	PCB support	Iron/steel	48
	Support for cable support	Iron/steel	34
		Plastic unspecified	38

[32] https://electronicshelponline.blogspot.com.es/2016/02/samsung-oled-tv-smps-troubleshooting.html (accessed on 21 March 2018)

Component		Material	Mass (g)
	Internal support	Aluminium	353
	Lamps support	Aluminium	30
PCB and connectors	Main PCB	Various (rich in precious metals)	245
	PCB (secondary)		61
	PCB (secondary)		1
	PCB	Various (rich in precious metals)	55
	Film connectors (#4)		4
	PCB (secondary)	Various (poor in precious metals)	300
	PCB (secondary)		8
LCD screen	LCD (larger than 100 cm2)	Glass, plastics, others	473
	Plastic light guide	PMMA	1565
	Plastic foils	Plastics	100
	Fluorescent lamps (#2)	Glass + various	8
Others	Capacitors (#2, diameter larger than 2.5cm)	Various	9
	Fan	Plastic, steel	19
	External cables	Copper, plastic	120
	Internal cables	Copper, plastic	25
	Speakers	Steel	137.2
		Plastics	58.8
	Screws	Iron/steel	30

2.5.4 Software

The operating system installed in normal TVs (i.e. not a smart TV) is normally not subject of updates, as this type of TV runs with the same software during its entire life. This software is used to control volume, brightness, subtitles, image format, tune channels, etc.

With the introduction of smart TVs, manufacturers seem to be upgrading the software/firmware for a better use experience and efficiency of the system. Normally the updates can be downloaded from the manufacturer's website and it can be downloaded directly from the TV with an internet connection or by pairing a device (computer or tablet) to the TV (directly or via an intermediate storage device such as a USB stick).

Issues with software updates might arise if future versions of software cannot be installed due to insufficient pre-installed memory. Moreover, consumers and testing organisations detected some smart TVs which after a few years of use are not compatible with the most common apps for video streaming, and therefore are turned into a non-smart TV.

3 ASSESSMENT OF REPARABILITY AND UPGRADABILITY

Three levels have been conceived for assessing the reparability and upgradability of ErP (Cordella et al. 2018a):

- Calculation of quantitative indicators (quantitative assessment), which aim at supporting the analysis of the technical complexity of products and of environmental/economic impacts associated to repair scenarios;
- Definition of checklists of qualitative attributes (qualitative assessment), which aim at establishing requirements with which to improve the reparability and upgradability of products;
- Rating and aggregation of parameters into indices (quali-quantitative assessment), which build on the previous elements and aim at assessing reparability and/or upgradability of alternative design options.

The adoption of one or more levels depends on specific targets, familiarity with tools and methods, and availability of data.

3.1 Identification of relevant aspects and priority parts

Independently from the level of assessment, as preliminary step it is required to identify relevant aspects and priority parts for the repair/upgrade of a product, TVs in this study.

Products are generally made of a large number of parts. In order to reduce the complexity of the assessment, it may be appropriate to focus only on those parts that are more relevant for repair and/or upgrade operations, which are referred to in this context as "priority parts". Relevance is expressed in this context in terms of functional importance and likelihood of failure/upgrade (Cordella et al. 2019b).

The identification of priority parts is a core part of the assessment which should as far as possible based on the analysis of:

1. Failure modes, their frequencies and the impacted parts;
2. Frequency and distribution over time of repair operations;
3. Typical upgrade features and frequencies of upgrade;
4. Technical, market and legal barriers associated with the repair/upgrade operations (e.g. unavailability of repair instructions, spare parts and/or software updates, costs, disassembly steps/difficulty).

The analysis can be fed by different sources of information as for instance: technical-scientific documents containing data on product's design analyses (e.g. Failure Mode and Effect Analysis, stress analysis and damage modelling); durability/reliability testing results; risk assessments; statistical surveys about accidental breakdowns and normal wear-out; experts' judgements and field experience (e.g. demand of spare parts). All in all, insights can be provided by a broad pool of sources that include: manufacturers of products and parts, repairers, reuse and remanufacture organisations, consumer testing organizations, insurance companies, researchers and regulators.

When the number of priority parts is considered too large to be operational, priority parts could be ranked based on economic, environmental and technical considerations.

Due to the difficulties in gathering robust quantitative information, a matrix has been defined for the quali-quantitative assessment and selection of priority parts (see Table 11). As a practical guidance, it is considered that:

- The functional importance of a part is higher if that part is necessary in the product to deliver main functions[33];
- A higher priority is set for parts more likely to fail. A 10% has been indicatively set as threshold. A lower priority could be associated with failure rates below 10% or when supported by qualitative information.

Table 11 Matrix for the quali-quantitative assessment and selection of priority parts

		Likelihood of failure	
		High	**Normal**
Functional importance	**High**	3	2
	Normal	2	1

Note: the higher the score the higher the priority ranking

3.1.1 Failure modes and impacted parts

A study conducted by WRAP (2011) on three LCD TVs, identified the following most common faults in these products:

- Screen faults – due to damage, sometimes caused by impact;
- Power circuit board faults;
- Main circuit board faults – including hardware and microchip software;
- Damage to connections – often between circuit boards;
- Damage to television stands.

Their study aims at providing guidance to buyers and manufacturers to procure and produce longer lasting and easier to repair TVs. According to that study, assemblies such as the screen that are fragile and critical to use, are particularly susceptible to damage. Damage occurs through strains on connectors and printed circuit boards that are subject to flexing, causing strain on soldered joints. Electronic parts and solder can also become damaged by variations in temperature and humidity for example, that can aggravates poorly soldered joints and corrupts chips. Continuing with this work, WRAP published a more detailed study about durable LCD TVs (WRAP 2014). Common failures and impacted parts of TVs were identified in that report, their findings are summarised in ANNEX I.

A study about user behaviour in Europe[34] identifies other problems for flat TVs. The most common problem would be the remote control followed by screen and connectors. For more recent televisions, the streaming from the smartphone or tablet is also a common problem, and for smart TVs the portal with apps.

Another common failure in LCD televisions are faulty capacitors that can lead to: flickering screen, screen image disappears after several seconds, dim screen, slow start, power LED on but no image,

[33] According to prEN 45552 (2018) a primary function is necessary to fulfil the intended use, whilst a secondary function enables, supplements or enhances the primary function(s). Note: depending on the product, the function of a part could also include aesthetic aspects.
[34] Confidential information from stakeholders

shuts down for no apparent reason, no LED no picture or no sound, sound and no picture and unusual colours. The capacitors can be examined on the televisions and see if they are in bad condition[35].

Other failure modes have been also identified by independent repairers and websites containing repair information for LCD TVs[36]. These are included in ANNEX I, as well as other failures identified with the input of stakeholders involved in the development of this study.

Building on the information gathered, a summary of failure modes and respective causes is provided in Table 12 (the list also contains failures of smart TVs).

Table 12 Typical failure modes and cause of LCD TVs

Failure mode	Cause	Source(s)
Remote control does not work	- Electronic faults on the PCB of the remote control, which could be caused by poor connections, part failures and/or battery leakage/corrosion - The print on the keypads might get worn - Damaging the casing - Insert batteries the wrong way - Not following the instructions	WRAP
Screen related Image disappears immediately Lines in the image Image showed with a mosaic effect Entire LCD defective	- Failure in the inverter that supplies energy to the backlights - Weakening of backlights - Failure in one of the parts in the T-con board - Failure in the transference of the low-voltage differential signalling - Failure in one of the parts in the T-con board - Failure in the low-voltage differential signalling - Overheating image processor	Independent repairers
Failure when streaming from smartphone/tablet	- Failure when pairing the TV with the devices sometimes due to lack of compatibility between the devices or complex set up	Consumer organisation
Connectors	- Weak mounting on the main PCB or by a user mistake in forcing the plugs into the connector	WRAP
Software updates of the smart TV platform	- Lack of minimum support during the lifespan of the TVs for the most relevant video streaming apps (not even the pre-installed ones)	Consumer organisation
Digital synchronizer	- Complex set up or unclear instructions	WRAP

[35] http://apike.ca/content/2012/11/how-find-bad-capacitors-tv.html (accessed on 21 March 2018)
[36] http://buscotecnicos.com/blog/?p=519 (accessed on 23 March 2018)

Poor sound quality or no sound	- Case vibrations - Speaker damaged physically - Fault with the sound PCB	WRAP
USB ports not working	- Burn out ports - Outdated firmware of the TV - Compatibility issues with the format of the USB (NTFS, FAT32 or exFAT)	Stakeholders
No power supply	- Poor contact of the on-off switch - Fault on the power PCB (e.g. failure in the transformer)	Stakeholders

3.1.2 Typical repair operations

Repairing a TV requires electronic knowledge from the repairer and access to the service manual of the product, these two aspects influence in raising the price of the total cost of the repair operation, to the point that the consumer could consider more convenient the purchase of a new TV.

Problems related to the different boards could be easily fixed by facilitating the replacement of the corresponding board and/or the specific part on the board (e.g. fuse, capacitors, diodes). To do so, manufacturers should facilitate the disassembly of the TV by avoiding soldering of the board and use robust connectors or plugs. An example of the required steps to disassemble a flat TV is given in section 2.2.2. Websites like iFixit include detailed manuals about how to replace specific parts of a TVs (for example, one of them describes how to replace a faulty diode from the power board of an LCD TV).

According to the input of stakeholders involved in the development of this study, the most expensive part to replace in a TV is the screen (LCD module). The most common and cheaper repair operations are instead related to remote control and power supplies (capacitors). Repair of main board, power board or sound board can be found at a middle position. Repair of speakers can be expected to be relatively cheaper when the problem is not related with the board. Faults in the main board or the display module can be fixed by either replacing or repairing these parts.

3.1.3 Typical upgrade operations

The upgrade of TVs normally implies the substitution of the product by a new one. The upgrade of specific parts or features appears limited. For example, upgrading from LCD to OLED TV is impossible as these are completely different technologies which require different performance of components. On the other hand, upgrading a normal LCD TV to a smart TV can be carried out by connecting a smart TV receptor (like for example the google chromecast or the apple TV). In these cases the TV only needs to have the correct connector to plug the receptor.

Software upgrades are instead possible for smart TVs and they are provided by the manufacturer. Their frequency of update is also influenced by the updates in the applications or platforms that smart TVs offer. Limitations on processing power or space in the hard drive can limit future upgrades of software in smart TVs, as identified by consumers and testing organisations in some models. One solution to keep the smart TV updated was offered by Samsung called the "evolution kit". It consisted of a device, in the form of a small box, which improves the performance of a TV through enhanced processors once connected. The kit included the latest contents and features developed by the manufacturer. Nevertheless, this kit was not very successful among consumers and it is not offered by Samsung in new TV models.

3.1.4 Priority parts

A list of priority parts, to be considered in the following steps of the assessment, has been defined based on Table 11.

Table 13 List of priority parts with relevance basis and weight (calculated according to the matrix defined in Table 11)

Part	Failure likelihood	Functional relevance	Weight
Main board	High (a)	High	3
T-con board (usually combined with the main board)	High (a)	High	3
Sound board (usually combined with the main board)	High (a)	High	3
Power board / Internal power supply	High (a)	High	3
Inverter board (sometimes combined with power board)	High (a)	High	3
External power supply (when applicable)	High (b)	High	3
Speakers	High (a)	High	3
LVDS connectors	High (a)	High	3
Backlights (Lamps / LEDs)	High (a)	High	3
TV stand	Normal (a)	High	2
Remote control	High (a)	High	3
Connectors for external equipment (c)	High (a, b)	Normal	2
Capacitors, batteries and accumulators (c)	High (a, b)	High	3
DVD/Blue ray module (when applicable)	Normal (b)	Normal	1
HD/SSD (when applicable)	Normal (b)	Normal	1

(a) Input from section 2.1.1
(b) Listed in the revised Ecodesign Directive on displays[37]
(c) According to industry experts, these parts are included in boards (e.g. main board, T-con board, power board) and high level skills and equipment are required for their repair. In EU, due to price constrains, the entire board is usually replaced rather than these parts. Repairs of these sub-parts are instead carried out in other regions of the world where labour costs are lower.

3.1.5 Technical barriers for repair and upgrade

According to stakeholders involved in the development of this study, the most relevant barriers which can hinder repair and/or upgrade are:

- Difficulties in the identification of parts. In some cases it can be hard to identify parts, for instance when marking has become illegible due to overheating. In such cases, the availability of diagrams and lists of parts is important to facilitate their identification. However, this information is not always available to independent repairers.
- Use of adhesives. Some manufacturers use adhesives to fix the back cover of TVs which makes disassembly difficult with common tools.
- Use of proprietary tools. The use of commonly available tools should be preferred over that of proprietary tools for the disassembly of TVs.
- Difficulties in the identification of the problem. When the display is used as interface to provide a diagnosis of the problem but it does not work, it can be complicated to identify the problem. In such cases, a possible solution could be to allow the switch to auxiliary interfaces like a blinking LED.
- Spare parts. Some parts of the circuit boards are difficult to find on the public market as spare parts and in some cases even impossible, especially for the parts of the T-con board. On the

37 http://ec.europa.eu/transparency/regcomitology/index.cfm?do=search.documentdetail&Dos_ID=16995&ds_id=59740&version=2&page=1(accessed on 11 June 2019)

other hand, some manufacturers like LG[38] already provide spare parts publicly for some of their models, where circuit boards can be found as well.

- Lack of standardisation of LCD screens. In the study "Réparez vous-même vos appareils électroniques" (Boyer 2014), it was identified that screens with identical specifications often have different connectors and operate with different signals (number of leads, signal frequency, voltage). Even screens with identical dimensions, mounting means and connectors may not be interchangeable. The same model of TV may be equipped with a different type of LCD and the firmware may or may not be adaptable to another type. Repair could be made much easier if screens of identical size and specifications had identical interfaces, at least for a given brand. This would allow repairers to stock common parts and potentially recover parts for repair purposes from appliances presenting another defect.

The main barriers specifically encountered for upgrade are the lack of processing capacity of the TV and/or the insufficient pre-installed memory, necessary to support newer versions of software and to store them, respectively.

[38] http://www.spareslg.com/gb/familias-tv-20-# (accessed on 8 June 2018)

3.2 Fully quantitative approaches

From a purely design-oriented perspective, repair and upgrade of products are influenced by the complexity of its assembly/disassembly. This is also linked to the concept of disassemblability, i.e. the ability to disassemble a product in its parts in a reversible way. As described in the Annex, several methods can be found in literature to measure such complexity (see for instance: Das et al. 2002; Fang et al. 2015; Gershenson et al. 1999; Giudice and Kassem 2009; Kobayashi and Higashi 2013; Olson and Riess 2012; Soh et al. 2015; Vanegas et al. 2016). In particular, the following approaches have been considered of possible interest to assess the disassembly complexity:

1. Analysis of disassembly sequences and disassembly depths;
2. Calculation and analysis of the time for disassembly (Vanegas et al. 2016).

Both approaches can be applied to understand the difficulties associated to the disassembly and extraction of priority parts of TVs, and to potentially identify design options facilitating repair/upgrade operations. The time for disassembly is an aggregated parameter to assess the overall disassemblability of products taking into account aspects as number of disassembly steps, easiness to access parts or difficulty of the operation itself[39]. Although more comprehensive, it is anticipated that the time for disassembly is even more sophisticated and difficult to apply compared to the separate analysis of its integrating aspects.

However, the use of LCA has to be mentioned as well among the quantitative approaches since the resulting calculations are necessary elements to understand impacts associated to repair/upgrade scenarios and conditions under which they can be favourable. This could also be supported by LCA-based indices quantifying relative benefits over a reference scenario (Cordella et al. 2018a, Tecchio et al. 2016).

Quantitative approaches can provide useful tools for the assessment of the product reparability and upgradability, but requires a certain effort both in terms of data input and calculations. Although data collection and assessment and verification of results can be difficult in practice, a critical interpretation of the results can provide valuable information about the ability to repair and upgrade products, as shown for TVs in the following sub-chapters.

3.2.1 Life Cycle Assessment

A streamlined LCA has been performed to analyse the environmental impacts associated to the manufacturing of an LCD TV and to replacement / repair scenarios.

3.2.1.1 Goal and scope

The main goal of this LCA application is to understand when the repair of TVs could be a more environmentally friendly solution than substituting faulty TVs.

As represented in Figure 9, the life cycle stages considered in the assessment are manufacturing of the TV (including raw material extraction and production of parts), transport and use of the product. Repair has been also included in the respective scenarios. The end-of-life treatment of the TV has not been included in the assessment to simplify the analysis, which focuses on the use and repair of TVs. The end-of-life can vary depending on the geographical contexts and is not considered to change significantly between replacement and repair of TVs. The main difference is that this will occur later

[39] Disassembly time could be measured, but this would be subjective since the overall length depends, among other factors, on the operator skills. Standard time units representing the effort needed to perform an operation could thus be assigned to each task of the disassembly process

in time in case of repair, for an overall reduction in the production of electrical and electronic waste, proportionally to the life time extension.

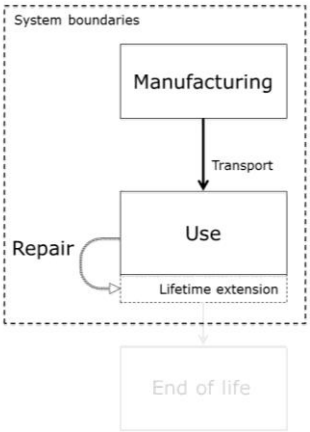


Figure 9 System boundaries of the LCA study

The functional unit of this study is the use at home of a virtual LCD TV of 20.1" under average European conditions (see Table 14Table 14 for further details). Two scenarios have been defined to model the use stage of the TV (see Figure 10):

1. Replacement Scenario: the product A is used during its average lifetime (10 years, as estimated in section 1.4) without the need of being repaired. At the EoL, the TV is replaced with a new product B.
2. Repair Scenario: a failure occurs during the use of the product and this needs to be repaired (the product is called A_R). The failure could occur at different times during the use stage (e.g. at year 1, 4 or 8).

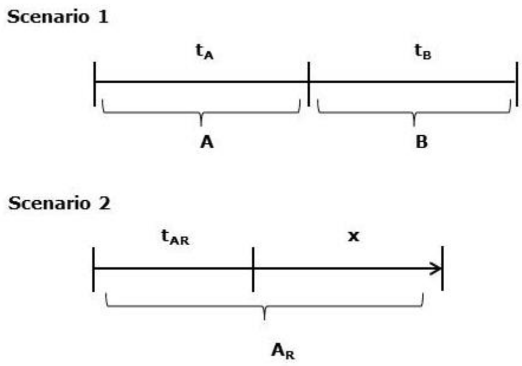


Figure 10 Use stage scenarios

The following nomenclature is used in the assessment:

- A: TV model where no repair takes place;
- B: TV model which replaces model A;
- A_R: TV model where repair takes place;

- t_A: expected lifetime of TV model A;
- t_B: expected lifetime of TV model B;
- t_{AR}: lifetime of TV model A_R before a failure occurs;
- x: additional time of use of TV model A_R after repair.

Following the description of the scenarios 1 and 2, and taking into account the life cycle stages considered in the scope of this study, the environmental impacts of each TV model can be calculated as follows:

$$I_i = M_i + T_i + (u_i \cdot t_i)$$

Where:

- I_i: overall environmental impacts of product i;
- M_i: environmental impacts during manufacturing of product i;
- T_i: environmental impacts during distribution of product i from factory to consumer;
- u_i: environmental impacts per year of use of product i;
- t_i: expected lifetime in years of product i.

In the case that a repair operation takes place, the environmental impacts during manufacturing and transport of the spare part (M_{RP} and T_{RP}, respectively) have to be also considered in equation 1.

From the observation of Figure 10 it appears evident that the lifetime of products A and B does not necessarily match with the lifetime of product A_R. The two scenarios have to be assessed with respect to the same period of time, which is t_A + x. This means that the impacts due to the use of product B for a time t_B have to be allocated to the period x – (t_A – t_{AR}).

To understand when repairing a TV can be beneficial (Scenario 2) means to analyse how long the repaired TV has to last (i.e. "t_{AR} + x" according to the nomenclature used in Figure 10) in order to compensate the environmental impacts of replacing a product (Scenario 1). This is also referred to as "break-even time" in the present application. Repair can be convenient for periods of use longer than the break-even time.

3.2.1.2 Life cycle impacts modelling

The method used to calculate the environmental impacts is the CML-IA baseline v3.05[40], which considers the following impact categories: abiotic depletion (kg Sb eq), abiotic depletion (fossil fuels) (MJ), global warming potential (100yr) (kg CO_2 eq), ozone layer depletion (kg CFC-11 eq), human toxicity (kg 1,4-DB eq), fresh water aquatic ecotoxicity (kg 1,4-DB eq), marine aquatic ecotoxicity (kg 1,4-DB eq), terrestrial ecotoxicity (kg 1,4-DB eq), photochemical oxidation (kg C_2H_4 eq), acidification (kg SO_2 eq), eutrophication (kg PO_4eq). These have been quantified based on the attributional modelling approach described below, and with the support of the software tool SimaPro 8.5.2.0[41] and the Ecoinvent database 3.5[42, 43].

[40] https://www.universiteitleiden.nl/en/research/research-output/science/cml-ia-characterisation-factors (accessed on 7 February 2019)
[41] https://simapro.com/ (accessed on 7 February 2019)
[42] https://www.ecoinvent.org/database/database.html (accessed on 7 February 2019)
[43] The European Commission has been working on the development of a harmonised method to assess the Environmental Footprint of products and organisation, https://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm (accessed on 3 December 2019)

The bill of materials used to model the TV manufacturing stage is shown in section 1.5.3, which refers to a 20.1" screen size. The trend towards larger screen sizes of TVs is analysed indirectly in the sensitivity analysis by modulating the parameter M (see section 2.2.1.2). The same bill of materials has been used for products A, B and A_R. Energy consumption and emissions in the manufacturing stage have not been considered, as their contribution to the environmental impacts is negligible compared to that of the materials (Ardente and Mathieux 2012).

The distribution of the product to the consumers has been modelled using the default scenario provided in the guidelines for Product Environmental Footprint Category Rules[44].

Finally, the energy consumption during the use stage has been modelled using the data reported in Table 14Table 14. It has been reported from stakeholders that the average use of TVs change over time and that, with the smart functionality of TVs, consumers could use TVs daily longer, between 6 and 8 hours/day (i.e. +50 -100% compared to the average value considered in Table 14Table 14). For the purpose of this assessment, data from has been used and a sensitivity analysis performed.

At first instance, it has been assumed that all the TV models (A, B and A_R) have the same characteristics in terms of manufacturing, transport and use. An allocation factor has been attributed to the TV model B based on time (see section 2.2.1.1). Variation of key parameters has been applied in a sensitivity analysis.

For the repair scenario, three parts of the TV have been selected based on the list of priority parts presented in section 2.1.4 and on the inventory data available. These are: main PCB, T-con board, and speakers.

Table 14 Assumptions during the use stage (Ardente and Mathieux 2012)

Parameter	Amount	Units
Product lifetime	10	years
Use of the product on mode	4	hours/day
User of the product in standby mode	20	hours/day
Energy consumption on mode	40	W
Energy consumption standby mode	0.3	W

3.2.1.3 Results

Figure 11 shows the contributions of manufacturing, transport and use stages to the impacts associated to product A without considering repair. The results show that manufacturing is the primary contributor to the life cycle impacts for all categories. Depending on the impact category, contributions vary from almost 80% to nearly 100%, as it is the case for abiotic depletion. Based on the modelling assumptions made and the data used, impacts of manufacturing are mainly due to the circuit boards, i.e. T-con board, main board and sound board. These represent 93% of the global warming potential impact for the manufacturing stage. For the other impact categories their

[44] http://ec.europa.eu/environment/eussd/smgp/pdf/PEFCR_guidance_v6.3.pdf (accessed on 25 January 2019)

contribution ranges from 87% in photochemical oxidation to 98% in abiotic depletion and acidification.

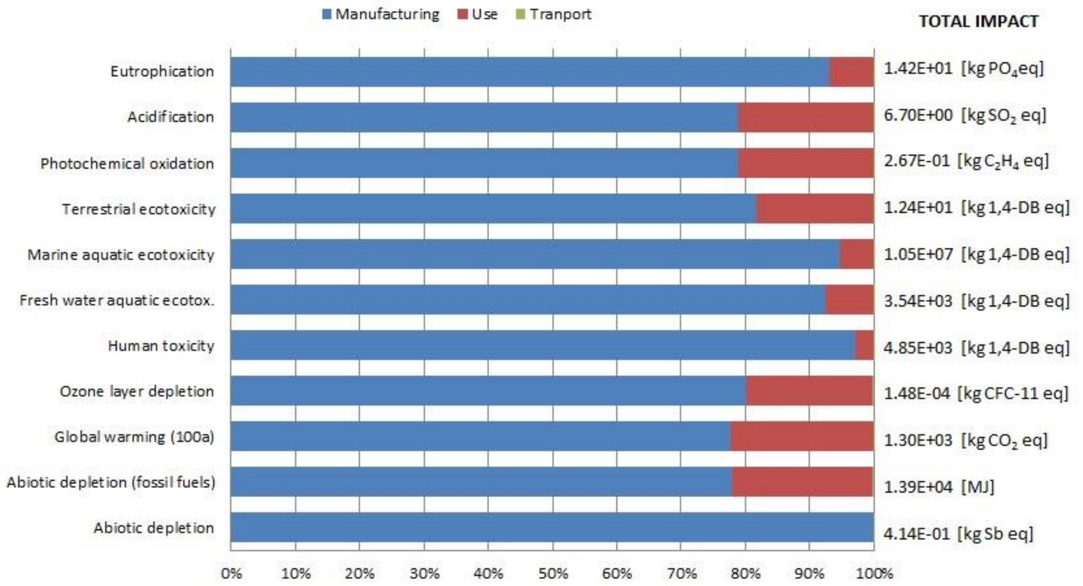


Figure 11 Contribution to the environmental impacts of the different life cycle stages of an LCD TV

Following the modelling described in the section above it has been calculated after how many years repairing a TV could be considered as a more environmentally friendly scenario than replacing the TV with a new one.

It has been assumed that the failure of parts occurs at year 4. Results of the calculations for Global Warming Potential (GWP) are shown in Table 15. The year of failure does not influence the results from an environmental point of view: the lifetime after repair (x) varies if failure occurs for example at year 1 or 8, but not the break-even time, i.e. the total lifetime that the TV should last to be an environmentally viable solution. When calculating the break-even time for other impact categories the number of years obtained did not change significantly (variations are of the order of ± 0.1 years).

The repair operation implies additional impacts due to the replacement of the part, which are compensated if the product is used longer up to the point in which repair becomes potentially more beneficial than replacing a device. In the case of T-con board and main PCB, the device should be used at least 3-4 years longer than the average to make repair beneficial. The choice if to repair or not the product will depend on socio-economic considerations. Extra-time of use is instead negligible in case of the speakers. This means that repair of speakers could be always an attractive solution.

Table 15 Calculated lifetimes when the GWP impact of Repair and Replacement Scenarios are equals

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

As expectable, it can be noticed that the lifetime of the TV has to be extended more years when higher environmental impacts are associated to the part to be repaired. From the inventory used in this study, the T-con board has a higher mass than the main PCB and, therefore, a higher impact. Repairing specific parts (e.g. capacitors) without changing the entire board could result in reduced environmental impacts. Regarding the speakers, their environmental impact is sufficiently low to not require an extension of the lifetime to compensate the emissions.

Contribution of the use stage to overall life cycle impacts of the TV, as calculated in the present study, appears lower than other available LCA information about LCD TVs (see Figure 12 and Figure 13 for comparison). This difference could be due to the assumptions made for power consumption of the TV and hours of use of the device. According to a literature review conducted in this study, values for power consumption could be up to 180 W and 5W for the on mode and standby mode respectively (Thomas et al. 2012). This value is influenced by the size of the screen and the energy efficiency of the product/technology. A sensitivity analysis on the energy use for this phase is performed in section 2.2.3.2.

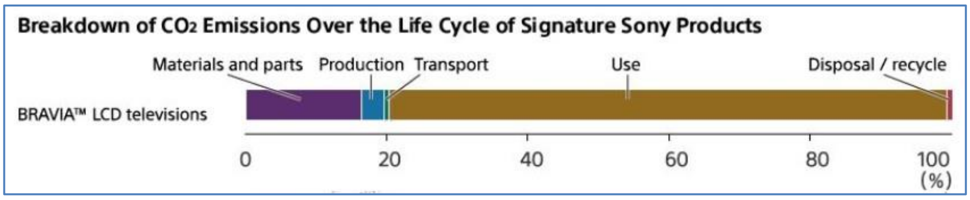


Figure 12 LCA of a Sony Bravia LCD TV[45]

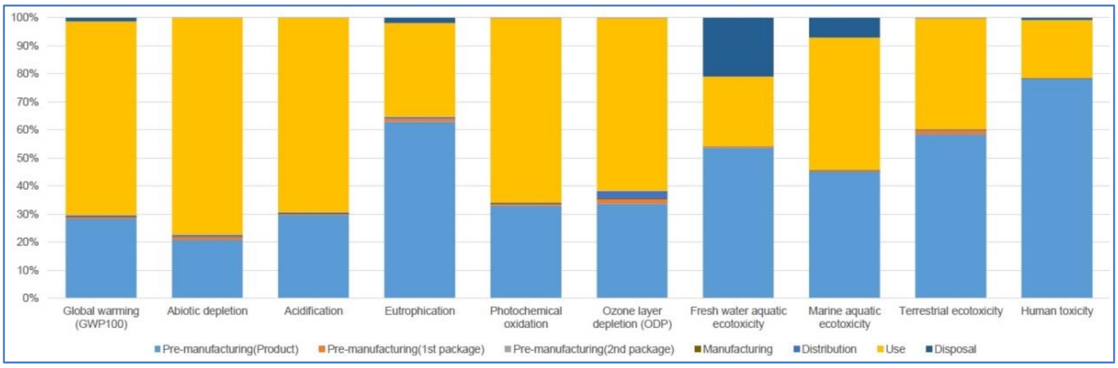


Figure 13 LCA of a 55-inch Ultra HD display by Samsung[46]

3.2.1.4 Sensitivity analysis

The modelling and assessment of the impacts associated to the life cycle of an LCD TV is based on a series of assumptions. A sensitivity analysis has been performed for the scenarios involving the failure of the main PCB to understand the influence of the most important assumptions on the GWP impact. The parameters considered are:

- The environmental impact due to manufacturing (M_i) and the use of the device (u_i),
- The expected lifetime (t_i).

To analyse the variability or results, each parameter has been multiplied by a factor ranging from 0.5 to 1.5 (i.e. corresponding to variation of ± 50%), as shown in Figure 14 and Figure 15. Two cases have been analysed:

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[45] https://www.sony.net/SonyInfo/csr_report/environment/products/dfe.html (accessed on 11 February 2019)
[46] https://images.samsung.com/is/content/samsung/p5/sec/aboutsamsung/sustainability/pdf/2018/2018Life-CycleAssessmentforHHPandDisplay_180831.pdf (accessed on 11 February 2019)

- Case 1: product A is equal to product B (which means that $M_A = M_B$, $t_A = t_B$, $u_A = u_B$), and therefore variations in these parameters affect both products equally;
- Case 2: the life cycle impacts of product A are kept unvaried, while the life cycle impacts of product B are varied.

Results are shown in Figure 14 and Figure 15 for Case 1 and Case 2 respectively.

For Case 1 it is observed that:

- If the impact of manufacturing a TV is higher, importance of materials increases and the break-even time decreases, meaning that a shorter lifetime extension is needed to compensate the repair of the device. This corresponds to a smaller contribution of the repaired part to the overall impact of the manufacturing stage, and is consistent with the results reported in Table 15. Vice versa, the opposite occurs when impacts of manufacturing are lower.
- The calculation of the break-even time is not affected by the use stage if products A, B and A_R have the same energy consumption (only impacts due to materials are relevant to calculate the break-even time).
- The shorter the expected lifetime of the device the shorter the break-even time, since the relevance of materials increases. The break-even time varies in the same order of magnitude as the factor applied to TV models A and B, meaning that it is reduced by 50% when applying a 0.5 factor to the expected lifetime and increased by 50% with a 1.5 factor.

The results of the sensitivity analysis for Case 2 have the same pattern as for Case 1. More specifically, for Case 2 it is observed that:

- Same results are obtained when M_A is kept constant and M_B is varied (while other parameters are kept unvaried).
- When the energy use decreases for product B (e.g. due to increased energy efficiency or shorter use daily), the break-even time becomes slightly longer because the impact of product B decreases[47].
- The break-even time is reduced by 13% when a 0.5 factor is applied to the expected lifetime and by 6% with a 0.75 factor. Vice versa, this is increased by 6% and 13% with the application of 1.25 and 1.5 factors, respectively. Variability of results is lower than for Case 1 since only product B is affected.

[47] The hours of use of TVs could be +50/100% longer than the average considered in this assessment. This means that user behaviour could have a high influence in the assessment of the environmental impacts.

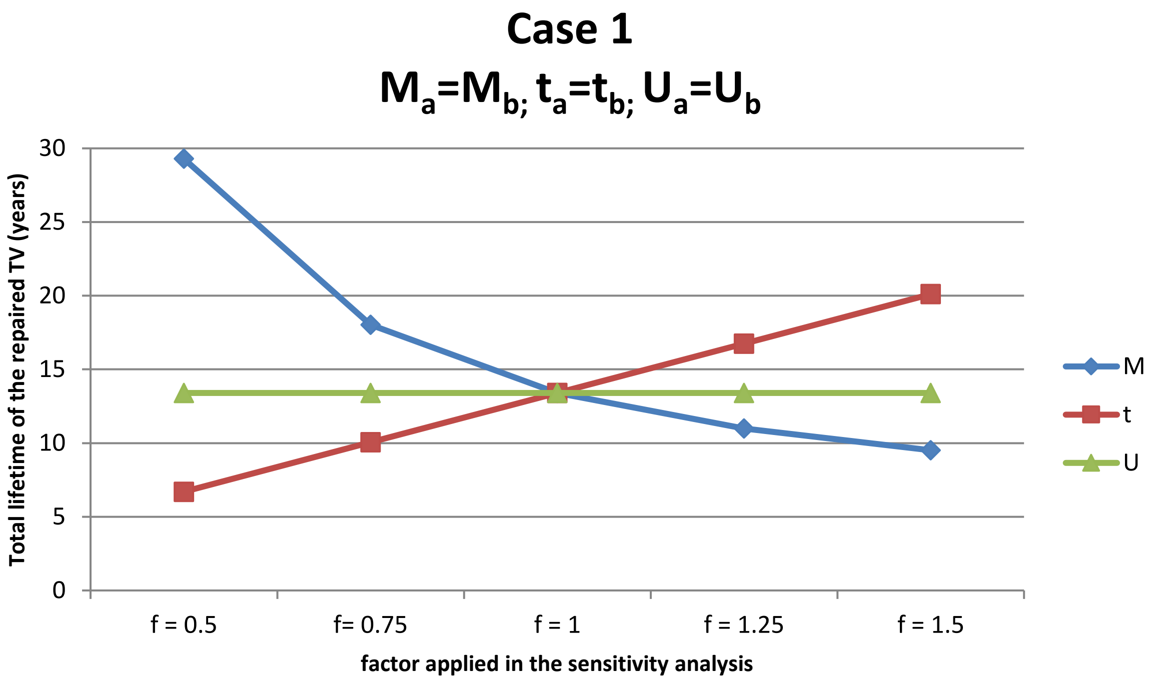


Figure 14 Results of the sensitivity analysis for GWP in Case 1

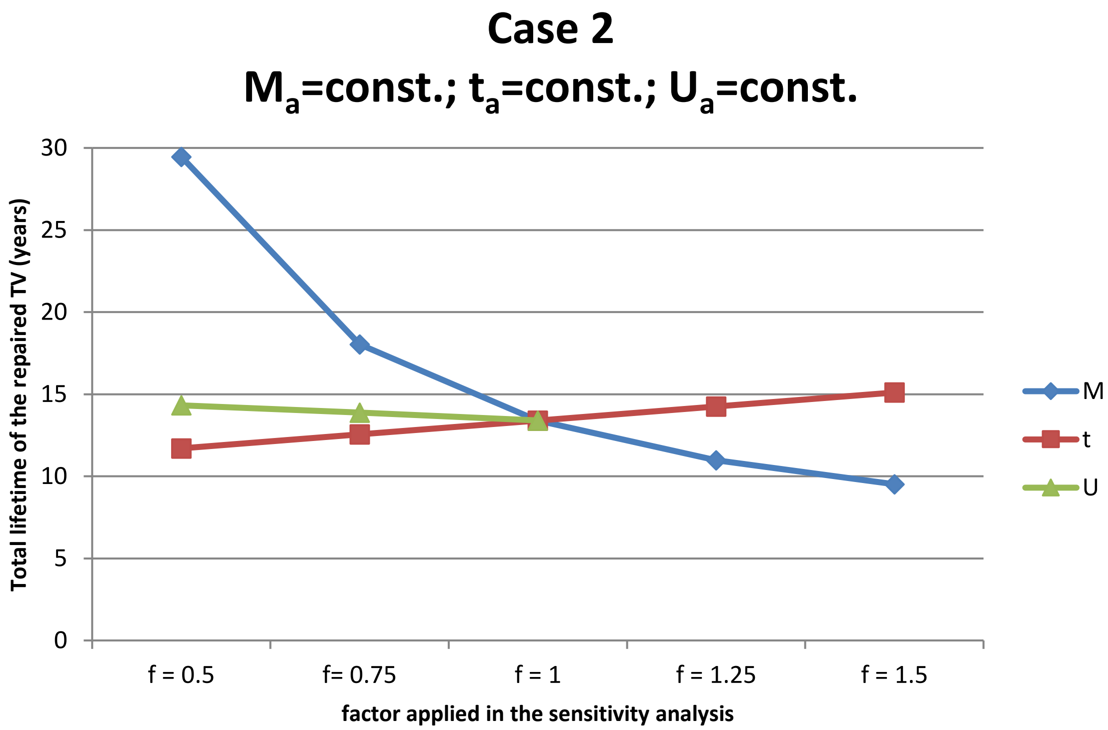


Figure 15 Results of the sensitivity analysis for GWP in Case 2

3.2.2 Steps for the disassembly of parts

A disassembly step can be defined as an operation that finishes with the removal of a part, and/or with a change of tool[48]. Accessing a target part through a reduced number of steps can contribute to make the disassembly process easier, in association with other parameters such as fasteners and connectors used, tools and skills needed.

Two important definitions can be associated to the definition of disassembly step:

- The disassembly sequence, which is the order of steps needed to remove a part from a product (which might include the access to fasteners).
- The disassembly depth, which is the number of steps required to remove a part from a product.

The disassembly depth can be obtained by applying the following iterations (Kobayashi and Higashi 2013):

1. Every components that can be removed are set at Level 1 and a list of remaining components is made;
2. Every components that can be removed are set at Level +1 and a list of remaining components is made;
3. Go back to point 2.

The analysis of disassembly sequences and depths is fundamental to assess the effort required to access and/or replace priority parts. Although it does not consider other characteristics affecting the ease of removing parts or the effort needed, the disassembly sequence and depth can influence the time needed to repair the product and, potentially, the cost of the repair/upgrade operation.

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. Optimal disassembly sequences can be for instance found through process simulation (Go et al. 2012) or on through the analysis of their relative accessibility and importance (Kobayashi and Higashi 2013).

By definition, disassembly has to be reversible, i.e. to enable re-assembly without causing damages to functional parts of the product. Depending on its relevance and on the availability of information, the analysis of disassembly steps could also include the reassembly process.

According to a study from WRAP (2011), it is a common practice to use clips as joint technique for the cover of the TV. According to industry the use of clips reduces the effort for disassembly. On the other hand, consumer organizations claim that these are more prone to break and can increase the risk of damaging the TV when opening the device for repair.

The WRAP (2011) study also encountered difficulties to find fastening points in mid to high-cost models. In favour, all the models assessed in their study used standard screws which allow disassembly and reassembly. A part from screws and clips, some manufacturers use adhesives to fix the back cover, which makes disassembly practically impossible, according to an NGO.

Regarding the circuit boards, the same study from WRAP (2011) concludes that power circuit boards were easy to access and they could be easy replaced at board or part level. This was not the case of the video circuit board and the control inverter, which in some cases were located between the cover and the screen, hindering or making impossible the access to them. They also conclude that the

[48] COMMISSION DECISION (EU) 2016/1371 of 10 August 2016 establishing the ecological criteria for the award of the EU Ecolabel for personal, notebook and tablet computers

majority of electrical joints were designed with clip-fit connectors or spades, which facilitate the replacement of parts.

In order to facilitate the disassembly of the parts of a TV which are prone to fail, the manufacturer has to provide clear indications on how to disassemble the product, as well as facilitate the access and disassembly of the part by using adequate joining techniques, as indicated in the findings from the WRAP study mentioned about. An example of indications to disassemble an LCD TV is provided in Table 16 (referred to the model PDI-P23LCD)[49].

The disassembly starts with the removal of the stand and back cover, which are usually attached with screws.

Once the back cover is removed the repairer can have access to all the boards and cables connecting them, although this depends on the specific model. For example, some TVs can indeed have the T-con board in another assembly level (between the screen and the cover) and it could be even soldered.

All the boards need to be removed to have access to the LCD module of the TV. Normally they are attached with connectors and plugs which might require delicate movements as the connectors and/or boards can be fragile. Separating the LCD module might require the removal of several screws as this part is normally attached to different parts of the TV and frame.

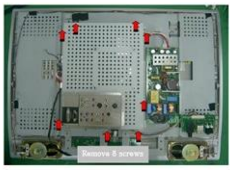
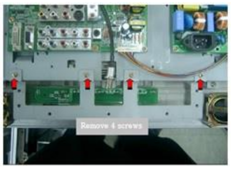
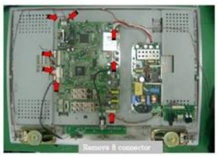
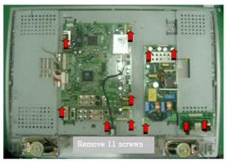
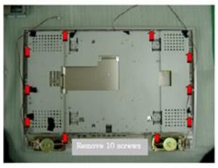
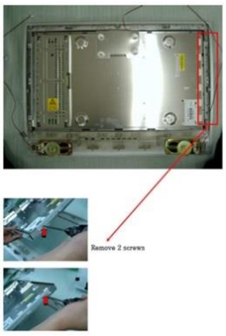
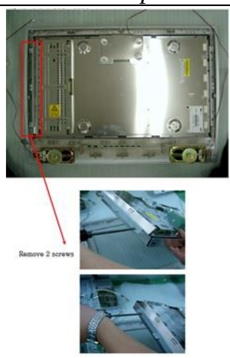
Once the LCD module is removed, the remaining part is the front cover of the TV.

Since the steps to disassemble a TV can vary from manufacturer to manufacturer and from model to model, the example used in Table 16 is valid only for illustrative purposes.

The tools needed to disassemble a TV are normally easy to find. The time for the total disassembly is influenced by the skills of the repairer, apart from the number of screws and/or connectors to be removed. More recent models of LCD TVs might use less screw, or even none, and more plastic parts. A quantitative analysis of disassembly steps is provided below for a sample of 12 models.

[49] http://cdn2.hubspot.net/hubfs/2506483/PDiarm_Oct2016/pdf/PD196I93R1.pdf (accessed on 21 March 2018)

Table 16 Example of disassembly steps for an LCD TV[50]

Step 1: Removal of stand	*Step 2: Removal of back cover*	*Step 3: Metal plate and rear chassis*
		
Step 4: Remove bracket	*Step 5: Disconnect 8 plugs on Main PCB*	*Step 6: Remove 11 screws from main PCB and SMPS PCB*
		
Step 7.1: Remove LCD module – part 1	*Step 7.2: Remove LCD module – part 2*	*Step 7.3: Removal of LCD module – part 3*
		
Step 7.4: Removal of LCD module – part 4	*Step 7.5: Removal of LCD module – part 5*	*Step 7.6: Removal of LCD module – part 6*
		

50 http://cdn2.hubspot.net/hubfs/2506483/PDiarm_Oct2016/pdf/PD196I93R1.pdf (accessed on 21 March 2018)

3.2.2.1 Analysis of disassembly steps

Based on available data it has been possible to conduct an analysis of the number of steps needed to access the different circuit boards identified as priority parts (main board, T-con board and sound board) and the speakers of a sample of 12 LCD TVs. The data used in the analysis has been obtained from the Recycle Information Centre[51], which is part of the Close WEEE[52] project and includes information about safe disassembly procedures for reuse and recycle[53].

Table 17 describes the steps needed to access the PCBs and the speakers, showing that for the majority of the cases investigated it is only needed to dismount the back cover to access these parts. In 4 of the 12 models analysed it is needed to disassemble another metal part which acts as protector to PCBs. The main difference among the models is the way in which the back cover is attached to the main frame: the number of screws used varies from 8 to 27, while the number of clips/connectors ranges from 0 to 42. Therefore, the disassembly of the back cover could be a tedious task for repairers when the number of fasteners and connectors used is excessive. It should be also observed that for large models the operation might require two technicians. Moreover, stakeholders involved in this study have mentioned that manufacturers are using less and less screws and more clips in new models of TV. However, as mentioned earlier, it has been reported that this trend could increase the risk of damaging the TVs when opening them for repair (WRAP 2011).

With this approach, the disassemblability of a product is evaluated in terms of disassembly steps. By considering the consecutive removal of fasteners with the same tool a single step, the ease of disassembly is not affected if one or more fasteners are removed consecutively and without a change of tool.

Having this in mind and looking at the results of the analysis, it can be considered that the number of disassembly steps needed to extract PCBs and speakers from a TVs will not vary significantly among different models. Although information about the disassembly of the product is very relevant to enable repair/upgrade operations, the analysis of disassembly steps does not appear to bring sufficient added value to compare TVs.

The results from the analysis do not show any issue related to the accessibility to certain circuit boards, as highlighted in the study from WRAP (2011) mentioned earlier. This is due to the fact that the databased consulted in this exercise is focused on disassembly for recycle/recovery of parts; therefore accessibility of parts for repair is not reported. Because of this, it would be recommendable to conduct further research to extend the analysis to the disassemblability and accessibility of parts for a broader sample of TV models, including different and recent technologies.

[51] https://ric.werecycle.eu/ (accessed on 10 August 2018)
[52] http://closeweee.eu/ (accessed on 10 August 2018)
[53] In this context "disassembly" can refer to "dismantling" (irreversible disassembly)

Table 17 Analysis of disassembly steps for different LCD TV models

Model	Difficulty*	Description to disassemble PCBs	Description to disassemble speakers
[1] Medion P12181	Very easy	PCBs can be accessed after step 1, when the back cover is removed (8 screws and unfasten clips). The PCBs can be disassembled by removing the corresponding screws, 11 in total.	No information
[2] Panasonic TX-32AW304	Moderate	PCBs can be accessed after step 1, when the back cover is removed (14 screws and 16 clips). All PCBs can be disassembled after removing the connectors, clips and tape used as well as the corresponding screws.	Speakers can be accessed after removing the back cover in step 1 and they can be disassembled manually.
[3] Philips 40PFK4509/12	Moderate	PCBs can be accessed after step 1, when the back cover is removed (16 screws and 42 clips). All PCBs can be disassembled after removing the connectors, tapes and corresponding screws. One of the PCBs has two clips that need to be released.	Speakers can be accessed after removing the back cover in step 1, 3 screws per speaker need to be removed for their disassembly.
[4] Polaroid P50LED14	Moderate	PCBs can be accessed after step 1, when the back cover is removed (22 screws). For the complete disassembly of all PCB parts another step to remove some metal and plastic parts is needed. PCBs can be disassembled by removing the connectors, clips, tape and corresponding screws.	Speakers can be accessed after removing the back cover in step 1, the disassembly is done by removing them from their mounting.
[5] Samsung UE32H6470SSXZG	Moderate	PCBs can be accessed after removing the back cover (11 screws). All PCBs can be disassembled after removing the connectors, tapes and corresponding screws.	Speakers can be accessed after removing the back cover and disassembled by removing them manually from their mountings.
[6] Hisense LTDN40K220WSEU	Moderate	PCBs can be accessed after removing the back cover (27 screws and 15 clips). All PCBs can be disassembled after removing the connectors, tapes and corresponding screws. One of the PCBs includes two clips.	Speakers can be accessed after removing the back cover and disassembled by removing them manually from their mountings.

[7] LG 24PN450B	Moderate	PCBs can be accessed after removing the back cover (23 screws). All PCBs can be disassembled after removing the connectors, tapes and corresponding screws.	Speakers can be accessed after removing the back cover and disassembled by removing them manually from their mountings.
[8] LG 47LM760S	Moderate	PCBs can be accessed after removing the back cover (24 screws, 4 clips and some connectors). All PCBs can be disassembled after removing the connectors, tapes and corresponding screws.	No information
[9] PEAQ TFT32NUMUNE	Moderate	PCBs can be accessed after removing the back cover (16 screws). All PCBs can be disassembled after removing the connectors, tapes and corresponding screws.	Speakers can be accessed after removing the back cover and disassembled by removing them manually from their mountings.
[10] Telefunken T39EX1425	Moderate	PCBs can be accessed after removing the back cover (21 screws and some connectors). For the complete disassembly of all PCBs another step to remove some metal and plastic parts is needed. PCBs can be disassembled by removing the connectors, clips, tape and corresponding screws.	No information
[11] Vestel 40"	Moderate	PCBs can be accessed after removing the back cover (21 screws). For the complete disassembly of some PCBs another step to remove a protective metal mounting is needed. PCBs can be disassembled by removing the connectors, clips, tape and corresponding screws.	Speakers can be accessed after removing the back cover and disassembled by removing them manually from their mountings.
[12] Toshiba 48L1443DG	Moderate	PCBs can be accessed after removing the back cover (21 screws and some connectors). For the complete disassembly of some PCBs another step to remove a protective metal mounting is needed. PCBs can be disassembled by removing the connectors, clips, tape and corresponding screws.	Speakers can be accessed after removing the back cover and disassembled by removing them manually from their mountings.

*According to Recycle Information Center (https://ric.werecycle.eu/)

3.2.3 Disassembly time

As previously said, the disassemblability of a product is influenced by number of disassembly steps and ease of access to parts, tools needed and difficulty of the operation itself. These aspects could be combined in a single indicator: the disassembly time.

Time can be measurable directly but its measurement is subjective to the operator skills. Manual/semi-automatic operations are generally relevant for repair processes, while the level of automation should increase at the industrial scale.

Different methods (Boks et al. 1996; Desai and Mital 2003; iFIXIT 2018; Kroll and Carver 1999; Kroll and Hanft 1998; McGlothin and Kroll 1995; Olson and Riess 2012; Peeters et al. 2018; Sodhi et al. 2004; Vanegas et al. 2016, 2018) have been proposed, which range from empirical estimations through linear equations to detailed and direct measurements and more elaborated quantifications. In order to limit measurement and calculation uncertainties, is recommendable to refer to standard time units (Zandin 2003) for specific disassembly operations, as done in the eDiM (Peeters et al. 2018; Vanegas et al. 2016, 2018). The eDiM enumerates a series of parameters which need to be defined based on the disassembly sequence of the product.

Time provides an indication of the operational costs associated to repair/upgrade, in case a service is paid, but it should be considered with other factors (e.g. the cost of spare parts). Moreover, its calculation is more complex and field research is needed in case of data gaps. Although being an interesting concept, its applicability should be evaluated on a case-by-case basis.

For this study on TVs, the calculation of the disassembly time is based on the eDiM and targeted to PCBs in general and to the speakers, similarly to the previous section. The information available to calculate disassembly times does not make sufficient differentiation between PCB types of TV. Because of this, the main board, T-con board and sound board and the other PCBs identified as priority parts are analysed as a single group.

The parameters needed for the calculation of the disassembly time according to the eDiM are shown in Table 18. This represents a generic calculation sheet for the eDIM time. The information to fill in columns from 1 to 6 have been obtained from Table 17 and complemented with further details obtained from RIC[54] (e.g. type of tool). Reference time values have been obtained from Vanegas et al. (2016). It has to be mentioned that the data used to calculate disassembly times comes from different sources which did not provide complete information for TVs. Therefore it was necessary to make some assumptions fill data gaps:

- When the number of connectors used (column 3 of Table 18) was unknown, a reference value of 4 has been used;
- Some characteristics of the connectors are needed to determine the time reference value (columns 7 to 12 of Table 18), as for instance the diameter of the screws and the force applied to remove clips, snapfits and tapes. The highest values provided in Vanegas et al. (2016) have been considered (most conservative assumption).

[54] https://ric.werecycle.eu/ (accessed on 10 August 2018)

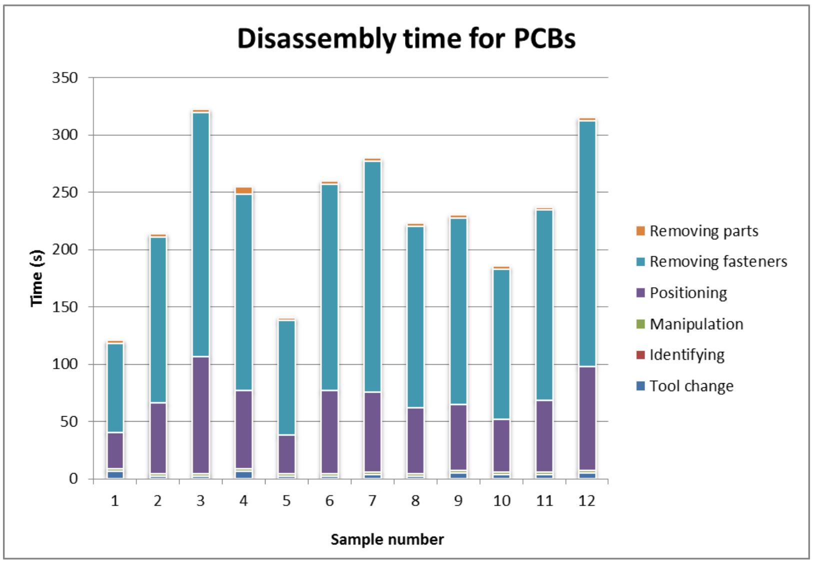
Table 18 Generic eDiM calculation sheet

1	2	3	4	5	6	7	8	9	10	11	12	13
Disassembly sequence of components	Disassembly sequence of connectors of components	Number of connectors	Number of product manipulations	Identifiability (0, 1)	Tool type	Tool change (s)	Identifying (s)	Manipulation (s)	Positioning (s)	Disconnection (s)	Removing (s)	eDiM (s)
1												
2												
…												
N												

The disassembly times calculated for PCBs and speakers according to the eDiM are represented in Figure 16. The average disassembly times are 232.2 seconds for PCBs and 242.5 seconds for speakers. As order of magnitude, disassembly times range from about 100 to 350 seconds showing that the variation is not significant from a practical point of view. The main contribution to the disassembly time is apparently done by removing fasteners.

Due to the nature of the data used and to the assumptions made, a critical interpretation of the results is needed. The main purpose of this application is to show how time for disassembly can potentially feed the assessment of the reparability and upgradability of products, and to show which indications can be provided for TVs.

When the values given in the assumptions have been varied no significant changes in the final eDiM calculations have been observed.



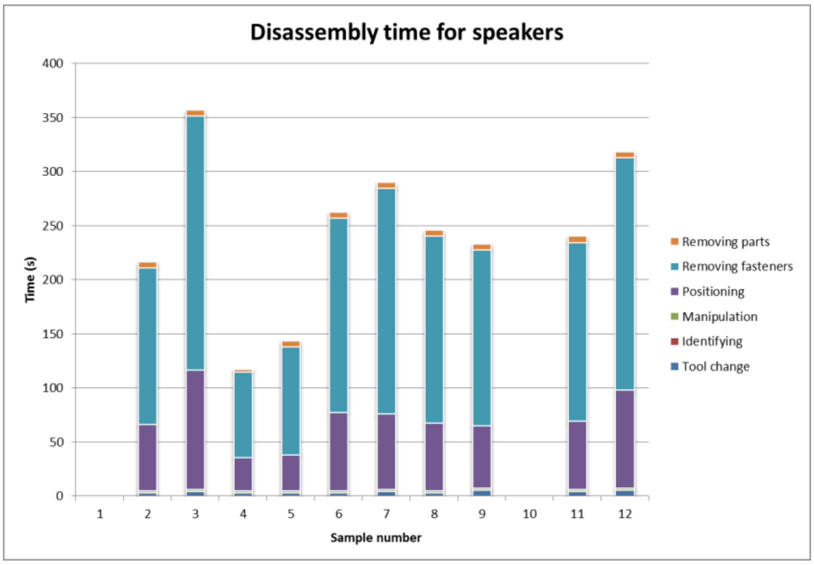


Figure 16 Disassembly times calculated for the PCBs and speakers using eDiM (Note: no information about the removal of the speakers was available for samples [1] and [10])

3.3 Qualitative attributes

This level of the assessment consists in the development of a product-specific checklist of positive attributes that can positively influence the reparability and upgradability of TVs.

Based on information available in the literature (Commission Decision (EU) 2016/1371; Flipsen et al. 2016; IEEE 1680.1, 1680.1/Draft_23, 1680.3; iFIXIT 2017) and the outcome of the JRC study about a scoring system on reparability (Cordella et al. 2019b), a generic list of parameters influencing repair and upgrade has been created and listed in Table 19.

It should be noted that there is quite important overlap between repair and upgrade of products since both operations can be considered as the replacement of a part (in one case to return a faulty product to a condition where it can fulfil its intended use; in the other case to enhance the functionality, performance, capacity or aesthetics of a product). Some parameters that a first sight could be considered inherently associated with upgrade operations only can be in reality important also for the repair of the product, for instance in those cases associated with 2nd hand market or change of user.

Table 19 Parameters influencing the repair and upgrade of products

Design	Process
1) Disassembly depth/sequence 2) Fasteners 3) Tools 4) Disassembly time	5) Diagnosis support and interfaces 6) Type and availability of information 7) Spare parts 8) Software and firmware 9) Safety, skills and working environment 10) Data transfer and deletion 11) Password reset and restoration of factory settings 12) Guarantee

For each parameter, a pass/fail requirement can be defined to indicate when a product is more reparable and/or upgradable.

Different approaches can be used in the evaluation of parameters. For example, parameters 1 and 4 could be potentially evaluated through the quantitative methods shown in sections 2.2.2 and 2.2.3. More qualitative approaches can be followed for the other parameters.

Although focused on qualitative aspects "only", this level of the assessment can provide useful indications to design products which are easier to repair and upgrade. However, this level does not allow taking design variations into account (i.e. a product can be more reparable/upgradable or not).

The requirements should be adapted depending on the level of ambition of the policy tool in which this level of the assessment is potentially implemented (e.g. mandatory or voluntary policies) (Cordella et al. 2018b).

3.3.1 Selection of parameters for TVs

A selection of parameters has been made to take into account the characteristics of TVs. For each parameter, a pass/fail requirement has been defined.

The following parameters reported in Table 19 have been excluded from the analysis of TVs:

- #4 "disassembly time", since a relevant differentiation among TV models does not seem possible with this parameter, as discussed in section 2.2.3. The definition of reference values for a representative sample of products would require a significant amount of resources, for a parameter that is covered indirectly by other parameters.
- #9 "safety, skills and working environment", since priority parts like PCBs require to be repaired by professional repairers, and other priority parts like the remote control and the TV

stand have not been identified to be an issue in terms of safety, skills and working environment.

3.3.2 Checklist of positive attributes for TVs

Examples of how positive attributes could be defined for each parameter selected for TVs are described below. However, the ambition level should be modulated to take into account the context of the application (e.g. design optimisation, cut-off of worst products, labelling of front runners).

#1 "Disassembly depth/sequence"

Information about the disassembly sequence is made available to professional repairers and consumers for each priority part.

If any of the priority parts is listed in the point 1 of Annex VII of Directive 2012/19/EU that information has to be made available by law on a free access website.

#2 "Fasteners"

Fasteners can be removed without causing damage or leaving residue which precludes reassembly or reuse of the removed part.

#3 "Tools"

The repair/upgrade process is feasible for each priority part with commonly available tools and the list of tools needed is provided by the manufacturer with free access.

#5 "Diagnosis support and interfaces"

A list of the most frequent failure modes of the TV together with a description of the cause is provided to users and professional repairers. The list includes at least the failure modes of the priority parts identified in Table 13. Description of error codes, messages indicated on the screen and/or blinking light indicators are provided. The list is to be provided either in printed or online form.

#6 "Type and availability of information"

Repair and maintenance information is made available for at least 7 years, after placing the last unit of the model in the market, at least to professional repairers, including:

- Product identification and exploded view;
- Instructions for regular maintenance;
- Troubleshooting charts;
- Repair or upgrade services offered by the manufacturer;
- List of necessary repair and test equipment;
- Component and diagnosis information (such as minimum and maximum theoretical values for measurements);
- Safety issues related to the use, maintenance and repair, as well as guarantee issues (e.g. commitment to repair in case of failure, post-repair guarantee if any);
- Disassembly sequences;
- Wiring and connection diagrams;
- Diagnostic faults, error codes (including manufacturer-specific codes, where applicable) and data records of reported failure incidents (where applicable).
- List of available updates, spare parts and recommended retail prices, as well as the procedure to order them and the repair costs of the common failures as offered by the manufacturer.

Part of this information is to be disclosed for free to end users, like instructions for regular maintenance, repair or upgrade services offered by the manufacturer and safety and guarantee issues. Depending on its level of sensitiveness, other information from the list could be disclosed to end users as well.

Channels for communicating information may include printed manuals, websites, digital information carriers such as QR codes, DVDs or flash drives.

#7 "Spare parts"

Different spare parts are to be made available depending on the repairer:

- For professional repairer: internal power supply, connectors to connect external equipment (cable, antenna, USB, DVD and Blue-Ray), capacitors, batteries and accumulators, DVD/Blue-Ray module (if applicable), and HD/SSD module (if applicable); and
- For end-users and professional repairers: external power supply and remote control.

For each priority part:

i. Spare parts are declared to be available for at least 7 years after placing the last unit on the market;
ii. Spare parts are deliverable within 15 working days;
iii. Lists of spare parts and recommended retail prices set by manufacturers (and/or contractors, if applicable) are made publicly available and with free access (see #6).

Requirement ii does not apply in the case of unavoidable and temporary circumstances that are beyond manufacturer's control such as a natural disaster.

For software and firmware, #8 applies instead of #7.

#8 "Software and firmware" (for smart TVs only)

Software/firmware updates and support, covering also pre-installed apps on the product, are offered for a duration of at least 8 years after placing the last unit of the model on the market.

The manufacturer should provide updates to allow the use of the recent versions of apps and platforms provided with the TV, this includes as well software for pairing other devices (e.g. computers, smartphones, tablets).

The update of feature should be achievable in the product without performing a product exchange, for example by using an external memory device (e.g., USB card or cable connection, SD card, or equivalent) or from a remote source using a network connection. The port, slot, or connector that is used for the firmware upgrade shall be accessible without tools.

Information on upgrading the product firmware is provided in the user manual.

#10 "Data transfer and deletion"

Secure data transfer and deletion is available on request to support the deletion of all data contained in data storage parts (i.e. hard drives and solid state drives)

#11 "Password reset and restoration of factory settings"

Password reset and restoration of factory settings (whilst ensuring security of personal data of previous user) is permitted using services offered by the manufacturer (service reset)

#12) Guarantee

A commercial guarantee of 2-to-7 years is offered by the guarantor, and including a "commitment to free repair as first remedy" in case of failures and, where relevant, a "commitment to upgrade the product periodically".

3.4 Quali-quantitative assessment

Classification and rating criteria can be defined for each attribute described in the previous section to analyse design options with a better differentiation level. These can be used to build a scoring framework to assess the reparability and upgradability of different product models (Cordella et al. 2019b).

The scoring framework can be conceived as a hybrid system composed of pass/fail requirements and rating classes:

1. Specific pass/fail requirements, to be fulfilled in order to consider a product as reparable/upgradable, and thus eligible for being scored;
2. Scoring requirements based on rating classes indicating to what extent/ how much a product is reparable or upgradable.

Points ranging from 0 to 1 have been modulated proportionally to different rating classes for each parameter assessed at priority part/product level[55]. 0 corresponds to the case in which repair/upgrade is not possible. Points above 0 have been set to conditions facilitating the repair/upgrade of products, with 1 being the ideal condition. Since the fulfilment of pass/fail requirements is by definition considered to enable main repair/upgrade operations, a score higher than 0 is in general assigned in the corresponding rating/classification criteria.

For each parameter, rating is applied either for the product or its priority parts. In the latter case, rates of priority parts are weighted to calculate an overall product rate. Weights reported in section 2.1.4 can be applied. When it can be demonstrated that a priority part or a parameter does not apply to a specific product, that part or parameter can be excluded from the assessment. Table 20 compiles the classification and rating of parameters proposed for the assessment of the reparability and upgradeability of TVs.

The focus on a reduced number of indices could stimulate the removal of barriers to repair/upgrade. Parameters can be combined into indices based on the following approach:

1. A score is calculated for each parameter (when scores are assigned for each priority part, a weighted average is calculated) and combined into indices addressing: design for disassembly (parameters from #1 to #4), repair and upgrade process (parameters from #5 to #12), overall reparability and upgradability of a product (parameters from #1 to #12).
2. The aggregation is made by assigning a weight to each parameter (based on the specificities of a defined product group) and calculating the weighted average. As general rule, weights are set to 1 by default and the weight is doubled when a parameter is considered more important.
3. The analysis of the reparability and upgradability of specific priority parts of products can also be carried out by calculating, for each priority part, the weighted average of the scores assigned to each parameter.

Although this quali-quantitative assessment can allow analysing design options with a better differentiation level, the assessment itself becomes more subjective due to the inclusion of elements like evaluation criteria, weighting factors and rating scales.

[55] Scores can be rescaled if needed, for instance resorting to 5-10 classes, also depending on intended application and related purposes (e.g. mandatory requirements or voluntary/mandatory label in a regulatory context, support tool for manufacturers, retailers and reviewers of products)

Table 20 Classification and rating of parameters for the assessment of reparability and upgradeability of TVs

Parameter	Pass/fail criteria	Rating classes[(a)]	Support to assessment (A) and verification (V)	Weight of the parameter
1) Disassembly depth/sequence	Information about the sequence to follow to disassemble each priority part has to be provided to consider the product reparable. If any of the priority parts is listed in the point 1 of Annex VII of Directive 2012/19/EU that information has to be available by law on a free access website.	Not included (see section 2.2.2.1)	A: A description supported by illustrations of the steps needed to disassemble priority 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.	High = 2
2) Fasteners	None	A score is assigned for each priority part according to the reversibility and reusability of the fasteners used for its assembly. I) 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 or upgrade process = 1 pt. II) 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 = 0.5 pt. III) Non-removable: original fastening systems are not removable or reusable, as defined above = 0 pt. Note(s): In case different types of fasteners are used in the assembly of a priority part, the score corresponding to the worst type of fasteners case will be considered.	A: A description supported by illustrations of the fasteners to be removed for the disassembly of priority parts is needed. V: Physical disassembly and inventory of fasteners are needed.	High = 2

3) Tools	The repair/upgrade process is feasible for each priority part with commonly available tools	A score is assigned for each priority part according to the complexity and availability of the tools needed for its repair/upgrade: I) Basic tools: repair/upgrade of the priority part is feasible without any tools, or with tools that are supplied with the product, or with the list of basic tools provided in note 1 = 1 pt. II) Other commercially available tools (if needed): repair/upgrade of the priority part is unfeasible with basic tools; other tools are also required that are not proprietary tools = 0.5 pt. Note(s): 1) Indicative list of basic tools (independently from the size): Screwdriver for slotted heads, cross recess or for hexalobular recess heads (ISO2380, ISO8764, ISO10664); Hexagon socket key (ISO2936); Combination wrench (ISO7738); Combination pliers (ISO5746); Half round nose pliers (ISO5745); Diagonal cutters (ISO5749); Multigrip pliers (multiple slip joint pliers) (ISO8976); Locking pliers; Combination pliers for wire stripping & terminal crimping; Prying lever; Tweezers; Hammer, steel head (ISO15601); Utility knife (cutter) with snap-off blades; Multimeter; Voltage tester; Soldering iron; Hot glue gun; Magnifying glass.	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.	High = 2
4) Disassembly time	Not included (see sections 2.2.3 and 2.3.1)	Not included (see sections 2.2.3 and 2.3.1)	Not included (see sections 2.2.3 and 2.3.1)	Not included (see sections 2.2.3 and 2.3.1)

5) Diagnosis support and interfaces	None	A score is assigned <u>for the product</u> based on the availability of diagnosis support and interfaces to aid the identification of typical failure modes associated to the priority part: I) Intuitive/ coded interface with public reference table: all main faults can be diagnosed either by i) a signal that can be intuitively understood, or ii) by consulting fault-finding trees and/or reference codes information supplied with the product = 1 pt. II) Publicly available hardware/ software interface: to be diagnosed, some of the main faults need the use of hardware, software and other support which is publicly available = 0.66 pt. III) Proprietary interface: to be diagnosed, some of the main faults need the use of proprietary devices, change of settings or transfer of software which are not included with the product = 0.33 pt. Note(s): 1) Typical failure modes associated to LCD TVs are listed in Table 12 2) Publicly available hardware / software interface can include hardware functionality testing software tools developed by a third party, provided the software tools are publicly available and the manufacturer provides information on their accessibility and applicable updates. The product can be equipped with an appropriate interface for hardware and software to do fault diagnosis and reading, adjustment or resetting of parameters or settings (e.g. external memory device, data cable connection, or from a remote source using a network connection in the case of smart TVs). The port, slot, or connector that is used for the hardware and software interface is accessible without tools.	A: The following documentation is needed, where applicable: - Description of failure modes and related coding (if used); - Reference to the required hardware material /software tools required (if used); - Contact details of support service, services offered and associated costs (if any). V: Check of actual availability and operability.	High = 2

6) Type and availability of information	Repair and maintenance information is made available for at least 7 years, after placing the last unit of the model in the market, at least to professional repairers, including: - Product identification and exploded view; - Instructions for regular maintenance; - Troubleshooting charts; - Repair or upgrade services offered by the manufacturer; - List of necessary repair and test equipment; - Component and diagnosis information (such as minimum and maximum theoretical values for measurements); - Safety issues related to the use, maintenance and repair, as well as guarantee issues (e.g. commitment to repair in case of failure, post-repair guarantee if any); - Disassembly sequences; - Wiring and connection diagrams; - Diagnostic faults, error codes (including manufacturer-specific codes, where applicable), data records of reported failure incidents (where applicable). - List of available updates, spare parts and recommended retail prices, as well as repair costs of the common failures as offered by the manufacturer. Depending on the level of sensitiveness, a part of this information may also to be disclosed to other end users. Channels for communicating information may include printed manuals, websites, digital information carriers such as QR codes, DVDs or flash drives.	A score is assigned <u>for the product</u> based on the cost and availability of the information listed on the left column note: I) All information is available publicly at no additional cost = 1 pt; II) Otherwise = 0.5 pt.	A: All relevant information for maintenance, repair and upgrade needs to be compiled and made available to the target audience. V: Check of actual availability.	High = 2

7) Spare parts	Different spare parts are to be made available depending on the repairer: - For professional repairer: internal power supply, connectors to connect external equipment (cable, antenna, USB, DVD and Blue-Ray), capacitors, batteries and accumulators, DVD/Blue-Ray module (if applicable), and HD/SSD module (if applicable); and - For end-users and professional repairers: external power supply and remote control. For each priority part: i) Spare parts are declared to be available for at least 7 years after placing the last unit on the market – different lists defined for professional repairers and end-users; ii) Spare parts are deliverable within 15 working days; iii) Lists of spare parts and recommended retail prices set by manufacturers (and/or contractors, if applicable) are made publicly available (see #6). This requirement does not apply in the case of unavoidable and temporary circumstances that are beyond manufacturer's control such as a natural disaster. For software and firmware, #8 applies instead of #7.	a) A score is assigned for each priority part based on the additional period of time during which spare parts are available: I) The spare part is declared to be available for at least 5 years longer than required in legislation (i.e. 12 years) = 1 pt. II) The spare part is declared to be available for at least 3 years longer than required in legislation (i.e. 10 years) = 0.66 pt. III) The spare part is declared to be available for the minimum time required in legislation (i.e. 7 years) = 0.33 pt b) A score is assigned <u>for each priority part</u> based on the target groups: I) The spare part is publicly available to all interested parties = 1 pt. II) The spare part is available only to professional repairers = 0.5 pt. Score (#7) = Score (#7a) x Score (#7b) Note: 1) For software and firmware #8 applies instead of #7	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.	High = 2

8) Software and firmware (only for smart TVs)	Software/firmware updates and support, covering also pre-install app on the product, are offered for a duration of at least 8 years after placing the last unit of the model on the market.	a) A score is assigned for the product based on the additional period of time during which software/firmware updates and support are offered: I) Software/Firmware updates and support are offered for at least 5 years longer than required in legislation (13 years) = 1 pt. II) Software/Firmware updates and support are offered for at least 3 years longer than required in legislation (11 years) = 0.5 pt. III) Software/Firmware updates and support are offered for the minimum time required in legislation (8 years) = 0 pt b) A score is assigned for the product based on the cost of the software/firmware update service: I) Software/Firmware updates and support are offered free of charge for the entire period of time (depending on the choice of a) = 1 pt. II) Software/Firmware updates and support are offered free of charge for Z years = Z/X (X= number of years in point a) pt Score (#8) = Score (#8a) x Score (#8b)	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.	Normal = 1
9) Safety, skills and working environment	Not included (see section 2.3.1)	Not included (see section 2.3.1)	Not included (see section 2.3.1)	Not included (see section 2.3.1)
10) Data transfer and deletion (only for smart TVs)	None	A score is assigned for the product based on the availability of secure data transfer and deletion functionality: I) Built-in secure data transfer and deletion functionality is available to support the deletion or transfer of all data contained in data storage parts (i.e. hard drives and solid state drives) = 1 pt. II) Secure data transfer and deletion is permitted without restrictions, using freely accessible software or hardware solutions = 0.66 pt. III) Secure data transfer and deletion is available on request to support the deletion of all data contained in data storage parts (i.e. hard drives and solid state drives) = 0.33 pt.	A: Information about the availability of secure data transfer and deletion functionality / service is needed. V: Check of actual availability.	Normal = 1

11) Password reset and restoration of factory settings (only for smart TVs)	None	A score is assigned for the product based on the availability of an option for resetting the password and restoring the factory setting: I) Integrated reset: password reset and restoration of factory settings (whilst ensuring security of personal data of previous user) is permitted without restrictions, using functionality integrated within the product = 1 pt. II) External reset: password reset and restoration of factory settings (whilst ensuring security of personal data of previous user) is permitted without restrictions, using freely accessible software or hardware solutions = 0.66 pt. III) Service reset: password reset and restoration of factory settings (whilst ensuring security of personal data of previous user) is permitted using services offered by the manufacturer = 0.33 pt.	A: Information about the availability of a feature / service for password reset and restoration of factory settings is needed. V: Check of actual availability.	Normal = 1

12) Guarantee	None	A score is assigned based on the availability of a "commercial guarantee" for the (entire) product offered by the guarantor, and including a "commitment to free repair as first remedy" in case of failures and, where relevant, a "commitment to upgrade the product periodically": I) A commercial guarantee of at least 10 years is offered = 1 pt. II) A commercial guarantee of at least 7 years is offered = 0.66 pt. III) A commercial guarantee of 2-to-7 years is offered = 0.33 pt. Note(s): 1) "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. 2) For the purpose of being able to be taken into account in the "Repair Score System", 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). 3) Long-, mid-, and short- terms to be defined at product group level or mirrored from the requirement on spare parts.	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.	Normal = 1

(a) Classification and rating of parameters adapted from Cordella et al. (2019b)

4 CONCLUSIONS

This study has been carried out to provide approaches and methods to assess the reparability and upgradability of ErP. Methods have been applied for the analysis of TVs.

Approaches can be categorised into quantitative, qualitative and quali-quantitative, all of them based on the preliminary identification of priority parts:

- Quantitative methods (Life Cycle Assessment and calculation of disassembly steps/times) are more complex, both in terms of data and calculation needs, but can be valuable tools for understanding when the repair/upgrade of a product is relevant and for identifying possible design barriers for the product disassembly.
- The qualitative approach is the easiest method among those considered and aims at the definition of a positive list of pass/fail requirements to screen products. Nevertheless, this approach does not allow a graded differentiation between products and it would be suitable to identify front-runners on the market or cut-off requirements.
- In between, quali-quantitative approaches can allow the differentiation between design options in a relatively simple but more subjective way through the development of scoring criteria with which to rank a product.

In the specific case of TVs it was found that:

- Most relevant parts, taking into account their likelihood to failure and their functional importance, are: main board, T-con board, sound board, power board, inverter board, IPS/EPS, speakers and backlights (lamps/LEDs).
- Results of the LCA show that circuit boards are the major contributor to the environmental impacts of the manufacturing stage (93% for GWP). In case of failure of these parts, the repair of a TV s can be more convenient than its replacement from an environmental point of view only if the repaired product is used for a considerably longer period of time (about 35-40% longer than an expected lifetime of 10 years). For parts as speakers that have less relevance in terms of environmental impacts the repair would be environmentally convenient even with a marginal increase of the time of use.
- There seem to be no significant differences in terms of disassembly complexity of parts. However, other attributes can play an important role for the repair/upgrade of this product, as for example the availability of spare parts and their cost. Repair is in general favourable if the cost is low, while strategies oriented towards an increased longevity of parts could be more effective for more expensive parts.

Given the similarities of TVs with other types of electronic displays, for which the main difference is the absence of a tuner card, it is in expected that the outcomes of this study could be in general extended to a large extent also to other electronic displays. Nevertheless, similarities and differences with TV displays should be carefully assessed on a product basis before translating specific results to other types of display.

The study can support standardisation work on material efficiency of TVs and other Energy-related Products (e.g. the ongoing CEN/CENELEC JTC10 standardisation process) as well as the possible methodological refinement and applications of the Repair Score System developed by JRC. The information gathered can even constitute a reference for policy making and designers (e.g. the revision of the EU Ecolabel requirements for TVs or the potential development of a reparability label). In the perspective of applying a repair score system to real products on the market, future developments could cover the analysis of a representative sample of products and the calculation of disassembly sequences and times for disassembly in order to better understand if any significant deviations from the outcomes of this study exist.

ACKNOWELDGEMENTS

The authors are grateful to the European Commission for financing this work through the Administrative Agreement N. 070201/2015/SI2.719458/ENV.A.1 signed by DG ENV and DG JRC.

The authors would like to thank the experts involved in the development of this study, representing Member States, industry, NGOs and consumer testing organisations, for the input provided.

The authors are also grateful to colleagues in DG JRC, DG ENV and DG ENER for the input provided for the report as well as to Mr. Rick Nowfer for the editorial support.

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ANNEX I: BACKGROUND INFORMATION ABOUT FAILURES

Background information about failures, and summarised in section 2.1, is reported in the following tables.

Table 21 Common failure in LCD TVs according to WRAP (2011)

Part	Failure mode
Remote control	- Electronic faults on the PCB of the remote control, caused by poor connections, part failures and/or battery leakage/corrosion. - The print on the keypads might get worn. - Damaging the casing. - Insert batteries the wrong way. - Not following the instructions.
Power supply	- Fault with the power supply, the remote power button or the TV on-off switch. Caused by a poor switch contact or a fault on the power PCB.
Control board and connectors	- Failures can cause screen and picture failures. This can be due to poor connectors or an electronic fault on the control PCB. - Faults on external connectors (SCART, HDMI and Aerial sockets) can be caused by weak mounting onto a PCB or by a user mistake in forcing the plugs into the connector.
Speakers and mounts	- Poor sound quality due to case vibrations, speaker damaged physically transit or a fault with the sound PCB resulting in poor or no sound. - Thermal or mechanical faults by excess input power, power outside the speaker bandpass and excessive diaphragm movement through low frequencies.
Stand wall, mount and case	- Some are weak in relation to the TV weight. - Cracking and failure, crack propagation, although this issue does not occur with metal stands which are becoming more popular.
Programming / set-up	- Complex set-ups, tuning procedures and/or poor instructions can lead to consumer dissatisfaction and returns, despite not having a real failure.

Table 22 Additional failure modes in LCD TVs according to independent repairers and stakeholders involved in the development of this study

Failure mode	Cause
Image disappears immediately	The main cause is due to a failure in the inverter that supplies energy to the backlights. This failure can also be made by other irregularities in the board, as for example the weakening of the backlights and as consequence the inverter identifies the drop of energy consumption, switching off the TV for security measures.
The TV does not switch on	It can be generated by a failure in the transformer or in the power supply, generating a failure in the electricity supplied to the circuit boards.
Lines in the image	The most common cause is a failure in the T-con board or irregularity in the transference of the LVDS.
Image showed with a mosaic effect	It is normally caused by a failure in one of the parts in the T-con board, although sometimes it can be caused by a failure in the LVDS.
Firmware/software problems	Incorrect settings
	Incorrect or disturbed supply signals
	Failure of CCFL tubes or LED strips
Entire LCD defective	Overheating of image processors due to lack of cooling. Sometimes these processors are surface mounted and very complex to repair. The cost of the replacement leads to an entire appliance replacement with a failure caused by a minor part.

The failure of transference of the LVDS is more related to the connectors on the boards rather than the LVDS cable itself, according to stakeholders consulted. Because of this, the LVDS cable is not considered to be included as priority part.

ANNEX II: ADDITIONAL INFORMATION ABOUT ASSESSMENT METHODS

This section includes additional information about quantitative methods which could be potentially used in the assessment of the disassemblability of products. However, these have not been considered applicable for policy and verification purposes, at least for the moment, due to their complexity.

a) Quantitative raking of priority parts

Building on the work of Kobayashi and Higashi (2013), a fitness function has been drafted in Annex II that consider the following aspects:

1. Frequency of failure of parts
2. Relative importance of parts (for instance due to economic/environmental/functional reasons)[56]
3. Disassembly depth of parts, expressed as number of parts that need to be removed to reach the target part (see Section 2.2.2).

The three factors could be combined by applying the following equation:

$F_i = f_{Ri}^{\alpha} \bullet I_{Ri}^{\beta} \bullet (D_i / D_{max})^{\gamma}$

Where:

- F_i is the overall score for part i;
- f_R is frequency of failure for part i;
- D_i is the typical number of steps needed to disassemble part i;
- D_{max} is the maximum number of steps needed to disassemble a part from the product;
- I_{Ri} is the relative importance of the part in the product (note: it could be more convenient that cheaper parts are more reparable and that more expensive parts are more durable);
- α, β, γ are parameters modulating the relative importance of the previous factors for the overall assessment: α is always 1 for reparability; β and γ could vary from 0 (no importance) to 1 (full importance) depending on the potential of the factor to influence reparability.

The method can be refined and calibrated when applied to the analysis of specific products of interest.

[56] The assessment of the relative importance of components can either rely on: their economic or environmental "value" (more practical and simpler procedure); or the Life Cycle Assessment of the economic and environmental benefits associated with the replacement of the components compared with the purchase of new products (more comprehensive but complex).

b) Disassembly indices

Giudice and Kassen (2009) propose a different concept of disassembly depth than that described in section 2.2.2. According to them, the disassembly depth is a normalised index calculated based on the number of parts to be removed, the fastener types and difficulty coefficients.

Using the minimum number of fasteners is a key principle in design for disassembly. Different fastener types may indeed require different unfastening tools, different access directions and different disassembly configurations, which would ultimately result in an increase in the disassembly effort (Fang et al. 2015). The disassembly depth proposed by Giudice and Kassen could be thus considered as a measure of the design complexity of a product.

The parameter is calculated with the following equation:

$$\boldsymbol{dd = dd_{sc} + \beta \cdot dd_{JC} = \frac{1 + n_D}{n} + \beta \cdot \frac{\sum_{k=1}^{h} \propto_k \cdot f_{Dk}}{f}}$$

Where:

- dd is the disassembly depth of a part
- $(1 + n_D)$ is the number of all the parts to be removed (including the part whose disassembly depth is being evaluated),
- n is the total number of parts,
- h is the number of fastener types
- f_{Dk} is the number of fasteners of the k^{th} type to be removed,
- f is the total number of fasteners in the system,
- α_k is the difficulty of disassembling a k^{th} type fastener (Allowing for values of the coefficients α_k in the interval [0, 1], $\alpha_k = 1$ indicates the maximum difficulty of disassembly),
- β is a coefficient ($\beta > 1$) which takes into account the greater weight of the second term dd_{JC} with respect to the first dd_{SC}.

The index dd can assume values from 0 to $1+\beta$, with the maximum value expressing the maximum disassembly depth. This occurs when, in order to remove a part, it is necessary to disassemble all the fasteners and all the other parts present in the system.

The index dd of a specific component can be compared to the maximum disassembly depth of the analysed system, obtaining for each component the normalized value:

$DD_i = dd_i / dd_{MAX}$.

This approach is more comprehensive than that presented in section 2.2.2 as it considers the difficulty to disassemble the different junction typologies. However, it is more complicated since introduces α and β coefficients, which need to be quantified for the analysed product based on other methods (e.g. the disassembly time, as presented in Section 2.2.3). This method is potentially interesting but its applicability is considered difficult.

Additional methods are also available to assess disassembly complexity. The disassembly complexity of an individual component could be intuitively assessed also through the use of entropy in information theory (Fang et al. 2015) by considering (1) the number of fasteners types, and (2) the number of fasteners for each fastener type, as indicated below:

$$M_{COM} = \sum_{i=1}^{N_t} \log_2 \left(N_f(i) + 1 \right)$$

Where:

- N_t is the number of the joining types, and

- $N_{f(i)}$ is the number of fasteners of type i.

When the number of fasteners is low, the addition of a fastener is significant, while the opposite is true for more complex systems. Moreover, the variation of the fastener types is considered to overweight that of the number of fasteners. This could be a relatively simple index to potentially measure the structural complexity of a product. However, this method:

1. allows only an assessment at the product level (for which it would be also difficult understanding when the complexity is acceptable or not)
2. does not take into account the difficulty in fitting the parts of a product together.

Another parameters to assess the disassembly complexity is provided by Soh et al. (2015). According to them, the disassembly complexity is the extent to which individual components or sub-assemblies have geometrical/physical attributes that can cause difficulties or problems during handling and removal of components. Given a disassembly sequence, the evaluation is based on the application of the following formula to each component to remove:

$$\boldsymbol{I_{com}} = \frac{\boldsymbol{C_h \sum_1^J C_{h,f} + C_r \sum_1^k C_{r,f}}}{\boldsymbol{\sum_1^J C_{h,f} + \sum_1^K C_{r,f}}}$$

Where:

- $C_{h,f}$ is the difficulty factor for attributes belonging to the handling group (the values are defined by the authors)
- J is the number of handling attributes matched for each part
- $C_{r,f}$ is the difficulty factor for attributes belonging to the removal group (the values are defined by the authors)
- K is the number of non-zero removal attributes matched for each part
- $C_h = \frac{\sum_1^J C_{h,f}}{J}$ is the handling complexity factor
- $C_k = \frac{\sum_1^K C_{r,f}}{K}$ is the average removal complexity factor

The overall complexity is the sum of the complexity indices calculated for each component listed in the disassembly sequence. The application of this method would be difficult, although not excessively since it mainly requires data from the Bill of Materials. As for the former method, the challenging element would be to assess when the complexity of a product is high or low.

Table 23 Example of disassembly codes and steps to separate batteries in computers

Group	Attribute	Description	Difficulty factor (C_f)
Handling (h)	Size	> 15 mm	0.75
		6-15 mm	0.81
		< 6 mm	1
	Thickness	> 2 mm	0.27
		0.25-2 mm	0.5
		< 0.25 mm	1
	Weight	< 4.5 kg	0.5
		> 4.5 kg	1
Removal (r)	Mechanical unfastening process (U-effort)	Screw/bolt standard head	0.56
		Screw/bolt special head	0.88
		Nut and bolt	0.84
		Retaining ring/circlips	1
		Interference fit	0.72
		Key	0.6
	Tools required	0 tools	0
		1-3 tools	0.6
		> 4 tools	1
	Specialised tools	None	0
		Involved	1

Note:

1. The size of a part is defined as the largest non-diagonal dimension of the part's outline when projected on a flat surface. It is normally the length of the part.
2. Thickness for a non-cylindrical part is defined as the maximum height of a part with its smallest dimension extending from a flat surface while for a cylindrical part the thickness is its radius (if its Ø < length otherwise it is considered as non-cylindrical)
3. The difficulty factor for a mechanical unfastening process is normalized from the U-effort indices obtained by Das et al (2002)
4. Specialized tools include improvised tools that are used not for its intended purposes, e.g., using a hammer with a flathead screw driver to knock a part out from its position.

c) Modularity index

Modularity is a feature of products that can enhance their disassemblability and/or upgradability and consequently act against their early disposal due to technical obsolescence.

Subassemblies, which are relatively modular in nature, are modules. Modules contain a high number of components that have minimal dependencies upon and similarities to other components not in the module (Gershenson et al. 1999).

Gershenson et al. (1999) proposed a method to measure the relative modularity of a product to encourage a design approach oriented to product modularity. The method is based in four steps:

1) Generation of a Component Tree - A component tree details the physical relationships among components at all levels of abstraction. The product is divided into its constitutive modules and components. The modules are further classified into subassemblies, components, and lastly product attributes that describe the components.

2) Generation of Process Graphs – A flow chart diagram is built that includes the various life cycle processes and (sub-)tasks that each of the components in all of the modules undergo are noted down.

3) Construction of evaluation Matrices - Using the component tree and process graphs, two modularity evaluation matrices are constructed, one to record similarities and one to record dependencies. The square matrix has row and column headings corresponding to the most specific levels of the component tree and process graphs. The contents of the two modularity evaluation matrices are the similarity and dependency relationships among components and processes. Each subassembly and process is broken down into its constitutive elements, attributes, and subtasks. The boxes contain the weights of the similarity and dependency relationships. Different relationships can exist between similarity and dependency:

- *Component-Component Dependency* occurs when two components are reliant upon each other with respect to their physical design, specifically their attributes.
- *Component-Component Similarity* is not used because changes in one component do not necessarily affect the design of the other.
- *Component-Process Dependency* details relationships in which product design is contingent upon the life-cycle process a component undergoes, *i.e.* process drives design. If the same process drives the designs of two different components, the components should be grouped in the same module so that they can evolve with the process and minimize effects on other components.
- *Component-Process Similarity* details relationships in which a component uses or goes through the life-cycle process. The logic is to group components that undergo the same life-cycle processes in one module to minimize the impact a change in process will have on the product.
- *Process-Process Dependency* and *Process-Process Similarity* do not affect product design directly, due to the exclusion of component interaction.

A set of ratings to insert in the modularity evaluation matrices, is shown in Table 24.

Table 24 Similarity and dependency ratings

Similarity	Dependency
1: Not similar	1: Not dependent
2: Slightly similar	3: Dependent
3: Similar	5: Highly dependent
4: Very similar	
5: Extremely similar	

4. *Calculation of the Relative Modularity* - For a high degree of modularity, it is important to have a high similarity between components within a module (S_{in}), a low similarity between a component of a concerned module and other components outside of the module (S_{out}), a high dependency between components within the module (D_{in}), and a low dependency between a component within a module and a component outside of the module (D_{out}). The measure of relative modularity is:

$$\boldsymbol{Modularity} = \frac{\boldsymbol{S_{in}}}{\boldsymbol{S_{in} + S_{out}}} + \frac{\boldsymbol{D_{in}}}{\boldsymbol{D_{in} + D_{out}}}$$

Where:

- S_{in}: Component similarities between each component within a particular module.
- S_{out}: Similarities between the components of a module and each component external to the module.
- D_{in}: Dependencies between each component within a particular module.
- D_{out}: Dependencies between the components of a module and each of the components that are external to the module.

$$\boldsymbol{S_{in}} = \sum_{m=1}^{M} \sum_{i=r}^{s-1} \sum_{j=i+1}^{s} \sum_{k=1}^{T} \sqrt{S_{ik} \cdot S_{jk}}$$

Where:

- m is a module, i, j are components in the same module, and k is a task.
- M = number of modules in the product
- r = first component in module m or module n.
- s = last component in the module m or module n
- T = number of processes under consideration
- S_{ik} is similarity between component i and task k
- S_{ik} is similarity between component j and task k

$$\boldsymbol{S_{out}} = \sum_{m=1}^{M} \sum_{i=r}^{s-1} \sum_{n=m+1}^{M} \sum_{j=r}^{s} \sum_{k=1}^{T} \sqrt{S_{ik} \cdot S_{jk}}$$

Where:

- i, j are components not in the same module, and n is a module

$$\boldsymbol{D_{in}} = \sum_{m=1}^{M} \sum_{i=r}^{s-1} \sum_{j=i+1}^{s} \sum_{k=1}^{T} \left(\sqrt{D_{ik} \cdot D_{jk}} + D_{ij}\right)$$

Where:

- i, j are components in the same module.
- D_{ik} is the dependence between component i and task k
- D_{jk} is the dependence between component j and task k
- D_{ij} is the dependence between component i and component j

$$\boldsymbol{D_{out}} = \sum_{m=1}^{M} \sum_{i=r}^{s-1} \sum_{n=m+1}^{M} \sum_{j=r}^{s} \sum_{k=1}^{T} \left(\sqrt{D_{ik} \cdot D_{jk}} + D_{ij}\right)$$

Where:

- i, j are components not in the same module.
- M = number of modules in the product.
- D_{ik} is the dependence between component i and task k
- D_{jk} is the dependence between component j and task k
- D_{ij} is the dependence between component i and component j

Although addressing an interesting topic, implementing this method appears difficult, especially for complex products. The calculation of the modularity with the method requires indeed extensive work, especially during the construction of the matrix.

d) Accessibility index

Accessibility represents the ease or difficulty with which a part can be reached. The more difficult to access a part, the more time is required to remove it. Accessibility of a part could be quantified through an Accessibility Index (Soh et al. 2015):

$$\boldsymbol{I_{acc}} = -\left(\boldsymbol{log_2 \frac{\Delta X}{X} + log_2 \frac{\Delta Y}{Y} + log_2 \frac{\Delta Z}{Z}}\right)$$

Where

- I_{acc} = Accessibility index
- ΔX = part accessible range along X-axis
- ΔY = part accessible range along Y-axis
- ΔZ = part accessible range along Z-axis
- X = Largest dimension of part along X-axis
- Y = Largest dimension of part along Y-axis
- Z = Largest dimension of part along Z-axis

The accessibility index (I_{acc}) measures how easy a part can be grasped by a hand or a tool during a disassembly operation (a minimum value of 1 mm should be assigned to ΔX if a part could not be grasped at all). Accessibility of fasteners is not considered as part of this index. If fasteners for a particular part are difficult to access, it implies certain parts of the product have to be removed prior to that particular part.

A method for assessing fastener accessibility during a disassembly operation is defined in Fang et al. (2015), however, the modelling is difficult as it requires a complete understanding and control of the geometric features of the entire assembly.

These methods are considered too complex and not of practical use in this context.

e) Recoverability index

Recoverability means the possibility that a component can be restored to its original specification for reuse. A method for assessing the recoverability of component is provided by Fang et al. (2015). Recoverability is determined by the fastening failure rate (γ), the relative recovery cost factor (k), the number of joining types (N_t), and the number of contact surfaces of each joining type ($N_{s(i)}$), as indicated below:

$$\boldsymbol{M_{REP} = EXP\left(-\sum_{i=0}^{N_t}\left(\frac{k_i}{1-\gamma_i}\cdot log_2(N_s(i)+1)\right)\right)}$$

Recoverability falls within [0, 1]. However, this method is considered too complex and not of practical use in this context.

f) Time for disassembly

As described in section 2.2.3, the disassemblability of products is influenced, among other technical aspects, by the number of steps needed to disassemble parts of the product, by the ease of access to components and by the difficulty of the operation itself. These characteristics can be summarised in the time for disassembly.

Time can be measurable directly but its measurement is subjective to the operator skills. This should better refer to standard disassembly operations to limit measurement and calculation uncertainties. Manual / semi-automatic operations are generally relevant for repair processes, while the level of automation can increase at the industrial scale.

Different methods have been proposed, which range from empirical estimations through linear equations to detailed and direct measurements and more elaborated quantifications (e.g. using standard units of times). Most significant methods are described in the followings. Although interesting as concept, its applicability, to be evaluated on a case-by-case basis, could be complicated.

f1. U-effort method

The U-effort method (Sodhi et al. 2004) calculates an Unfastening Effort Index (UFI) which takes into account the main attributes influencing the time needed to unfasten commonly used connectors, such as size or shape.

The disassembly time (TU-effort) per connector required by an average worker is calculated according to the following equation, measured in seconds.

$TU{-}effort = 5 + 0.04 * (UFI)$

The UFI score for each connector type is calculated with the following equation

$UFIi = \Psi i + \beta a * Ai + \beta b * Bi + \beta c * Ci + \beta d * Di$

Where

- *i* represents the code of the connector type,
- Ai, Bi, Ci Di represent the different causal attributes, and
- βa, βb, βc, βd represent the weight of each attribute.

For example, for a screw, these causal attributes are head shape, length, diameter and use of washers.

One limitation of this method is the need of casual attributes for each connector, which can complicate the calculations when new connectors are used. Another limitation is that this method does not consider the time to change tools, to identify connectors and to manipulate the product.

f2. Philipps ECC method

The Philips ECC method (Boks et al. 1996) calculates the disassembly time required using a database which contains disassembly times for unfastening commonly used connectors and for specific disassembly tasks, such as tool change or component handling.

The times used in the Philips ECC method are determined based on time measurements made during real disassembly sessions using a stopwatch, or by analysing videos of disassembly tasks.

The method includes a database to calculate the disassembly time of products based on the time required for releasing specific categories of connectors and for different disassembly tasks. Once the disassembly sequence and type of connectors are provided, the model automatically determines the required handling, tool operations and disconnection time based on the times required for the individual tasks stored in the database.

The main limitation is considered to be the low level of accuracy for measuring the time and calculating product-specific average values.

f3. Desai & Mital method

Desai and Mital (2003) developed a method of design for disassembly in which the disassembly time is determined taking into consideration five factors: force, material handling, tool utilisation, accessibility of components and fasteners, and tool positioning. The times for common disassembly tasks are based on detailed time studies.

The main drawback of this method is that it does not account for the time needed for preparatory tasks, such as reaching for the tool, picking it up, and putting it back. Therefore, the disassembly time estimation could be seen as being incomplete.

f4. Kroll method

The main goal of the Kroll method (Kroll and Carver 1999; Kroll and Hanft 1998; McGlothlin and Kroll 1995) is to serve as a design tool for disassembly that can highlight opportunities for reducing the disassembly time. The method defines 16 basic disassembly tasks (Table 25) and four categories of difficulty: accessibility, positioning, force and a category for other non-standard aspects that affect disassembly time, called “special”.

Table 25 Basic disassembly tasks of the Kroll method

1. Unscrew	5. Remove	9. Hold/Grip	13. Peel
2. Turn	6. Flip	10. Saw	14. Clean
3. Wedge/Pry	7. Deform	11. Drill	15. Grind
4. Cut	8. Push/Pull	12. Hammer	16. Inspect

The method is very detailed, as it covers a large range of conditions for disassembly tasks, which is not always essential for product policy that aims to benchmark products.

f5. Ease of Disassembly Metric

At the state of the art, the Ease of Disassembly Metric (eDiM) (Vanegas et al. 2016) appears one of the most comprehensive methods, although it comes with a significant computational effort. The eDiM method is based on the Maynard Operation Sequence Technique (MOST)[57] and requires information about product components and adopted fasteners that can be directly verified within the product. The tasks necessary to disassemble a particular component/product are listed and reference time values (coming from MOST) is associated to each of them, representing the effort needed to perform such operation. The overall eDiM, measured in time units, is calculated by summing all contributions associated to a determined disassembly sequence. Subjectivity is reduced when single disassembly activities are measured and standard values quantified, as done in MOST. As shown in Table 26, a spreadsheet can be used to calculate the eDiM. The first six columns of the table contain data to compute the time needed to carry out different disassembly tasks:

1) Components are listed in Column 1 in the order of disassembly. If components are attached by different connectors, they can be repeated in the column.
2) Connector types used are listed in Column 2 in the order in which they should be unfastened to remove the different components. An example is provided in
3) Table 27 to show different connector types and their main characteristics.
4) The number of connectors of the same type in a component are specified in Column 3.
5) The number of any manipulations needed to access a connector are listed in Column 4. This could for instance be the case of a product that has to be turned upside down to remove the connector.
6) Information on the ease of identification of the connector is contained in Column 5. Two categories, visible and hidden, are presented in
7) Table 27;
8) The type of tool required for disconnecting the fasteners is listed in Column 6. Tools can be selected from a predefined list. The box is left empty if no tool is required;

The time needed for the disassembly process is estimated through the last seven columns based on the information provided in the first six columns and the MOST reference time values provided in

Table 27 and Table 28:

9) Column 7 indicates the time needed to change tools defined in column 6. This is calculated based on the information on connectors provided in
10) Table 27, from which it can be determined whether a tool is required for disconnecting that type of connector.
11) Column 8 indicates the time needed to identify connectors. This is calculated using the information provided in Column 5 and the reference time values.
12) Column 9 indicates the time needed for product manipulation. This is calculated using the number of manipulations reported in Column 4 and the reference time values.
13) Column 10 indicates the time needed for positioning tools, in relation to the type of connectors used. This is calculated by multiplying the connectors specified in Column 3 by the reference time values for tool positioning.
14) Column 11 indicates the time needed for disconnecting the fasteners. This is calculated by multiplying the fasteners indicated in Column 3 by the reference time values for disconnecting the corresponding type of fastener.

[57] MOST is a measurement technique used by industrial engineers and practitioners to measure assembly times of a wide variety of products. Reference values have been determined by using it.

15) Column 12 indicates the time needed for removing components. This is calculated once per component.

13) The overall eDIM for a set of components is assessed in Column 13 as sum of time values reported in columns 7 to 12.

Table 26 Generic eDiM calculation sheet

1	2	3	4	5	6	7	8	9	10	11	12	13
Disassembly sequence of components	Disassembly sequence of connectors of components	Number of connectors	Number of product manipulations	Identifiability (0, 1)	Tool type	Tool change (s)	Identifying (s)	Manipulation (s)	Positioning (s)	Disconnection (s)	Removing (s)	eDiM (s)
1												
2												
…												
N												

Table 27 Proposed MOST sequences for the disconnection of fasteners

Connectors	Characteristics	Tool	MOST sequence	TMU	Time (s)
Screw	Length < 2 X diameter (D)				
- Type 1	Screw D <= 6 mm	Power tool	L3	30	1.1
- Type 2	Screw 6 mm < D < 25 mm	Power tool	L6	60	2.2
- Type 3	crew D <= 6 mm	Screwdriver	L10	100	3.6
Snapfit					
- Type 1	Force < 5 N	Hand	L1	10	0.4
- Type 2	5 N < Force < 20 N	Hand	L3	30	1.1
- Type 3	20 N < Force	Hand	L6	60	2.2
Hinge					
- Type 1	Force < 5 N	Hand	L1	10	0.4
- Type 2	5 N < Force < 20 N	Hand	L3	30	1.1
- Type 3	20 N < Force	Hand	L6	60	2.2
Cable Plug					
- Type 1	Force < 5 N	Hand	L1	10	0.4
- Type 2	5 N < Force < 20 N	Hand	L3	30	1.1
- Type 3	20 N < Force	Hand	L6	60	2.2
Clamp					
- Type 1	Force < 5 N	Hand	L1	10	0.4
- Type 2	5 N < Force < 20 N	Hand	L3	30	1.1
- Type 3	20 N < Force	Screwdriver	L6	60	2.2
Tape					
- Type 1	Force < 5 N	Hand	L1	10	0.4
- Type 2	5 N < Force < 20 N	Hand	L3	30	1.1
- Type 3	20 N < Force	Hand	L6	60	2.2

Table 28 Example of table of reference values (time) for standard disassembly tasks based on MOST sequences

Disassembly task	**Description**	**Sequence**	**TMU**	**Time (s/task)**
Tool change	Fetch and put back	A1B0G1 + A1B0P1	40	1.4
Identi	Localising connectors			
	Visible are > 0.05 mm^2			
	Hidden: visible are < 0.05 mm^2	T10	100	3.6
	Product handling to access fasteners	A1B0G1 + L3	50	1.8
	Positioning tool onto fasteners	A1B0P3A0	40	1.4
	Removing separated components	A1B0G1 + A1B0P1	40	1.4

f6. Ease of Disassembly by iFixit

The Ease of Disassemble (EoD) method developed by iFixit (2018) also calculate a time for disassembly based on MOST. In this case the parameters considered are:

- part and subassembly number,
- quantity,
- mininum number of parts, t
- ask type (code),
- number of consecutive tasks repeated,
- required tool (code), and
- difficulty rates (accessibility, positioning, force, base time and special score).

f7. VDE method

In the VDE method (Olson and Riess 2012), the disassembly time is measured by considering the items or hand movements to disassemble, the difficulty of the step (from one to five and based on expert knowledge) and the joining technique (from one to five). The total disassembly time is then calculated multiplying these three parameters, as shown in Figure 17.

	Direction of Disassembly			1=best, 5=bad	Soldered/ Inlay (1), Glue bond /Hook/Insert/ Plug in (2), Screw (3), Rivet/Thermal weld (5)	Items x Time per Item x Difficulty	
Connection / Disassembly step	**Joined Parts**	**Joining Techniques**	**Items/Hand movement**	**Difficulty**	**Time per Item [sec.]**	**Total Disassembly Time [sec.]**	**Tool**
C01	Front display	Glue bond	10	5	2	100	Lever, Scraper
	Metal housing						
	Headphone jack						
	White plastic cover						
	Left bottom antenna						
	Right bottom antenna						
C02	Screws 1	Screw, cross	4	1	3	12	Screwdriver
	Metal cover 1						
	Main PWB						
C03	LCD PWB	Plug in	2	1	2	4	Lever
	Display flex						
	Main PWB						
C04	Front camera frame	Glue bond	2	1	2	4	Scraper
	Shock pad 1						
	Front display						
C05	Black glue strips 1	Glue bond	2	1	2	4	Scraper
	Black glue strips 2						
C06	Black glue strips 2	Glue bond	2	1	2	4	Scraper
	LCD PWB						

Figure 17 Calculation of the disassembly time according to the VDE method

KJ-NA-30000-EN-N

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of the European Union

doi:10.2760/501525

ISBN 978-92-76-11254-9