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Analysis of material efficiency aspects of Energy related Product for the development of EU Ecolabel criteria

Analysis of product groups: personal computers and electronic displays

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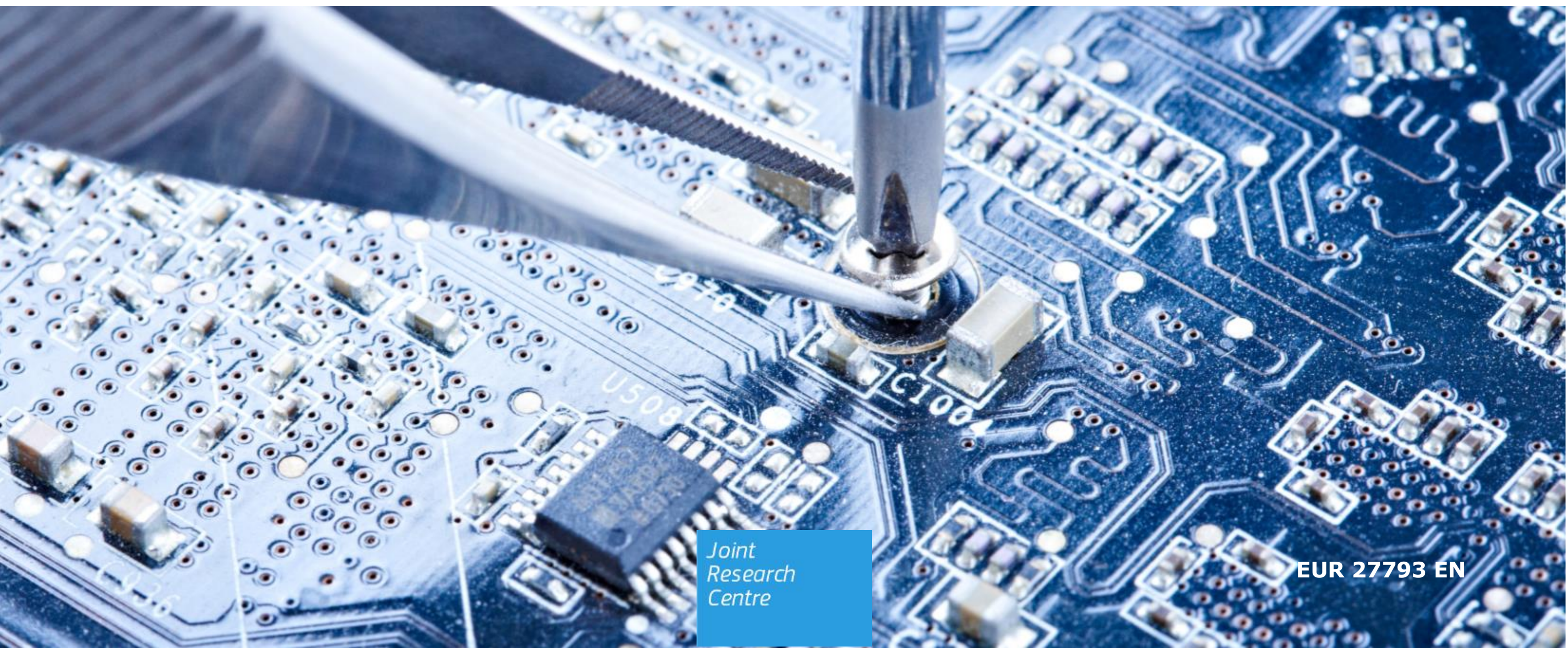

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Analysis of material efficiency aspects of Energy related Product for the development of EU Ecolabel criteria

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Executive Summary

This study is part of the 'Environmental Footprint and Material Efficiency Support for Product Policy' project funded by the Directorate-General for Environment (DG Environment) from 2012 until 2016. Material efficiency criteria for products have become increasingly relevant for European Union (EU) policy, as reflected in some of the latest communications in which the European Commission has manifested its willingness in 'moving towards a more circular economy'[1]. In particular, the Commission aims to go beyond its initial objectives and support innovative actions at all stages of the life cycle of products, from the extraction of raw materials, through material and product design, production, distribution and consumption of goods, repair, remanufacturing and re-use schemes, to waste management and recycling[2] (European Commission 2011; European Commission 2015). EU Ecolabel is one of the policy tools available to achieve such objectives, as it allows consumers and suppliers to identify products that pose less pressure to the environment.

This study is one of a series of publications that assesses the material efficiency of energy-related products (ErPs). Previous reports in the series have analysed the material efficiency of washing machines, electronic displays, commercial refrigerating appliances, dishwashers, vacuum cleaners and enterprise servers[3]. These products were selected because of their policy relevance at the time, as they were the subject of preparatory and/or technical studies within the scope of the EU's Ecodesign Directive and the EU Ecolabel scheme.

In 2014, the Joint Research Centre's Institute for Environment and Sustainability (JRC IES) started the analysis of portable computers and electronic displays in parallel with the technical studies for both product groups for EU Ecolabel. The objective was to provide scientific support to the analysis of potential material efficiency criteria that can help reduce their potential environmental impacts and improve their reuse and recycling. Some of the results of this report have been fed into the two technical reports. The draft criteria for the EU Ecolabel were further adjusted based on feedback from stakeholders.

The present report starts with a brief introduction and a description of the goals and objectives of the study. Then, it continues with a literature survey on diverse environmental labelling schemes as the EU Ecolabel, the Blue Angel, the Nordic Swan and The Institute of Electrical and Electronics Engineers (IEEE) 1860 family standard. Material efficiency criteria proposed in already existing schemes serves as a starting point to analyse, in more detail, the two product groups: portable computers and electronic displays. The study includes first the definition of the product group, a description of the bill of materials, the analysis of the design for repair and dismantling, a description of their End of Life (EoL), a review of environmental criteria specific for each product group, and then an analysis of some relevant environmental aspects.

[1] http://ec.europa.eu/environment/circular-economy/index_en.htm
[2] http://ec.europa.eu/smart-regulation/impact/planned_ia/docs/2015_env_065_env+_032_circular_economy_en.pdf
[3] The report can be downloaded from: http://bookshop.europa.eu/en/environmental-footprint-and-material-efficiency-support-for-product-policy-pbLBNA27467/

For portable computers, a more exhaustive analysis of the dismantling of batteries in newer portable computers models (namely, sub-notebooks and PC-tablets) is done. The results of the analysis illustrated the need to set up a criterion to facilitate the separation of battery packs; thus, those types of computers can not only be more easily repaired, but also treated according to the requirements of the Waste Electrical and Electronic Equipment (WEEE) Directive. For both computer types, the analyses were developed based on some findings from previous studies, and were elaborated further using audiovisual material available on the internet (see Annex). For subnotebooks, the results showed that only two out of 28 models have the battery packs externally accessible, with only one of the two models having a battery that is readily extractable without tools. For about half of the models, battery packs were extracted in three steps whereas, for the rest of models, the separation of battery packs needed more than three steps. For PC-tablets, all 21 models analysed except one had embedded battery packs. For eight out of 21 models, it was possible to remove the back cover using a spudger (a stick tool) by pressing clips and even without using tools. Battery packs were frequently fixed with screws or adhesives, or a combination of both, which increased the number of disassembly steps. In most cases, several connectors also needed to be unplugged before battery packs could be harvested.

For electronic displays, a criterion on 'design for dismantling and recycling' was formulated as the time needed to extract key components was indicated as relevant from an environmental point of view. Relevant key components are: printed circuit boards (PCBs), thin film transistors (TFT) and polymethyl methacrylate (PMMA) board light guides. Time thresholds were formulated based on data for displays of different sizes and on previous studies on electronic displays[4]. The time thresholds proposed to extract the three mentioned key components are: 260 seconds for displays with a size smaller than 25 inches; 340 seconds for displays with a size greater than or equal to 25 inches and smaller than 40 inches; and 480 seconds for displays with a size greater than or equal to 40 inches and smaller than 55 inches.

For both product groups, a criterion for 'material selection and compatibility with recycling' was suggested. Such a criterion is aimed to improve the recyclability of plastics through the use of single polymers or polymer blends compatible with recycling as well as the use of other substances that are all compatible with recycling. Other potential Ecolabel criteria referred to the marking of plastic parts in accordance to ISO 11469 and ISO 1043 to facilitate the separation of plastic parts.

In general, it is desirable that EU Ecolabel criteria and Ecodesign requirements are built upon technical analyses of the same features as well and designed as complementary tools to ensure the consistency of diverse policy objectives. The feasibility of implementing some of the criteria proposed in this report as Ecodesign requirements could be further investigated by more specific research in regard to their verification.

[4] The report can be downloaded from: http://bookshop.europa.eu/en/environmental-footprint-and-material-efficiency-support-for-product-policy-pbLBNA26185/

Abbreviations

ABS – Acrylonitrile butadiene styrene

AHWG – Ad-Hoc working group

ASA – Acrylic-styrene-acrylonitrile

BoM – Bill of materials

BFR – Brominated flame retardant

CCFL – Cold cathode fluorescent lamps

CENELEC – European Committee for electrotechnical standardization

CF – mineral fibre

DVD – Digital versatile disc

DVI – Digital visual interface

EC – European Commission

ECEEE – European council for an energy-efficient economy

ED – Electronic display

EMI – Electromagnetic interference

EoL – End of Life

EPEAT – Electronic product environmental assessment tool

ErP – Energy-related product

EU – European Union

EUEB – European Union Ecolabelling board

FR – Flame retardant

GF – Glass fibre

GHS – Globally harmonised system

GPP – Green public procurement

HDD – Hard disk drive

HDMI – High-definition multimedia interface

IEEE – Institute of electrical and electronics engineers

IES – Institute for environment and sustainability

ISO – International standard organisation

ITO – Indium tin oxide

IZM – Institut für Zuverlässigkeit und Mikrointegration

JRC – Joint Research Centre

LCD – Liquid crystal display

LED – Light emitting diodes

NGOs – Non-governmental organizations

ODD – Optical disk drive

PBB – Polybrominated biphenyl

PBDE – Polybrominated diphenyl ethers

PCB – Printed circuit board

PE – Polyethylene

PMMA – Polymethyl methacrylate

PS – Polystyrene

PP – Polypropylene

RAL – German Institute for quality assurance and certification

RAM – Random access memory

RBRC – Rechargeable battery recycling corporation

REACH – Registration, evaluation, authorization, and restriction of chemicals

RoHS – Restriction of hazardous substances

SD – Secure digital

SLIP – Backlight inverter and power supply boards mounted together

SMPS – Switched mode power supply

TCON – Timing controller

TFT – Thin film transistor

USB – Universal serial bus

VGA – Video graphics array

WEEE – Waste electric and electronic equipment

1. Introduction

Securing a more resource-efficient Europe is one of the seven flagship initiatives under the Europe 2020 strategy. Resources refer to raw materials such as fuels, minerals, and metals but also food, soil, water, air, biomass, and ecosystems. Resource efficiency means reducing inputs, minimising waste, improving management of resource stocks, changing consumption patterns, optimizing production processes, management and business methods, and improving logistics. Thus, it is a wide horizontal concept that can be applied to policy agendas for climate change, energy, transport, industry, raw materials, agriculture, fisheries, biodiversity, and regional development. As result since then, resource efficiency measures have become one of the most relevant targets in EU policies.

The implementation of material efficiency aspects has been progressively gaining importance in product policies, especially after the recast of the Ecodesign directive and EU Ecolabel regulation (European Parliament and the Council of the European Union 2009; European Parliament and the Council of the European Union 2010). In order to better understand the advances in the formulation of material efficiency measures, it has become necessary to review the existing criteria included in EU Ecolabel, and in other environmental labelling schemes, as well. Several Ecolabel criteria included aspects related to 'Lifetime extension', 'Design for disassembly', and 'End of Life management', among others. However, EU Ecolabel criteria tend to be formulated in a generic form, since voluntarily adopted verification procedures are less strict than those for Ecodesign requirements, which need to be frequently supported by standards. Two product groups are analysed in the present report with the objective of analysing how to develop some more specific criteria for material efficiency for EU Ecolabel.

2. Goals and scope of the report

The objective of the present report is to study potential non-energy efficiency measures, hereafter referred to as 'material efficiency' measures, which can be proposed within the EU Ecolabel schemes. The first step for such a purpose is to revise material efficiency criteria already included in existing environmental labelling schemes, mainly EU Ecolabel, but also other schemes as the Blue Angel, the Nordic Swan and the IEEE 1860 family standards. Indeed, the IEEE 1860 family standards are quite advanced in this type of criteria for electronic products. To illustrate more exhaustively how material efficiency criteria can be drafted and formulated, the present study analyses two product groups in more detail: personal computers and electronic displays.

Criteria proposed in this study are built upon the previous EU Ecolabel communications for personal and notebook computers (European Commission 2011) and televisions (European Parliament and the Council of the European Union 2009) that expired in December 2015. The objective is to advance towards more ambitious, specific, and verifiable criteria, but most importantly, to align criteria included in EU Ecolabel decisions with requirements under development for other product policies (i.e. the implementing measures based of the Ecodesign Directive). Thus, the results are aimed to contribute to the discussion of EU Ecolabel decisions under review, and enhance harmonization with other EU policies to support EU policy decisions.

3. Methodology to develop material efficiency criteria for EU Ecolabel

The first step to develop material efficiency criteria is to identify relevant product groups. Relevant product groups are those that are in harmony with the revisions to the EU Ecodesign Directive and the EU Ecolabel, and also support environmental factors such as a high volume of sales and the content of certain materials as precious metals, copper, and other materials targeted as critical raw materials by the EC (European Commission 2013). For this analysis, personal computers and electronic displays were selected from among all the 44 product groups addressed under the Ecodesign directive (Talens Peiró et al. 2016). Both of these product groups have also experienced one the greatest technology changes in the last decade due to the introduction of functionalities such as touch screens, the development of long-lasting batteries, and more energy-efficient lighting systems (i.e. LEDs). Such technological advances have resulted in a faster and more competitive market where the lifespan of these products have shortened considerably and, therefore, influence their future potential amount in terms of waste flow.

Once the product group to be assessed has been defined, the next step is to develop a literature survey. As part of it, material efficiency criteria already included by the EU Ecolabel, but also in other environmental labelling schemes, are revised with the objective of aligning potential criteria with those already in existence. Then, a more specific study on the bill of materials (BoM), the design of the product, and the end-of-life (EoL) management is also developed. The information about the BoM allows for the identification of components that contain hazardous substances and those that require specific treatment operations at their EoL, and also other materials relevant for their potential recovery. The analysis on the design of the product helps identify the characteristics of products that can ease reuse and recycling while the information about their EoL management allows for the discovery of possible burdens for reuse and recycling companies at their facilities.

The information from the literature survey is then used to detect 'hot spots'. By 'hot spots', we mean features and characteristics of the products that can be improved to facilitate repair, reuse, and recycling. For example, for portable computers we identified as a 'hot spot' the design of battery packs in some newer portable computer models (Sect. 4.5.1). For electronic displays, the major 'hot spot' is the accessibility to some components, namely the backlighting lamps, printed circuit boards, liquid crystal displays, and polymethyl methacrylate (PMMA) boards (Sect. 5.5.1). For both product groups, the content of plastic parts was relevant; thus, the recyclability of these parts is further discussed. The outcomes of those more detailed analyses are finally used to draft some potential material efficiency criteria for EU Ecolabel.

The next sections illustrate how the methodology is applied to personal computers and electronic displays. The methodology used can be applied to analyse other product groups relevant from a policy and environmental perspective.

4. Material efficiency criteria in environmental voluntary labelling schemes

This section briefly revises the material efficiency criteria for two of the most renowned environmental labels: Blue Angel and Nordic Swan. These labels are the oldest environmental labelling schemes in Europe, and also the most frequently used. As part of the revision, we decided to include the recently developed IEEE 1680 family of environmental standards, as they also propose novel environmental criteria for material efficiency which are potentially relevant and applicable to the case studies developed later on in this report.

4.1. EU Ecolabel

Following the EC/66/2010 regulation, EU Ecolabel is given to products that comply with a set of ecological criteria, which are specifically defined for each product category (European Parliament and the Council of the European Union 2010). EU Ecolabel (shown in Figure 1) was created to allow consumers and suppliers to identify products that pose less pressure to the environment. EU Ecolabel is a voluntary public scheme based on specific environmental criteria. All products supplied for distribution, consumption, and use in the European Economic Area (European Union plus Iceland, Lichtenstein, and Norway) and also those included in one of the established non-food and non-medical product groups, are eligible to obtain the EU Ecolabel. The EU Ecolabel is an integral and effective part of the wider Sustainable Consumption and Production (SCP) Action Plan (COM/2008/397), linking with other instruments, such as Green Public Procurement (GPP), the Eco-Management and Audit Scheme (EMAS), the Ecodesign Directive, and the Environmental Technologies Action Plan (ETAP), among others. Table A1 in the Annex illustrates the status of diverse product groups analysed under EU Ecolabel.

Figure 1. EU Ecolabel logo.

The development of a new product group criteria or the revision of existing EU Ecolabel decisions starts by building up an Ad-Hoc Working Group (AHWG). The AHWG is composed of industry, experts, NGOs, public authorities, and other interested parties, which will meet about three times a year to discuss the preparatory work for the product under study. The preparatory work includes a preliminary report, a proposal for draft criteria, and a technical report in support of those draft criteria. Preparatory work includes the feasibility, environmental and market studies, improvement analysis, and revision of existing life cycle analysis, or implementation of new analysis for the product. According to these results, the AHWG drafts criteria which are then discussed by the European Union Ecolabelling Board (EUEB), a body made up by competent bodies from each Member State and other interested parties. A draft of the criteria is circulated among the relevant services of the European Commission for approval before the EUEB approves the criteria. A vote is taken by a Regulatory Committee of national authorities and criteria are adopted through a Commission Decision (European Commission 2014).

Parties (companies/suppliers) interested in applying existing criteria for EU Ecolabel contact the competent body of the country (generally represented by the national and local environmental departments) that will follow, evaluate, and award the EU Ecolabel if criteria are met. Manufacturers and service providers willing to obtain the EU Ecolabel license must apply using the online application tool. Compliance to the criteria must be proved by a dossier made up of the declarations, documents, data sheets, and test results. If criteria and dossiers are completed, the Competent Body will award the EU Ecolabel to the product under review.

Although material efficiency criteria vary among product groups, in most cases EU Ecolabel criteria normally discussed are 'design', 'Life extension', and 'End of Life (EoL)'. Improvements in 'design' are analysed under the 'design for disassembly' criteria. For example, the last Commission decision for EU Ecolabel of televisions and imaging equipment states that manufacturers shall demonstrate that the product can be easily dismantled using tools usually available for the purpose of repair, replacement of parts, and ultimately for reuse or recycling (European Commission 2009; European Parliament and the Council of the European Union 2013). Another example is the EU Ecolabel criteria for personal and notebook computers which states that, to facilitate the dismantling of the product, the manufacturer should provide 'data on the nature and amount of hazardous substances […] gathered in accordance with Council Directive 2006/121/EC (REACH) and the Globally Harmonised System of Classification and Labelling of Chemicals (GHS)' (European Commission 2011).

'Life extension' criterion is frequently defined in terms of minimum guarantee time for reparation, and guaranteed availability of compatible spare parts for reparation and upgradeability for a certain number of years. For instance, the Decision 2009/300/EC for televisions established a commercial guarantee of functioning for at least two years, and the availability of compatible electronic replacement parts for seven years from the time that production ceases (European Parliament and the Council of the European Union 2009).

The criterion for 'EoL management' is generally defined by take-back schemes and recycling thresholds. For example, the EU Ecolabel criteria for personal computers in 2011 states that manufacturers shall offer, free of charge, the take-back for refurbishment and recycling of the product, and for any components being replaced. Regarding recycling thresholds, it sets that 90 % (by weight) of the plastic and metal materials in the housing and chassis shall be technically recyclable (European Commission 2011).

There are some other measures included in EU Ecolabels related to material efficiency, but included in other criteria. For example, the use of cardboard packaging of at least 80 % recycled material (European Commission 2011), the use of plastic bags in the final packaging made of at least 75 % recycled, biodegradable, or compostable material (European Parliament and the Council of the European Union 2013) or that packaging components shall be easily separable by hand into individual materials to facilitate recycling (European Commission 2011). For some products, as for example washing machines and dishwashers, a threshold in 'water consumption' is also included (European Parliament and the Council of the European Union 2001; European Parliament and the Council of the European Union 2003). The first EU Ecolabel for washing machines 2000/45/EC established that they should use less than or equal to 12 litres of water per kilogram of wash load.

Apart from the EU Ecolabel, there are other voluntary environmental labelling and standard schemes worldwide that include material efficiency criteria, which are interesting to further investigate. The most renowned Ecolabels are the German Blue Angel and the Nordic Swan. In addition, the IEEE standard for environmental assessment (IEEE 1680) is gaining importance as it includes material efficiency criteria from a holistic perspective for electronic products, mainly computers, imaging equipment, and televisions.

4.2. The Blue Angel

Blauer Engel, officially translated to English as The Blue Angel, is the oldest Ecolabel in the world, as it was introduced in 1978, and is thus being used as an example by other countries willing to establish environmental labelling (German federal environment agency 2011). It is given to products and services that are environmentally preferable from a life cycle perspective compared with other products serving the same purpose.

The process to develop criteria for products starts by interested parties (generally suppliers and/or manufacturers) sending possible comments to the German Federal Environment Agency who, after commenting the document, sends it to the Environmental Label Jury to make a decision. The Environmental Label Jury is a group of 13 people from environment and consumer protection groups, industry, unions, trade, media, and churches. The Federal Environment Agency conducts a technical preparation and presents proposals for the basic award criteria. Then, recommendations are sent to expert hearings where all the involved stakeholders (the German Institute for Quality Assurance and Certification (RAL), the Federal Environmental Agency, supplying industries, consumer associations, trade unions, and other experts) meet. After basic criteria are drafted, the Environmental Label Jury decides to adopt or reject them. The final step is the publication of the decisions by the Federal Ministry of Environment.

The process for existing basic award criteria is simpler. Suppliers and/or manufacturers provide evidence on the compliance with the criteria to the RAL, who reviews the applications. Then, the *Bundesland* (German state) sends comments to the RAL. The RAL then concludes the contract with the manufacturers/suppliers, and suppliers update their advertising using the Blue Angel.

The most important criteria related to material efficiency are performance, longevity, recyclable design, and material selection. The performance of products is mainly analysed based on the energy and power consumption, but also includes, in some cases, the use of certain materials during the operation of the product (German federal environment agency 2010). For example, washing machines shall not exceed the annual water consumption limits given in a table, with the maximum water consumption per kilogram of laundry being 12 litres for appliances with a load capacity equal or greater than 5 kg to 7 kg, and 10 litres for appliances with a load capacity equal or greater than 7 kg (RAL GmbH 2013).

Longevity is frequently defined by repairability, which tends to define a period of time for the availability of spare parts. For example, for personal computers the repairability criterion states that spare parts shall be guaranteed for at least five years from the time that production ceases, especially, rechargeable batteries. For certain products, as computers, longevity is also defined by upgradeability.

For instance for personal computers, upgradeability is described by providing a memory expansion comparable to that of Energy Star 5.0; installation, exchange, and expansion of storage capacity; installation and/or exchange of the optical drive, and at least four USB interfaces (RAL GmbH 2012).

Recyclable design can be described by diverse aspects such as, for instance, the design to easily separate components, the use of maximum types of plastics, and the provision of disassembly instruction manuals to end-of-life recyclers or treatment facilities. Just as an example, among the criteria for the design for recycling of computer monitors, there is a criterion called ‘structure and joining technique’ which, in brief, is described as the product being designed in such a way as to allow for easy manual disassembly by one person with the use of ordinary tools (RAL GmbH 2013).

Material efficiency criteria can prescribe the banning of certain substances in parts of the product. For instance, the criteria for computer monitors included the banning of carcinogenic and toxic substances in the housing and housing parts, the use of polybrominated biphenyls (PBB) in printed circuit boards, and mercury in backlights. It can be also include the enforcement labelling or marking of certain material so as to facilitate its later recycling, such as for example the marking of plastic parts greater than 25 grams in mass (RAL GmbH 2013).

In 2009, The Blue Angel logo was revised to include a specific inscription for each of the key protection goals. For instance, climate-friendly products include the inscription ‘protects the climate’. Other protection goals are ‘protects the water’ and ‘protects the resources’. From 2011 onwards, ‘protects the environment and the health’ replaced the existing ‘protects the health’ label. Figure 2 shows the different Blue Angel logos.

Figure 2. The Blue Angel logos from left to right: protects the climate, protects the water, protects the resources, and protects the environment and the health.

4.3. Nordic Swan

The Nordic Swan (shown in Figure 3) is the official Ecolabel for the Nordic countries: Denmark, Finland, Iceland, Norway, and Sweden. This environmental label, as with the EU Ecolabel and The Blue Angel, also aims to promote products and services with lower environmental impacts. Product groups to undergo the Nordic swan labelling processes are selected based on their relevance, potential, and how they can be controlled or ‘steered’. Then, products are assessed on criteria related to the climate and the global warming threats, such as energy use, renewable energy, and emissions to air and water; the use of chemicals and waste procedures, and to the quality and performance of the product. Criteria for the assessment are proposed by experts from the Nordic Ecolabelling organization and other experts from environmental organizations, industry, and/or national government. Criteria listed are sent for review before the Nordic Ecolabelling Board finalizes. They are also available to the general public on the national organizations' websites. Once criteria are defined, businesses can apply for the right to use the label on a product. The full process takes, on average, three to four years (Nordic ecolabelling 2001).

Figure 3. Nordic swan logo.

The Nordic swan label applied to a product is usually valid for three years, after which the criteria are revised to continue the process of reducing a product or service's environmental impact by taking advantage of new technological developments. Companies must reapply for a license once this time period has expired.

In the Nordic Swan labelling, material efficiency criteria are generally proposed in a section referred to as 'Design and Material', which includes diverse sub-categories such as 'Re-used plastic' and 'Disassembly' that vary from product group to product group.

Material efficiency criterion for plastics are included in a section known as 'Plastics in casings and their components' which describe criteria about the 'marking of plastics', the use of 'single plastic casing parts' and 'combined plastic casing parts', 'chlorine based plastics', and the use of flame retardants and phthalates in cables. 'Recycled material in packaging' criteria are also generally included for many product groups in a section titled 'chemicals and materials during production'. For example, for computers it sets a requirement of at least 50 % post-consumer recycled material in the product. The 'availability of spare parts' is another of the environmental criteria included frequently.

For some other product groups, the criterion goes even further by defining a threshold of reuse and recycling. For example, washing machines are requested to be designed in such a way so as to ensure the reuse and recycling of at least 75 % by weight. The criteria continue by explaining that joints must be easy to find and access, electronic components must be easy to find and remove, the product must be easy to disassemble using common standard tools, and it must be possible to separate out incompatible and hazardous materials.

4.4. IEEE standards for environmental assessment (IEEE 1680)

The IEEE's goal is 'to foster technological innovation and excellence for the benefit of humanity' (Institute of Electrical and Electronics Engineers 2009). The IEEE promotes the exchange of technical knowledge and information through a wide range of publications, including standards. In the past years, they have created the IEEE 1680 family of standards for the environmental assessment of electronic products. The IEEE 1680 standards are not a labelling system; however, this family of standards includes a list of criteria to reduce the environmental impact of electronic products. Certificates are given based on the scoring of the following eight categories: reduction/elimination of environmentally sensitive materials, materials selection, design for EoL, product longevity/life cycle extension, energy conservation, end-of-life management, corporate performance and packaging. Some of these categories include mandatory and optional criteria. Certification is awarded when mandatory criteria are satisfied and a required amount of optional points is achieved. The certification grades are bronze, silver, and gold. Bronze means the product satisfies 100 % of all required criteria. Silver is given to products that meet 100 % of all the required criteria and a minimum of 50 % of the available optional criteria points. Gold is for products that fulfil 100 % of all the required criteria and a minimum of 75 % of the available optional criteria points (Institute of Electrical and Electronics Engineers 2009). The Electronic Product Environmental Assessment Tool (EPEAT) registers products that meet the IEEE 1680 family of Environmental Assessment Standards. Figure 4 shows the logos for the IEEE 1680 standard.

Required: 100%/Optional: 75% | Required: 100%/Optional: 50% | Required: 100%

Figure 4. EPEAT logos for IEEE 1680 environmental assessment standards from left to right: gold, silver, and bronze.

The material efficiency criteria proposed by IEEE are being specifically developed for electronic products, thus their criteria remain very similar from product group to product group. Criteria include aspects such as ‘Product longevity/life cycle extension’, which refers to the availability of spare parts, and ‘design for EoL’, wherein manufacturers shall provide treatment information to reuse and recycling facilities that allows for easy identification of the presence and location of materials that require special handling. IEEE criteria also includes specific information about the identification and removal of specific parts such as printed circuit boards batteries, and other components containing any hazardous materials.

In line with the IEEE 1860 family standards, the so-called Standard for Documentation Schema for the Repair and Assembly of Electronic Devices (IEEE 1874), also known as the ‘oManual’, has been developed to provide a standardized format for manuals and their compatibility to be displayed on both computers and mobile devices (Institute of Electrical and Electronics Engineers 2013). The IEEE 1874 specification is an XML-based data standard that allows for the creation of dynamic, flexible, and structured manuals and publishing manuals as both user-friendly PDF/HTML files that are also machine-friendly (Schaffer and Wiens 2014). oManual files allow manuals to retain their ease of use, and also facilitate the maintenance and building upon of the same.

5. Development of EU Ecolabel criteria for personal computers

Personal computers include a vast number of product sub-categories such as desktop computers, integrated desktop computers, notebook computers, netbook computers, and tablet computers among others (Dodd et al. 2013). The replacement of desktop and notebook computers by tablet computers has been widely debated (Bradley 2011). However, although tablets have been under-cutting notebook sales, it is unlikely that they will entirely replace the full range of computers. Among the most important reasons: the processor in PC-tablets would still be weak in comparison to the power delivered by PC chips and virtual keyboards would not be universally accepted. On the other hand, PC-tablets enable people to undertake almost the same activities compared to traditional PCs, except for editing files. As tablets become more powerful from a hardware perspective, a trend to replace traditional desktop and notebook PCs is likely.

Figure 5 shows worldwide shipment figures for tablets, laptops (also regarded as notebook computers), and desktop PCs from 2010 to 2012 and also offers a forecast until 2019 (Statista - The statistics portal 2015). According to this prediction, global shipments of laptops will remain mostly stable until 2017, ranging from 180.9 million units in 2010 to 209 million units in 2017, respectively. Desktop PCs are predicted to steadily lose market share over the next few years.

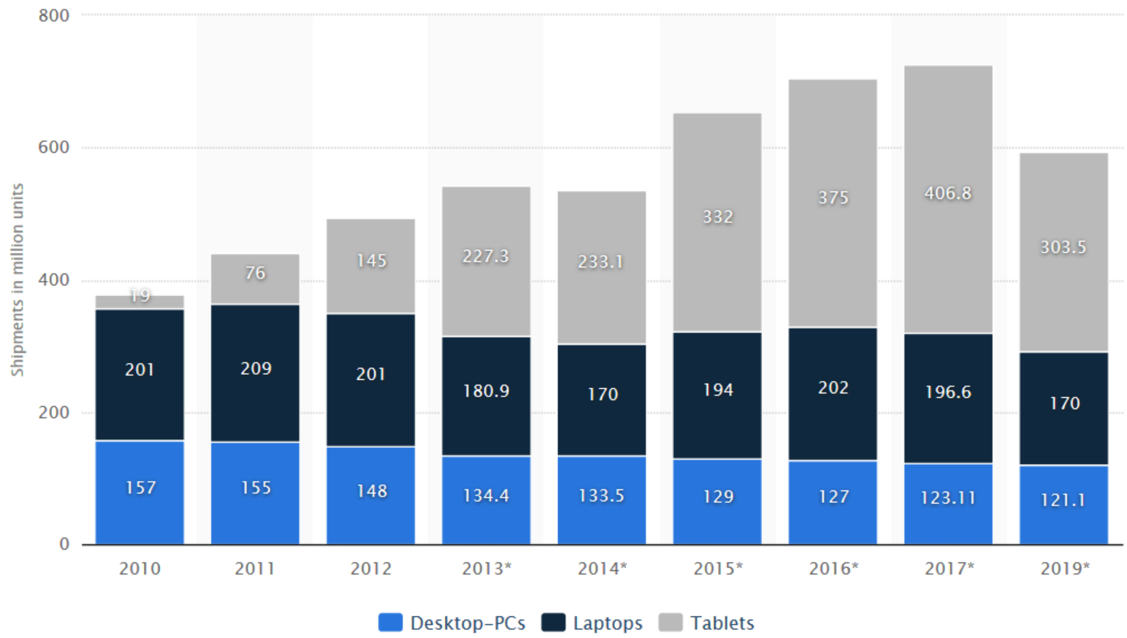

Figure 5. Forecast for global shipments of tablets, laptops, and desktop PCs from 2010 to 2019 (in million units). Source: Statista 2015.

Bearing in mind that EU Ecolabel aims at regulating products put on the market in the coming years, it becomes more relevant to focus on the current analysis in regard to notebook computers, especially new models which are thinner, lighter, and longer lasting. Good examples are tablet computers and subnotebooks, for instance. To better draft potential measures for EU Ecolabel for computers, it is important to analyse diverse aspects of this product.

First, the report clarifies the diverse types of portable computers available on the market. Then, it continues by providing a more detailed description of the bill of materials (BoM) and the design of diverse PCs. The objective of such technical analysis of the product is to identify the most relevant parts and components of the PCs. For portable computers, batteries seem to be a crucial component for repair, maintenance, and recycling, especially in new models such as PC-tablets and subnotebooks. As a result, an exhaustive review of the design for disassembly of battery packs in both types of portable computers is included. Furthermore, this section includes a comprehensive analysis of environmental criteria in current legislation and in other environmental labelling systems. The section concludes with several criteria that can help advance a better design, and thus the recycling of portable computers.

5.1. Definition of personal computers product group

Personal computers include diverse sub-categories. This study is limited to the analysis of notebook computers which are defined in decisions 2011/337 (European Commission 2011) and 2011/330 (European Commission 2011) as devices which:

a) perform logical operations and process data and are designed specifically for portability and to be operated for extended periods of time either with or without a direct connection to an AC power source;
b) use an integrated computer display and are capable of operation off an integrated battery or other portable power source. If a notebook computer is delivered with an external power supply this power supply is considered part of the notebook computer. Tablet personal computers, which may use touch-sensitive screens along with, or instead of, other input devices, shall be considered notebook computers.

Lately, traditional notebook computers have further advanced to develop other types of portable computers. Table 1 stresses the main features of these 'new' notebooks and helps one to better understand how they differ from traditional notebook computers.

Table 1. Description of different types of notebook computers (derived from information on products available in internet in 2015)

Types of notebook computers	Description
Netbook	Netbook computers feature small display sizes and keyboards, and have a typical mass lower than 2 kg. These devices omit optical disk drives to meet their size and weight features. They offer reduced computing power compared to a traditional notebook. An average prismatic battery pack last between six to nine hours on a single charge (Geek.com 2014)
Subnotebook	Subnotebooks are a very thin and light version of traditional notebooks. They are generally under 18-21 mm thick and 1.8 kg (Electronics Takeback Coalition 2012). Most types use solid state drives instead of hard disk drives. Subnotebooks use low power processors and feature fast boot times which return the device from standby mode in few seconds. They use prismatic battery packs lasting from five to 11 hours. Optical disk drives and Ethernet ports are generally omitted due to their limited size. The most famous versions of subnotebooks are commercialized under the name of Ultrabook TM (by Intel Corporation) and Macbook Air (by Apple Inc.)
Tablet computer or slates	For tablet computers, the display size varies from 7" to 12", and the thickness between 7.5 to 12 mm. They rely solely on touchscreen input, as physical keyboards are not featured, and have a solely wireless network connection (i.e. Wi-Fi, 3G). Tablet computers are primarily powered by an internal battery pack which can last from five to 13 hours (Blanco 2012)

5.2. Bill of materials (BoM)

To identify potential improvements in the design of products, it becomes necessary to study the material composition and the assembly/disassembly sequence. Although the material composition of laptops is already available in some scientific and technical reports, this information tends to be provided in quite aggregated terms by components, or by type of material without disclosing information about where the material is specifically used. As a result, dismantling one sample unit (in this case a laptop) becomes a useful way to obtain primary data about composition and also to study, more exhaustively, the assembly of the product. The latter result has also proven to be useful in terms of understanding the accessibility of certain components (which can be identified as 'hot spots', from an environmental and economic point of view).

Table 2 shows the bill of materials (BoM) of one notebook computer. The BoM has been determined by dismantling a product that reached its end-of-life. This explain the presence of components, as CFL lamps, which are not anymore included into new devices. As observed, the greatest mass is represented by plastics and metals. Plastics are mainly composed of blends of polycarbonate, acrylic-styrene-acrylonitrile with a mineral fibre (marked as PC-ASA-CF), polycarbonate with glass fibre (marked as PC GF20), and poly methyl methacrylate (PMMA). The remaining one fourth of the total mass of plastic is unmarked; therefore, it cannot be further specified. Most of the metals contained in the laptop are aluminium, magnesium alloy, and steel. The mass of these metals may vary from design to design, and also among manufactures. The battery, followed closely by different types of printed circuit boards (PCBs), is also identified as a relevant part of the laptop in terms of mass. The mass of other components such as the optical disk drive (ODD), hard disk drive (HDD) and fan are not further disaggregated. A more precise analysis of the material composition of these components requires a subsequent breakdown, which has not been performed in this analysis.

Among the materials and components described in Table 2, there are some components which still have a residual economic value to be reused in other laptop units (i.e. ODD, HDD) while other components only have the economic value of the materials embodied (i.e. batteries, PCBs).

Table 2. Simplified bill of materials of a notebook computer.

Parts/Components	Description of the material	Mass (g)
Plastic polymers	Blend 1 with flame retardant (PC+GF20 FR40)	109
	Blend 2 with flame retardant (PC ASA CF10 - FR40)	129
	Poly methyl methacrylate (PMMA)	105
	Unspecified plastic	103
Metals	Aluminium	189
	Magnesium alloy (AZ91D)	177
	Steel (including screws)	77
Glass		160
Batteries	Prismatic battery: Li ion	306
	Bottom battery: Lithium Manganese dioxide (CR2032)	3
Printed circuit boards (PCBs)	Motherboard	167
	Processor	4
	RAM cards	17
	PCBs with USB, HDD, keypad and mouse connectors	49
	Other PCBs	28
Other components	Optical disk drive (ODD)	212
	Hard disk drive (HDD)	96
	Fan	10
	Small LCD	5
	Speakers	5
	CCFL lamps	8
	Cables	17
Total		**1,976**

5.3. Design of the product

To understand the feasibility of extracting certain components in portable computers better, it becomes important to study, in detail, their assembly and disassembly sequences. A more exhaustive study on (dis)assembly will assist in identifying potential design improvements to facilitate the extraction, repair, and recycling of key components. Figure 6 shows the steps required for the disassembly of a laptop computer collected at their end of life.

The disassembly sequence of a laptop computer can be described by eight subsequent levels of operations where diverse items can be extracted. For instance, level 0 includes items that are accessible and extractable directly without the need to extract any other component and, in many cases, do not necessitate the opening of the product. Level 8 includes items accessible after extracting certain parts of the product beforehand. In the example illustrated in Figure 6, we observe that components such as the battery (item 1) and optical disk drive (item 2) are instantaneously accessible without the need to remove any other components. There are also two plastic lids (items 3 and 4) that can be unscrewed at this level. This operation allows access to other parts, such as a cable (item 6), the AC/DC current regulator printed circuit board (item 7), and a shell containing one hard disk drive (item 8). A further level of operation is needed to separate the hard disk drive (item 8a) from the shell (item 8b). Further dismantling of items such as the hard disk drive (item 8a) and display (item 11) are not included for simplification purposes.

Figure 6 helps one to understand the operations needed to recover certain valuable components such as memory cards (item 9), the display (item 11), and the processor (item 31), in addition to other parts that require separate collection according to legislation such as batteries (item 1 and 27a). The diagram also shows all items included in the motherboard (item 14), and that could be further separated for specific treatments. Suitable examples include the separation of the base cover of the laptop (item 29) for plastic recycling, or the fan (item 30) for reuse.

In conclusion, we can also observe that the design of this laptop computer has a certain degree of modularity, as it allows for the separation of specific components such as the battery (item 1), ODD (item 2), HDD (item 8a), and memory cards (item 9), which are likely to be more frequently replaced for upgrading and reparation without the need to extract many other components beforehand.

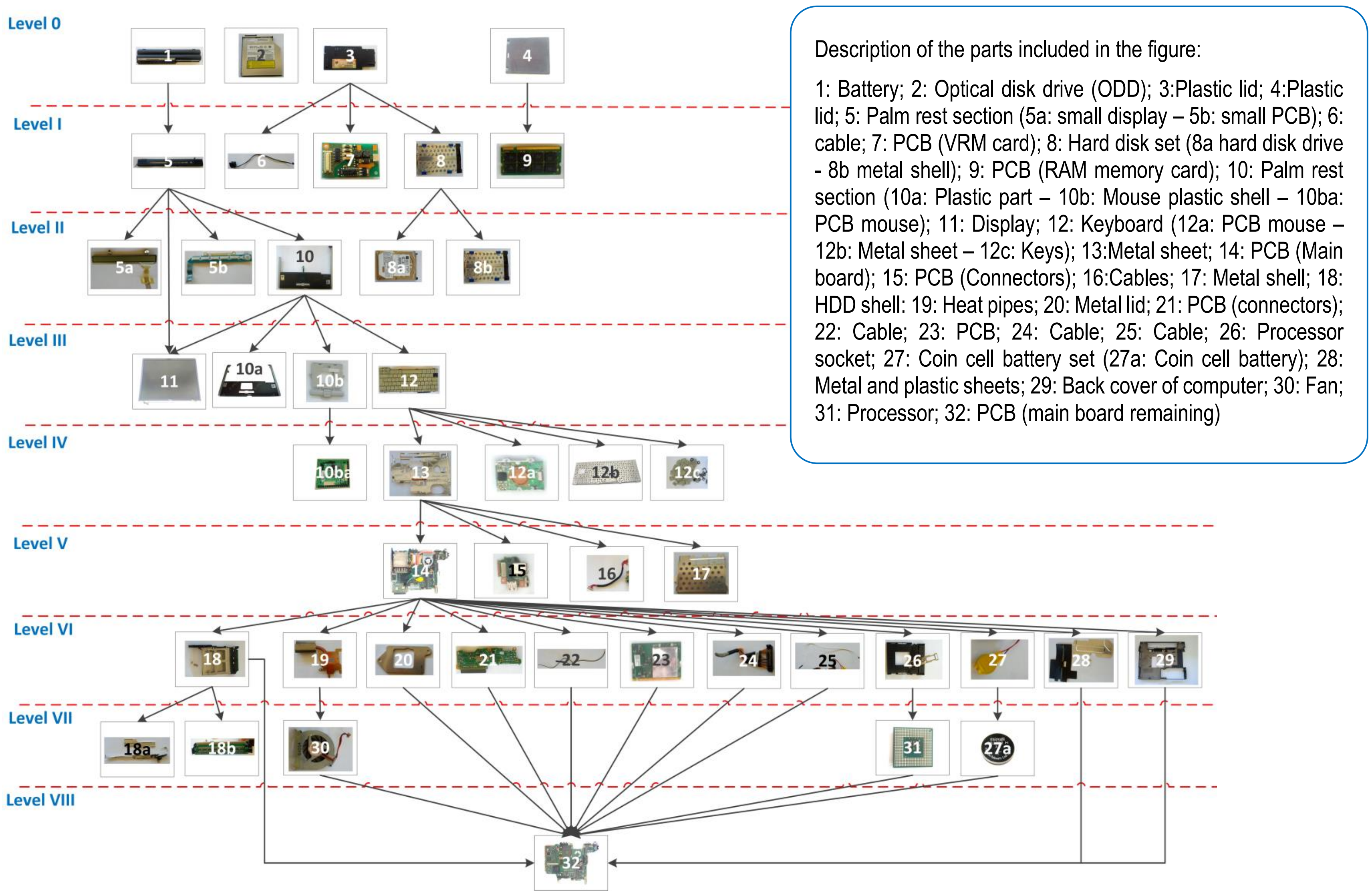

Figure 6. Steps required for the full dismantling of a laptop computer.

5.4. End of Life

As observed in an Italian recycling site, one of the major reasons to manually treat notebook computers is to separate the mercury lamps contained in the backlight system of the display, as requested by the WEEE directive (European Commission 2012). As mercury lamps are being phased out by light emitting diodes (LED) that do not contain mercury, the treatment of a portable computer will likely be changed in the near future, with a transition towards an undifferentiated shredding together with other WEEE. However, the content of certain materials (i.e. precious metals) in portable computer components supports the need for a more careful and manual dismantling.

Information about the recycling processes of computers has been complemented by information from observations conducted in other recycling plants in Europe, as well as information from the literature. For example, Van Eygen et al. illustrated the recycling of desktop and laptop computers in Belgium (Van Eygen et al. 2015). As described, collected computers are first checked and then sorted depending on whether they can be reused or recycled. Portable computers due to be recycled undergo a primary treatment step, where they are dismantled manually, to take out the various components that follow different treatments. Some parts, such as batteries and printed circuit boards (PCBs), are sent to an end-processing facility while the other dismantled components are further treated through operations such as shredding, magnetic separation, and eddy current separation. These operations allow for an additional separation of the materials contained in the product before said materials are delivered to end-processing. At the end-processing, material fractions (i.e. metal scrap) are converted into secondary materials. This last step foresees different routes for metals and plastic polymers.

For metals, scrap of iron and steel, aluminium, magnesium, copper, as well as fractions rich in non-ferrous metals such as PCBs, are sent to respective smelters. Base metals, such as iron, ending up in copper/integrated smelters, are transferred to the slag as impurities. Such fraction can be used as aggregate in Portland cement (Siddique and Khan 2011). Similarly, organic impurities in smelters act as an additional reducing agent and fuel, thus replacing cokes (Schlüp et al. 2009). The resulting mineral fractions are used as an additive in construction material, thus replacing gravel from mines.

Plastic polymers are separated and processed into secondary plastic pellets. The polymers separated are polypropylene (PP), polystyrene (PS), polyethylene (PE), acrylonitrile butadiene styrene (ABS) and poly(methyl methacrylate) (PMMA). Laptop batteries are recycled, and according to Hischier et al., the amounts of steel, cobalt, non-ferrous metals, and manganese oxide contained in them are recovered as secondary materials (Hischier et al. 2007). Button cell batteries were processed separately.

5.5. Proposal of EU Ecolabel criteria based on current regulation and other environmental schemes

As part of a more detailed analysis of the EoL of computers, it is necessary to revise the legislation set up for this aspect in other directives and regulations, but also in other environmental labelling schemes. Such analysis helps develop draft criteria aligned with those that are already in existence.

Facilitating the replacement of battery packs will potentially allow for extending the life time, and also facilitate reuse and recycling of portable computers and PC-tablets. The dismantling of batteries is discussed in several legal documents, such as the directives 2012/19/EU on waste electrical and electronic equipment (WEEE) and 2013/56/EC on batteries, and the Commission regulation 617/2013 on Ecodesign requirements for computers. All of these documents agree on the importance of disclosing information on whether batteries can be easily removed or not. Even though the WEEE and battery directives focus on the need to facilitate the separation of batteries from portable computers, they do not describe in further detail the design that would ensure such separation. The following paragraphs describe the main aspects for batteries included in the above mentioned documents.

- The WEEE directive encourages cooperation between producers and recyclers and measures to promote the design and production of EEE, notably in view of facilitating the re-use, dismantling, and recovery of WEEE, its components, and materials. Annex VII of the WEEE directive includes batteries in the list of substances, mixtures, and components that have to be removed from any separately collected WEEE (European Commission 2012).

- The battery directive 2013/56/EC explains that Member States shall guarantee that manufacturers design appliances to allow for the readily removal of waste batteries by the end-users or by qualified professionals that are independent of the manufacturer (European Commission 2013). Instructions on how to safely remove those batteries, and also of the types of battery if appropriate, should be provided together with the appliances.

- The Commission regulation 617/2013 established that manufacturers of notebook computers operated by battery/ies that cannot be accessed and replaced by the end-user shall include the statement *'The battery[ies] in this product cannot be easily replaced by users themselves'*, in the technical documentation, free-access websites, and on the external packaging of the computer (European Parliament and the Council of the European Union 2013). Such information shall be clearly visible and legible and be provided in all the official languages of the country where the product is marketed.

Besides these legal documents, there are several environmental labelling schemes applied to computers across Europe. The most famous are Blue Angel and Nordic Ecolabelling, both including laptops and PC-tablets, with the last ones also regarded as slates from hereafter. The

German eco-label, Blue Angel, includes ‘reparability’, ‘recyclable design’, and ‘consumer information’ aspects for batteries of computers including portable computers. For ‘reparability’, the label requests that rechargeable batteries shall be available for a period of five years from the end of production. The ‘recyclable design’ criterion describe that batteries shall be designed to allow for their easy disassembly by one person alone, and must be easy to remove without the use of any tool (RAL GmbH 2012). Under the ‘consumer information’criterion, Blue Angel states that the batteries must not be disposed of with the normal household waste but should, instead, be taken to a waste collection facility.

Computers, including notebook computers and tablets, awarded with the Nordic Ecolabelling must be designed in such a way that disassembly by a qualified person working alone is possible (Nordic ecolabelling 2013). Although this criterion does not specifically mention batteries, it applies to them as they are on the list of components included in Annex VII of the recast of the WEEE directive (2012/19/EU) (European Commission 2012). The ‘instruction for use’ criterion provides information about the type of batteries and accumulators used and on the user’s obligation to leave used batteries at a return station and not dispose of them within the household waste. Seventeen laptop computers have been awarded the Nordic Ecolabel (Ecolabel.se 2014).

Criteria about the dismantling of batteries from computers are also described in the 1680 Standard Series developed by the IEEE. The IEEE 1680.1 sets three compulsory, and one optional, criteria for batteries (Institute of Electrical and Electronics Engineers 2009). Compulsory criteria are included in the ‘design for End of Life’ and ‘End of Life management’ criteria, and declare that batteries shall be safely and easily identifiable and removable, manufacturers shall provide treatment information that identifies their presence and location, and a rechargeable battery take-back service at a competitive price equivalent to, or better, than that provided by the Rechargeable Battery Recycling Corporation (RBRC). The optional criterion is for product longevity and specifies that spare parts and/or compatibility with replacement parts shall be available five years after the end of production. Table 3 includes the description of all criteria regarding batteries in the three types of criteria analysed.

Table 3. Criteria for batteries contained in computers.

Criterion	Blue Angel (RAL-UZ-78a)	Nordic Swan Version 7.0; 06/2013-06/2016	IEEE Std. 1680.1™ -2009
Life cycle extension	(Under 'Longevity: reparability') Rechargeable batteries shall be available for a period of five years from the end of production (if provided).		(Under 'Product longevity/life cycle extension') Spare parts and/or compatibility with replacement parts shall be available five years after end of production.
Design for recycling	(Under 'Recyclable design: structure and joining technique') - Products shall be designed so as to allow for easy (manual) disassembly for recycling purposes to separate case parts, chassis, batteries (if applicable), display units (if applicable) and printed circuit boards as fractions from materials of other functional units, and, if possible, their recycling as a material. Rechargeable batteries, if applicable, must be easy to remove without the use of any tools.	(under 'Design and materials: disassembly') It must be possible to separate the substances, preparations and components listed in annex VII [5] of the WEEE directive (2012/19 EU).	(Under 'design for End of Life') - Manufacturers shall provide treatment information to reuse and recycling facilities that identifies the presence and location of materials that require special handling, especially nonstandard or new substances or new technologies, and including items such as batteries. - Circuit boards > 10cm² (measured on the largest face), batteries, and other components – any of which contain hazardous materials – shall be safely and easily identifiable and removable. (Optional under 'Reduction/elimination of environmental sensitive materials: batteries') With the exemption of technically unavoidable impurities, batteries and accumulators (internal to the computer system) shall not contain any lead, cadmium or mercury. Such impurities shall not exceed the limiting values as specified in the European Council and Commission Directive 2006/66/EC.
End of Life management	(Under 'Consumer information') Information that the batteries must not be disposed of with the normal household waste but instead should be taken to a waste collection facility.	(Under 'Instruction for use') Information about the type of batteries and accumulators used and on the user's obligation to leave used batteries at a return station and not dispose of them within the household waste.	(Under 'Rechargeable battery recycling') Manufacturers shall provide a rechargeable battery take-back service at a competitive price equivalent to, or better, than that provided by the Rechargeable Battery Recycling Corporation (RBRC). They must provide information about the service.

[5] Batteries are listed as components in Annex VII of the WEEE Directive 2012/19/EC

In summary, the criteria included by all the documents mentioned above repeat the idea of designing batteries so as to enable them to be readily dismantled. In traditional notebooks, battery packs are already designed to be easily removed, manually, from their underside without the need of removing the base cover, for example. Those batteries are generally extracted without the need of tools by just pushing a spring-loaded release. In new types of portable computers, namely subnotebooks and tablet computers, the easy and manual dismantling of batteries is no longer a common feature.

5.5.1. Design of batteries in portable computers

Battery packs represent one of the critical elements in portable computers in terms of environmental burden and contribution to the total impact of portable computers (Teehan and Kandlikar 2013). They are also one of the components regulated by several European directives, especially the battery, waste electrical, and electronic equipment directives (European Commission 2012; European Commission 2013). Furthermore, battery performance is one of the key features of choice for consumers (Dodd et al. 2014). Batteries are among the most commonly damaged components, coming just after keyboards and screens, and are more frequently damaged than hard disk drives and motherboards (Daoud 2010).

Based on the comments during the stakeholder's consultation of the EU Ecolabel process and also during the first observation of the design regarding new types of portable computers, namely subnotebooks and PC-tablets, we decided to develop a more exhaustive study about their design, with a special focus on battery packs. The aim of the study is to understand if criteria to facilitate the extraction of battery packs may be pertinent to ensure their effective reuse and recycling.

5.5.1.1. Batteries of subnotebook computers

Thanks to technological advances, subnotebooks, an improved version of notebook computers, and PC-tablets have entered the market. Subnotebooks are generally under 18-21 cm thick and 1.8 kg in weight, use a solid state drive, have a 'rapid start' which returns from standby mode within seconds, and a prismatic battery lasting five hours or more. In 2012, a study developed by the Electronics Takeback Coalition showed that only out of 28 subnotebook computers have user replaceable batteries, and that most of them required a service call to replace them (Electronics Takeback Coalition 2012). Figure 7 shows two example locations for battery packs in subnotebooks, which have been highlighted by discontinuous pink lines in both cases. Subnotebook 1 has the battery pack located in the exterior of the base cover and can be easily extracted by pressing a spring-loaded release. Subnotebook 2 has its battery pack embedded in the base cover. To extract it, the steps needed are: the removal of the blank SD card (located on a side), unscrewing and removal of the access door (located in the cover base), and unscrewing of the base cover. Once this is done, the computer needs to be turned upside down and then the keyboard loosened, the keyboard cable unplugged, the palm rest unplugged and removed, and finally the battery unscrewed and lifted out of the base cover (PSAParts 2013; Paine 2014).

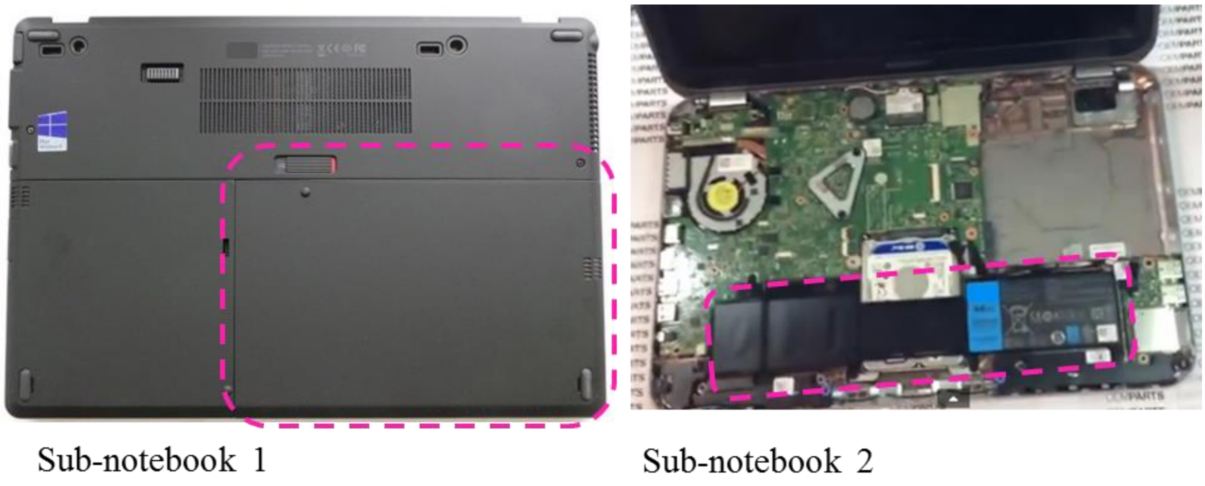

Figure 7. Location of the battery pack in two subnotebook computers: subnotebook 1 with external accessible battery pack, and subnotebook 2 with embedded battery pack accessible only after the base cover is unscrewed and the palm rest removed.

Using the analysis of subnotebooks included in the Electronics Takeback Coalition report (Electronics Takeback Coalition 2012) as a starting point, we performed a more exhaustive study of the steps required to access and extract battery packs for 28 subnotebook computers. The extraction of battery packs was studied by analysing audiovisual material uploaded on the internet (youtube.com). Table A2 of the annex of this report includes the links to videos illustrating the battery extraction and, in some cases, its extraction together with other components, for each of the subnotebooks included in the table below.

To synthetize our findings and draw general conclusion about the design of battery packs in the 28 units analysed, we have developed a code. The code defines six main groups, all defined alphabetically from A to F. For groups C, D, and E, subgroups have been further defined using numerical values. The numerical values are located before and/or after the code, and refer to the number of additional steps required to extract battery packs. For example, code C means that, to extract battery packs, first the base cover need to be opened, and then the battery can be unplugged and unscrewed. Code 1+C means that, before removing the base cover, rubber feet-covering screws or a side connector cover need to be taken out. Table 4 explains the information referred to in each code listed in the first column in further detail. The table describes whether the battery is embedded, and describes the steps required for the extraction of battery packs, the tools required for the dismantling and, finally, the number of units found with such features.

Table 4. Steps required for battery extraction in subnotebooks

Code	Embedded battery?	Steps	Number of steps	Tools	Number of units	%
A	No	Spring-loaded release	1	none	1	4
B	No	Unscrew battery pack	1	Screwdriver	1	4
C	Yes	Remove base cover, unscrew, and unplug battery pack.	3	Screwdriver	13	46
1+C	Yes	Steps described in C plus one pre-step. For example, remove rubber feet and connector cover on the side.	4	Screwdriver	2	7
2+C	Yes	Steps described in C plus two pre-steps. For example, remove rubber feet, connector shell on the side, and remove additional screws.	5	Screwdriver	2	7
1+C+1	Yes	Steps described in C plus one pre-step and one post-step. For example, remove rubber feet, connector shell on the side, remove adhesives, and unplug additional cables.	5	Screwdriver	2	7
D	Yes	Remove base cover, remove adhesive, unscrew and unplug battery pack.	4	Screwdriver	2	7
2+D	Yes	Steps described in D plus two pre-steps. For example, remove rear panel and HDD unit.	6	Screwdriver	1	4
E	Yes	Remove base cover, connectors, lift tape, unscrew and unplug battery pack, and pull without disconnecting speaker cables.	6	Screwdriver	2	7
F	Yes	Unscrew base cover, turn the computer and press the tab in to loosen the keyboard, unplug the keyboard cable, unplug and remove the palm rest, unscrew battery, and lift it out of the laptop.	6	Screwdriver	1	4
5+F	Yes	Steps described in E plus five pre-steps. For example, remove SD blank, unscrew and remove access door, remove the memory, and remove screws.	11	Screwdriver	1	4

The results show that only 8 % of the subnotebooks analysed have battery packs placed externally, whereas 92 % have embedded battery packs. For one of the subnotebooks with battery packs accessible from the exterior, the battery pack can be extracted manually by using a spring-loaded release (no tools) whereas, for another model with the battery externally accessible, a screwdriver is needed to remove three screws. For about 46 % of the analysed subnotebooks, the battery can be extracted by removing the base cover beforehand, unplugging the battery from the main printed circuit board (PCB), and then unscrewing it from the laptop chassis. About 32 % of the units require additional steps before and/or after removing the base cover, and also removal of adhesives. For 7 %, besides removing those parts, special care must be taken so as to not disconnect other battery cables. For 8 % of the units, a part from the base cover, the keyboard, and the palm rest need to be removed as well. In general, results show that the extraction of battery packs in subnotebooks is generally not facilitated.

5.5.1.2. Batteries of PC-tablet computers

For PC-tablets, battery packs are also generally built-in or embedded. In 2013, a study published by Fraunhofer Institut für Zuverlässigkeit und Mikrointegration (IZM) examined the disassembly of PC-tablets as a way to evaluate their design for repair and recycling (Schischke et al. 2013). The study provides an extensive description of the disassembly of 21 models of PC-tablets. In the report, separate analyses were performed for the opening, the removal of battery packs, and the main printed circuit board (PCB). Our study analysed some of the 21 PC-tablet models done by Schischke et al. that were easily identified by using audiovisual material available on youtube.com in more detail. For other models, it was not possible to compare information from the report with audiovisual material because we could not identify the manufacturing company, as Schischke et al. analysed each model without disclosing the manufacturer. Table A3 of the annex of this report includes a link to videos showing the battery extraction for some of the PC-tablets included in the table below.

Steps needed for opening and removing the battery are described separately, and include as many design details as possible. Analogously, as for subnotebooks, different codes to identify the more appropriate types of openings and the extraction of battery packs have been developed. For the openings, five alphabetical codes were defined, with A being the most convenient design to separate batteries. Table 5 shows a description of the steps for opening, the tools needed, and the number of units meeting such features for each code.

Table 5. Codes and description of aspects when opening PC-tablets.

Code	Steps	Tools	Number of units	%
A	Remove base cover by pressing clips.	Spudger/spattle	8	38
B	Remove the base cover by pressing clips and unscrewing.	Spudger and screwdriver	5	24
C	Remove the based cover by pressing clips and removing screws and adhesives.	Spudger, screwdriver	6	29
D	Remove the base cover by removing adhesives, or adhesives and screws.	Heat gun or heat pad, and screwdriver	2	10

Among the units studied, 38 % are opened by pressing the clips of the base cover using a spudger, 29 % by pressing clips plus removing screws and adhesives, and 24 % by pressing clips and unscrewing. About 10 % of the models require the use of a heat gun to remove the adhesive fixing the base cover to the display. Previous knowledge about the disassembly procedure helps with opening the unit in a less destructive manner, with less time, and also in locating relevant parts more easily (i.e. battery packs) (Schischke et al. 2013). Thus, marking the direction for opening the back cover of the PC-tablet can significantly facilitate the opening operations.

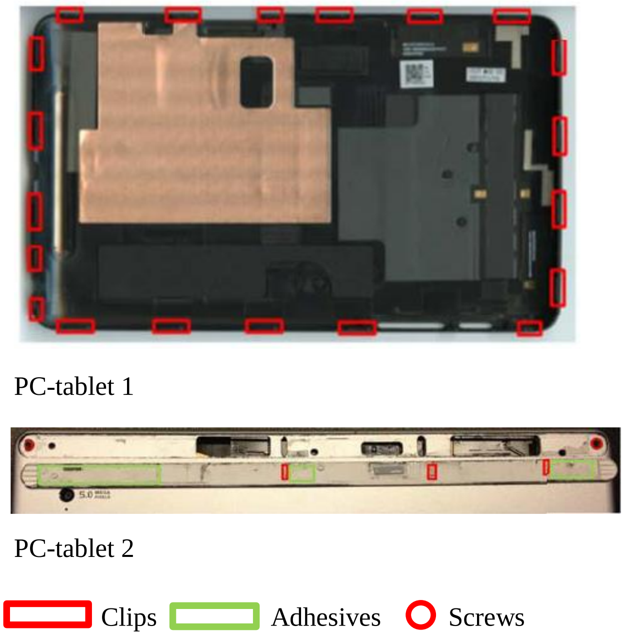

Figure 8. Fastening mechanism used in PC-tablets (Schischke et al. 2013).

Figure 8 shows two examples of openings for two PC-tablets. PC-tablet 1 uses only plastic clips (identified by red rectangles) to fasten the back cover to the display. Opening is done by pressing 20 clips, and then lifting with a metal spudger/spattle. PC-tablet 2 is characterized by a more complex opening-mechanism, as it uses a combination of plastic clips (red rectangles), adhesives (green rectangles), and screws (red circles). The unit was opened by levering a specific plastic part beforehand, which requires three clips to be pressed and glue to be removed. Then, two screws were removed and the display was levered using a spattle.

For the battery removal, four main alphabetical codes were defined (A to D). A stands for spring-loaded release whereas D means the removal of adhesives, screws, and connectors. For C and D, additional numerical codes were defined. Such values refer to the number of connectors that need to be unplugged for battery removal. ‘One’ means up to three connectors and ‘two’ means more than three connectors. For example, code C means that, to extract the battery pack, adhesives must first be removed. C+1 means that, besides removing the adhesives, three connectors also need to be taken out. Table 6 shows information regarding the extraction of battery packs in PC-tablets. A description on whether the battery is embedded, the steps to extract the battery, the tools, and the number of units meeting such features are included for each code.

Table 6. Codes and description of aspects when removing battery packs

Code	Embedded battery?	Steps	Tools	Number of units	%
A	No	Spring-loaded release.	none	1	5
B	Yes	Remove screws.	Screwdriver	1	5
B+1	Yes	Remove screws plus up to three connectors.	Screwdriver, spudger	2	10
C	Yes	Remove adhesive(s).	Heat gun or heat pad, spudger	2	10
C+1	Yes	Remove adhesive(s) plus up to three connectors.	Spudger	5	24
D	Yes	Remove adhesive(s) and unscrew.	Screwdriver, spudger	1	5
D+1	Yes	Remove adhesive(s) and unscrew, plus up to three connectors.	Screwdriver, spudger	6	29
D+2	Yes	Remove adhesive(s) and unscrew, plus remove more than three connectors.	Screwdriver, spudger	3	14

Among all the PC-tablets investigated, only one unit is designed to extract the battery manually without the need to open the device, while all of the other units are designed with embedded battery packs. As illustrated in Table 10, the majority of units need screws and/or adhesives to be removed, and connectors to be unplugged.

Figure 9 shows two examples of battery removal in PC-tablets. In PC-tablet 1, the battery pack can be manually removed without the need to open the unit. PC-tablet 2 is a good example showing that small components such as cameras, cables, tape or electromagnetic interference (EMI) shields often need to be removed to access main components such as batteries. PC-tablet 2 has the battery embedded and is, therefore, only accessible after opening the device, and removing adhesives, screws, and cables. Schischke et al. comment that, even though using strips (glue) instead of screws also secures the battery, screws are still a preferred option for facilitating the reparation and recycling of PC-tablets (Schischke et al. 2013).

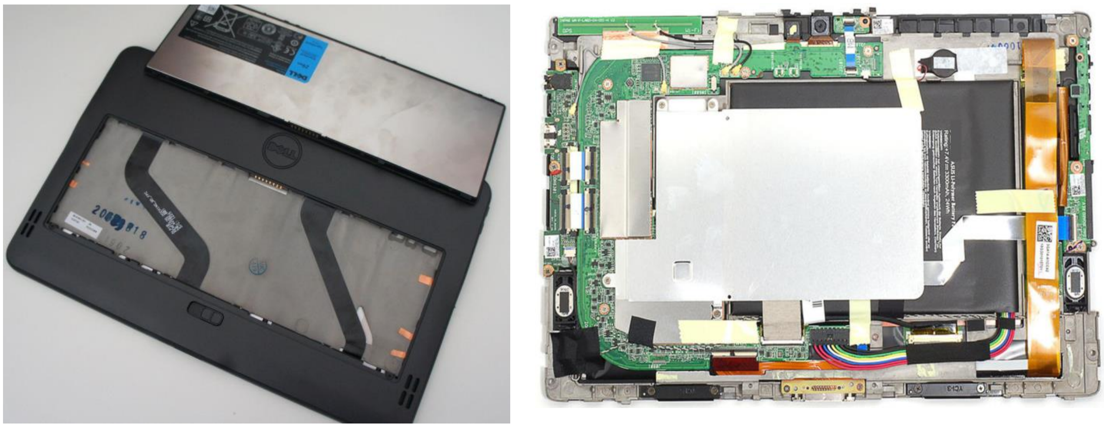

Figure 9. Location of the battery pack in two PC-tablet computers: PC-tablet 1 (left) with external accessible battery pack, and PC-tablet 2 (right) with embedded battery pack accessible only after opening the device, and then removing adhesives, screws, and cables.

5.5.1.3. Draft criteria on batteries

In conclusion, battery packs that are externally accessible from the underside provide the most convenient option for PC-tablets willing to achieve the highest environmental standards, and thus be awarded the EU Ecolabel. If the separation of battery packs from the rest of device, as stated in the WEEE directive, was performed effectively, then the amount of batteries shredded together with products would be significantly minimised (European Commission 2003; European Commission 2012). Manually extractable batteries would also contribute to improving the reuse and recycling of portable computers. Based on the findings described above, we propose that the following criteria be included in the EU Ecolabel for computers: cluster 3 ‘lifetime extension’ under the criterion ‘upgradeability and reparability’, and cluster 4 ‘End of Life management’ under the criterion ‘dismantling and recycling’:

Rechargeable batteries included in all portable computers shall be manually extractable by one person (user or service provider) without tools (i.e. by using one spring-loaded release) and without preliminary removal of any cover. Batteries should not be glued or soldered into the product. Instructions about how to separate battery packs shall be marked on the base cover of the chassis.

5.5.2. Recyclability of plastics parts

Scientific literature largely discussed the relevance of considering the recyclability of plastic parts in WEEE (Peeters et al. 2014). In particular, Peeters et al. (2014) discussed the compatibility in terms of recycling different mixtures of plastics in televisions (including flame retardants and different enclosures). Indeed, the more in-depth discussion and rationale about the use of flame retardants in plastic polymers of televisions is included in Section 5.5.2. For portable computers, by dismantling several units, we observed that about 25 % of their mass is made of plastics. The predominant types are polycarbonate, acrylic-styrene-acrylonitrile with a mineral fibre blend (marked as PC-ASA-CF), polycarbonate with glass fibre (marked as PC GF20) blends, and poly methyl methacrylate (PMMA). The remaining one fourth of the total mass of plastics is unmarked and, therefore, cannot be further specified. According to Peeters et al., efforts to differentiate those diverse plastic polymers would improve identification and separation (Peeters et al. 2014). Plastic fractions with high purity are needed to get high quality recyclates. Thus, as confirmed by various recyclers, marking and labelling would contribute to improving current recycling rates and the quality of the recyclates.

Compatibility for recycling should be also extended to other materials that are assembled/attached to plastic parts. The use of materials with distinct physical properties could facilitate their separation. For example, replacing stainless steel inserts in aluminium components with aluminium inserts or steel inserts (separable with high efficiency magnetic separators) could improve their recyclability. The criterion for the EU Ecolabel for electronic displays is proposed to be formulated accordingly.

Most of the plastic polymers contained in portable computers are used in the casing. In subnotebooks and PC-tablets, the material in the casing changes from model to model and, in many cases, is made of aluminium or magnesium alloys, or a combination thereof, and fiberglass-reinforced plastic or, possibly, aluminium-coated plastic (Portnoy 2012). Plastic casing is seen as a good alternative option to reduce the cost of new models. Predicting the material most used for new subnotebook and PC-tablet casing may be challenging, but it is fair to say that plastics will be likely play a significant role.

5.5.2.1. Draft criteria for the recyclability of plastic parts

Based on the findings described above, we propose to formulate the following criteria under 'Material selection and compatibility with recycling'.

Material selection and information to improve recyclability

(a) Recyclability of components
Assemblies made of materials mutually incompatible for recycling shall be separable
(b) Surface coating / metal inlays:

All plastic materials > 25 grams_used for housings and enclosures shall have no surface coatings that are not reusable/or recyclable, or metal inlays.

(c) Material information to facilitate recycling:
Plastic parts with a mass greater than 25 grams shall be marked in accordance with ISO 11469 and ISO 1043, Sections 1-2. Plastic parts containing flame retardants shall be marked with the symbol >FR< Plastic marking may include additional information related to the content of the flame retardant (ISO 1043-4 code) and CAS number, and the marking of the plasticizers and fillers.

For plastic parts > 200 grams, the marking should be large enough and located in a visible position so as to be identified by workers of specialized recycling firms.

Exemptions are made in the following cases:

(i) where the marking would have an impact on performance or functionality of the plastic part, including optical plastics;

(ii) where parts cannot be marked because there is not enough available appropriate surface area for the marking to be of a legible size so as to be identified by a recycling operator;

(iii) where marking is technically not possible due to the moulding method; or

(iv) where the addition or location of marking causes unacceptable defect rates under quality inspection, leading to an unnecessary waste of materials.

6. Development of EU Ecolabel criteria for electronic displays

The material efficiency aspects of electronic displays have been already analysed in previous JRC reports. Ardente and Mathieux showed that the recycling of electronic displays, supported by some manual dismantling, allows for higher recovery rates; this effect is particularly relevant for specific materials contained in the printed circuit boards (PCBs) and in the liquid crystal display (LCD) screens (Ardente and Mathieux 2012). To avoid losing significant amounts of materials when electronic displays are recycled by fully mechanical shredding, Ardente and Mathieux (2012) proposed four potential requirements for their Ecodesign. The first proposal is a requirement to improve the disassembly of key parts, such as printed circuit boards, LCDs, fluorescent lamps, and the plastic guide light (mainly composed by polymethyl methacrylate). Changes in the design of electronics displays to improve the disassembly of those parts will make recycling by manual disassembly more environmentally efficient and economically competitive. The second requirement consists of the declaration of the content of indium in electronic displays, which will also help to estimate the potential amount of indium available once displays have reached their End of Life (EoL). A third proposed requirement consists of marking large plastic parts according to ISO standards (ISO 11469 and ISO 1042-2) to improve their sorting at recycling plants; marking the type of flame retardant will also affect the recyclability of plastics. The fourth proposed requirement consists of defining a minimum threshold of the ‘recyclability’ rate of plastics, with the objective of this last one being the improvement of the separation and recycling amounts in regard to plastics.

Ardente et al. (2013) analysed the benefits of the extraction of key components from electronic displays, and assessed their benefits and environmental impacts (Ardente et al. 2013). Two types of key components were selected: PCBs and Thin Film Transistor (TFT) panels. The analysis identified several possible thresholds for the total time to extract those components. For electronic displays smaller than 25 inches (diagonal screen size), the time to extract PCBs larger than 10 cm^2, film conductors, and TFT panels embedded in electronic displays shall not exceed 260 seconds. While, for displays equal to or larger than 25 inches (diagonal screen size), the time shall not exceed 480 seconds. Improving the extractability of those key components will help optimize the EoL treatments of electronic displays, increasing the recovery rate of some rare, precious, and critical raw materials. The implementation of such requirements would allow for the recovery of about 86-261 tonnes of copper, 7-15 tonnes of silver, 2-5 tonnes of gold, 0.5-1 tonnes of palladium, and 5.5-11 tonnes of indium. The potential economic benefit of recovering such amount of metals is between EUR 58 to almost EUR 144 million and a reduction up to 30 % of various life cycle impact categories (e.g. related to human toxicity, ecotoxicity, and resource depletion). Furthermore, the separation of PCBs and TFTs will reduce the risk of contamination of other waste fractions by potentially hazardous substances (contained in PCB and TFT).

In light of the previous results, the analysis of electronic displays in this report is being done to align potential material efficiency requirements proposed for Ecodesign to criteria for EU Ecolabel.

6.1. Definition of electronic displays product group

The current scope of the EU Ecolabel criteria document for televisions is defined in the Commission Decision of 12 March 2009 ‘establishing the revised ecological criteria for the award of the community Ecolabel to televisions (European Commission 2009)’. The product group ‘televisions’ shall comprise: ‘Mains powered electronic equipment, the primary purpose and function of which is to receive, decode and display TV transmission signals’.

In the current review process of EU Ecodesign and Energy Labelling Regulations for televisions, the term ‘electronic displays’ is being proposed to replace ‘televisions’, which is a wider term and includes a greater range of display products. Electronic displays can be defined as (European Parliament and the Council 2014)[6]:

‘devices capable of displaying visual information from wired or wireless sources including: i) broadcast and similar services for terrestrial, cable, satellite, and/or broadband transmission of digital signals; ii) display-specific connections such as VGA, DVI, HDMI, DisplayPort; iii) non display-specific connections such as, but not limited to, Thunderbolt, USB; iv) media storage devices such as USB flash drive, SD memory card, or DVD/Blu-ray Disc or v) network connections, usually using Internet Protocol, typically carried over Ethernet or WiFi, including wireless digital streams such as AirPlay, DIAL, WirelessHD, WiDi.’

As part of the product group analysis, this report provides information about the bill of materials (BoM), the design of the product, and the EoL. Information contained in this section has been elaborated upon based on the existing literature and previous JRC reports concerning material efficiency aspects of electronic displays (Ardente and Mathieux 2012; Ardente et al. 2013).

[6] This definition refers to the last version of the draft regulation publicly available at the time of the present report.

6.2. Bill of materials

Table 7 shows the BoM of an exemplary LCD-TV of 20.1'' dimension screen using an integral cold cathode fluorescent lamp (CCFL) backlight system. The mass of the television is 7.19 kg. As observed, about 40 % of the mass of the television is made of plastics. While the main plastic types are polymethyl methacrylate (PMMA), and acrylic-styrene-acrylonitrile (ABS), some plastic components cannot be easily identified and are therefore declared as *unspecified plastics* (3 %). Most of the metals contained in televisions consist of aluminium (5 %), and iron/steel alloys (27 %). Iron/steel parts are mainly placed in the frame and in the cover. The mass of these metals may vary from design to design, and also among manufacturers.

Table 7. Bill of materials of an exemplary electronic display

Parts/Components	Description	Material	Mass (g)
Frames/covers	Back cover	ABS	920
	Main front cover	ABS	340
	Support	ABS	250
	Secondary front covers	PC	15
		Unspecified plastic	98
	Main metal frame	Iron/steel	1580
	Secondary metal frame	Iron/steel	261
	PCB support	Iron/steel	48
	Support for cable plugging	Iron/steel	34
		Unspecified plastic	38
	Internal support	Aluminium	353
	External support	Aluminium	30
Printed circuit boards (PCBs) and connectors	PCB 1	Various (rich in precious metals)	245
	PCB 2	Various (rich in precious metals)	61
	PCB 3 (smaller than 10 cm²)	Various (rich in precious metals)	1
	PCB 4	Various (Very rich in precious metals)	55
	Film connectors (linked to PCB 4)		4
	PCB 5	Various (poor in precious metals)	300
	PCB 6	Various (poor in precious metals)	8
Liquid crystal display (LCD) screen	LCD (larger than 100 cm²)	Glass, plastic, others (48.2 mg indium)	473
	Plastic light guide	Polymethyl methacrylate (PMMA)	1565
	Plastic foil	Unspecified plastic	100
	Fluorescent lamp	Glass and various (8 mg mercury, and 5.8 mg rare earths)	8
Fan		Plastic and steel	19
Speakers		Steel, plastic	196
Cables	External	Copper; plastic	120
	Internal	Copper; plastic	25
Others	Capacitors (with diameter greater than 2.5cm; linked to PCB 2)	Various	9
	Screws	Iron/Steel	30
Total			7,186

6.3. Design of the product

Liquid crystal displays (LCD) are the most commercialized type of electronic displays. In the last decade, LCDs mainly used cold cathode fluorescent (CCFL) tubes as a backlight system. However, CCFL technology is progressively being replaced by light emitting diodes (LED) due to the lower efficiency and quality of the image as well as their content of mercury, a substance catalogued as hazardous by the RoHS directive (European Commission 2011; Buchert et al. 2012; Veit et al. 2013). Besides the change of the type of backlight, the general structure of the electronic displays has been maintained. Although there is a large variety in the design of electronic displays, generally the main parts included are: a front cover and a plastic frame, and then a main printed circuit board (PCB)[7], speakers, an inverter board, a switched mode power supply (SMPS) board and a timing controller (TCON) all assembled to a steel sheet, and the screen[8] which contains the backlight system. Other parts can include connections (such as cables and thin films), secondary PCB, fans (optional), and several different frames and supports.

Figure 10 shows the comparisons of the components mounted in the steel sheet in two typical LCD displays, with CCFL backlighting (a) and with LED backlighting (b).

(a) LCD display with CCFL backlight **(b) LCD display with LED backlight**

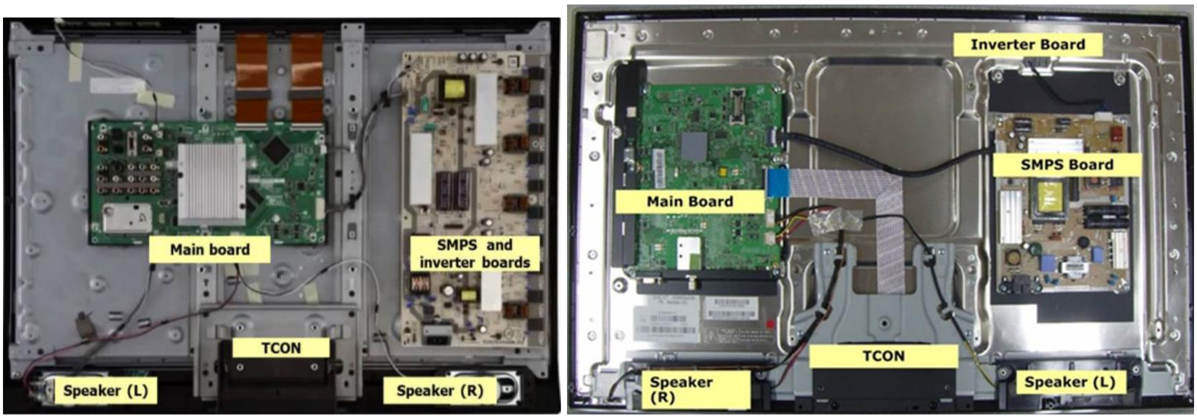

Figure 10. Components mounted in the back of two typical electronic displays (adapted from (Electro Help 2013; Shop Jimmy 2013).

As observed in Figure 10, a difference between CFL and LED backlighted displays is the location and the type of fastening of certain components. For example, in the Figure 10 (a) the backlight inverter and power supply (SMPS) boards are mounted together and then referred to as 'SLIP' boards. Those small differences, however, don't substantially modify the dismantling

[7] The components included in the PCB for the functioning of the LCD and LED are not all the same, however as their dismantling from PCBs is not yet a common practice; we limit the discussion to the disassembly of the complete PCB from the display.

[8] A screen is defined as the part of an electronic display containing the backlight system together with the polymeric layers and the glass.

sequence of the display, as the type of operations to dismantle the product remains the same. The placing of the backlight system varies analogously for each type of screen, as we observed for both back-lit technologies, wherein the backlight is placed behind the screen, or edge-lit, wherein the backlight is on the side of the screen.

According to our analysis, the dismantling of displays starts by removing the screws from the rear cover and taking down the support (when present), lifting up the rear cover, removing the cables and screws from SMPS and the main board and other side components (e.g. speakers, fans). Once the components mounted in the back of the display are removed together with the steel sheet and several frames, the screen section containing the backlight of the display remains accessible.

Figure 11 illustrates the diverse components that form screens. Typical LCD screens include one metal and one plastic frame in the front of the screen, and then a series of polymeric layers including diffuser sheets, polymethyl methacrylate (PMMA) sheets, reflective sheet with CCFL lamps, a printed circuit boards, and a back cover. In typical LED screens, CCFL lamps are replaced by LEDs whereas the rest of components of the screen remain the same as those for LCD (Veit et al. 2013). The dismantling sequence of LED can also be observed in several videos available online (Electro Help 2013; Shop Jimmy 2013).

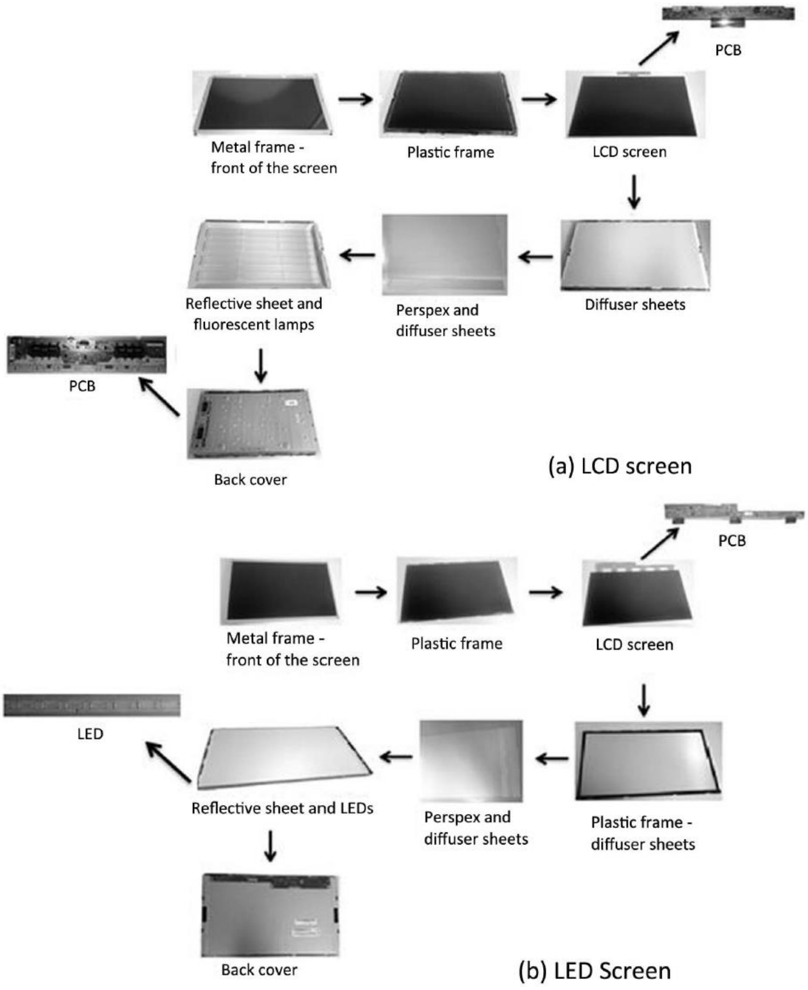

Figure 11. Parts of typical LCD (a) and LED (b) screens (Veit et al. 2013).

An LCD TV can have a variable number of CCFL lamps (from two to 20, depending on the screen size) and variable dimensions (typically around 10-40 cm long), positioned in the edge of the panel frames or running from side to side of the panel. LED backlights are usually mounted on rails, strings, or LED arrays. Figure 12 demonstrates how the two types of backlight systems are arranged. In both cases, the entire display must be disassembled to access them.

Figure 12. CCFL tube backlight units (a) are rapidly giving way to LED strings or rails (b) for LCD backlighting (Barney 2013).

In conclusion, electronic displays using an LED backlight have a similar structure as those using CCFL backlight units. As a consequence, the dismantling process is similar for both the technologies and it does not affect the dismantling sequence and related dismantling times significantly. We can conclude that the time for dismantling for electronic displays as assessed in the report 'Feasibility study for a standardized method to measure the time of extraction of certain parts from an Electrical and Electronic Equipment' for CCFL LCD can be extended to LED displays (JRC-IES, 2013).

6.4. End of Life

Portable computers and electronic displays have a similar EoL management. With an estimation of about 30 million devices reaching their EoL in the EU by 2015, flat panel displays represent one of the most relevant waste categories (Fakhredin and Huisman 2013). In recent years, a significant amount of scientific interest has been focused on this product group to improve its design for recycling (Dodbiba et al. 2008; Ardente et al. 2013; Peeters et al. 2014).

Based on the analysis of treatments of waste displays at the recycling plants, manual dismantling is currently the most common method of processing in the EU (Ardente and Mathieux 2014). According to Cyran et al., Europe has a lack of automated commercial-scale processes which can recycle electronic displays safely, economically, and at a high volume, as requested by European waste treatment standards (Cyran et al. 2010).

Some automated recycling technologies (based on the shredding in a controlled environment and mechanical sorting of recyclable fractions) are under development and being tested (McDonnell and Williams 2010; Stena metal group 2010). Recently, some companies claimed the installation of automated systems for LCD disassembly (Electrical Waste recycling group 2013; Automated LCD recycling 2014). However, quantitative disaggregated data on the quality and efficiency of these automated recycling systems have not been disclosed yet. Nevertheless, as highlighted by Ryan et al. and Elo and Sundin, automated systems for the pre-processing of displays have yet to cater to the treatment of different types of waste with very different characteristics (Ryan et al. 2011; Elo and Sundin 2014). This is largely limiting their effectiveness and development.

According to various authors, the most effective approach for disassembling/dismantling LCD systems would involve systems that combine both manual and automated processes (Shih et al. 2006; Ardente and Mathieux 2014; Elo and Sundin 2014).

6.5. Proposal of EU Ecolabel criteria based on other environmental schemes

The need for an easy and simple method to dismantle electronic displays and for the extraction of some key components has been highlighted in criteria for environmental labelling, as in the EU Ecolabel (European Commission 2009), Blue Angel (RAL GmbH 2012) and 'Nordic Ecolabelling' (Nordic ecolabelling 2013). A more specific and detailed criterion on design for the dismantling of electronic displays has been published by IEEE, although its application by manufacturers is only voluntary (Institute of Electrical and Electronics Engineers 2012). Table 8 shows the different existing environmental criteria for televisions.

Table 8. Environmental criteria for electronic displays (TVs and monitors).

Environmental label/scheme	Criteria
EU Ecolabel	The manufacturer shall demonstrate that the television can be easily dismantled by professionally trained recyclers using the tools usually available to them, for the purpose of: undertaking repairs and replacements of worn-out parts; upgrading older or obsolete parts, and separating parts and materials, ultimately for recycling.
Blue Angel (RAL-UZ-145)	The appliance shall be designed so as to allow for an easy and quick disassembly for the purpose of separating resource-containing components and materials.
Nordic Ecolabelling	The manufacturer shall demonstrate that the product can be easily dismantled […] for the purpose of separating parts and materials, ultimately for re-cycling. […] To facilitate the dismantling: fixtures within the products shall allow for this disassembly, e.g. screws, snap-fixes, especially of parts containing hazardous substances.
IEEE Std. 1680.3™ -2009	The time for dismantling the television for recycling shall be 'at most 10 minutes for products weighting less than 50 pounds (18.7 kg); and at most 10 min plus 1 min per each additional 5 pounds (1.87 kg) of total product weight, for products weighting 50 pounds or more'

6.5.1. *Design for dismantling of relevant parts*

According to the analysis of current EoL treatments at the European recyclers (Krukenberg 2010; Peeters et al. 2012; Peeters et al. 2013; Ardente and Mathieux 2014), the product's more relevant parts are:

- components containing mercury (backlighting lamps). The extraction of backlighting lamps is probably the most critical phase in the recycling of the displays, due to the risk of accidentally breaking the lamps and releasing mercury.
- printed circuit boards (PCBs) including capacitors. The extraction of PCBs are relevant because they can contain a number of hazardous substances, including arsenic, antimony, beryllium, brominated flame retardants, cadmium, and lead (EC, 2008), and also several precious and valuable metals (including gold, silver, and platinum group metals) (Chancerel et al. 2009).
- the liquid crystal display (LCD). The LCD contains the Thin-Film-Transistor (TFT) panel, which is relevant for its indium content (Chou et al. 2009). Indium in electronic displays is generally also used together with other substances such as arsenic, phosphorous, and tin. Indium arsenide (InAs) and indium phosphate (InP) semiconductors, and ITO are potentially hazardous and can cause lung disease and cancer (National Toxicology Program 2001; Chou et al. 2009; Lim and Schoenung 2010).
- the PMMA board. This is highly recyclable and valuable thanks to its high purity, relatively large mass (ranging from a few hundred grams in small displays to several kilogrammes in large displays), and high market price. The PMMA board is therefore stored separately and sold to plastics industries for monomer recycling (Kikuchi et al., 2014). In addition, other large plastic parts (e.g. support, frames) are economically and environmentally relevant for recycling (Ardente and Mathieux 2014; Peeters et al. 2014).

An analysis of studies in the literature on the dismantling of electronic displays is presented in Table 9. Unfortunately, these studies generally refer to the full disassembly of the displays (without any detail regarding the dismantling of the above mentioned key parts) and results are presented as aggregated average results over a large number of devices.

Table 9. Studies in the scientific literature on the disassembly of electronic displays.

*Data originally given in minutes. ** Data originally given in centimetres.

Year	Measure time for dismantling (seconds)	Size of display	Notes	Reference
2008	84*	not specified	Dismantling of the lamps	Kopacek B. ReLCD: Recycling and re-use of LCD panels. In: Proceedings of the 19th Waste Management Conference of IWMSA, 2008.
2009	216 to 522*	17"	No further details	Kim HJ, Kernbaum S, Seliger G. Emulation-based control of a disassembly system for LCD monitors. Int J Adv Manuf Technol 2009; 40:383–92. Kernbaum S, Franke C, Seliger G. Flat screen monitor disassembly and testing for remanufacturing. Int J Sus Manuf. 2009;1(3): 347 – 360
	372*		Estimation derived from data provided	
	60*		Average of 17 LCD TVs Destructive dismantling to extract PCB, lamps, LCD and optical plastics	
2010	540*	13" - 19" **	Average of 12 LCD monitors Dismantling at the component level (no further detail)	Cryan J, Freegard K, Morrish L, Myles N. Demonstration of Flat Panel Display recycling technologies. WRAP Project; 2010
	720*	20"- 40" **	Average of 11 LCD TVs Dismantling at the component level (no further detail)	
2011	600 to 2,100* (Av. 1,080)*	15" - 42" (Av. 17")	Average of 47 monitors Full dismantling No further details	Salhofer S, Spitzbart M, Maurer K. Recycling of LCD Screens in Europe - State of the Art and Challenges. In Glocalized Solutions for Sustainability in Manufacturing - Proceedings of the 18th CIRP International Conference on Life Cycle Engineering, Braunschweig, Germany, May 2- 4, 2011: 454-458
	840 to 2,400* (Av. 1,440)*	15" - 42" (Av. 32")	Average of 41 televisions Full dismantling No further details	
	386	15"	One LCD monitor (man.2001) Full dismantling in lab	Letcher B. Old and new LCD Monitor Assemblies - Disassembly differences. Report of the project 'Sustainable recycling of Flat Panel Displays - Project HÅPLA a Swedish initiative towards a comprehensive solution'. 2011a. Letcher B. Old and new LCD Television Assemblies - Disassembly differences. Report of the project 'Sustainable recycling of Flat Panel Displays - Project HÅPLA a Swedish initiative towards a comprehensive solution'. 2011b.
	502	17"	One LCD monitor (man.2003) Full dismantling in lab	
	402	19"	One LCD monitor (man.2007) Full dismantling in lab	
	1300	32"	One LCD TV (man.2007) Full dismantling in lab	
	625	40"	One LCD TV Full dismantling in lab	
	990	55"	One LCD TV (man.2010) Full dismantling in lab	
2014	157 to 1,779 (Av. 594)	19" - 50"	Average of 73 LCD TVs Full dismantling at recycling sites	Vanegas P., Peeters J. R., Dewulf, W., Cattrysse D., and J. R. Duflou, 'Disassembly targets for improving resource efficiency: analysis of environmental relevance for flat panel displays', in *Care Innovation conference*. Vienna, 2014.
	104 to 1,832 (Av. 667)	15"- 22"	Average of 27 LCD monitors. Full dismantling at recycling sites	

To cope with this data gap, a survey of recyclers in Europe has been performed and five facilities (one in Belgium, one in Spain, two in Italy, and one in the United Kingdom) have been visited. The time for dismantling key components has been recognised as a way to approach the 'design for dismantling' of the display. The time for dismantling is one of the most relevant parameters driving the treatments at the recycling facilities. As a matter of fact, recyclers tend to balance costs for disassembly (mainly labour costs) with potential revenues from a more accurate separation of components (Ardente et al. 2013).

A campaign to collect data about diverse treatments of waste displays was organised at a recycling site in Italy. As part of this campaign, the time to dismantle waste displays, and thus separate their components, was measured for 70 display units (Ardente et al. 2013). To make the resulting time for dismantling more robust, data obtained from this study was represented together with data provided by the other following studies (see Figure 8).

- In 2011, Letcher developed a project with the purpose of comparing general differences in the assemblies of old and new LCD monitors and televisions. For LCD monitors, a database of 41 monitors manufactured in 2003 and 70 monitors manufactured in 2007 was populated. This database contained information about the brand, module manufacturer, physical dimensions, weight, and certain components and features. In addition to this database, the time for dismantling two representative units was measured (Letcher 2011). The units measured were: a 17" LCD monitor manufactured by Dell in 2003, and a 17" LCD monitor manufactured by Samsung in 2007. A similar study was developed for LCD televisions. Information about 19 units manufactured in 2006 and seven units manufactured in 2010 was collected. Time to dismantle one representative unit out of each manufacturing year was measured (Letcher 2011). All the representative LCD monitors and televisions were fully dismantled by an experienced operator in a specialised workshop.
- Vanegas et al. developed a campaign, similar to the one developed by JRC-IES, to estimate the time to dismantle LCD monitors and televisions in a recycling site in Belgium (Vanegas et al. 2014). Dismantling times for the complete separation of all the parts contained in displays were measured for 27 monitors and 73 televisions.

Figure 13 shows data given by the Ardente et al. 2013 (JRC-IES) study, Letcher 2011, and Vanegas et al. 2014, which includes time for dismantling for a total of about 52 monitors and 115 televisions. The number of units when disaggregated per size are: 86 units of less than or equal to 25", 66 units bigger than 25" and smaller than 40", and 15 units equal or greater than 40" and smaller than 55". Representing all the data together increases the number of samples, and also helps obtain estimates more representative geographically. The data illustrated above helped develop Figure 14 which shows the percentage of displays of different sizes and their time for dismantling PCB (larger than 10 cm^2), PMMA, and TFT panels.

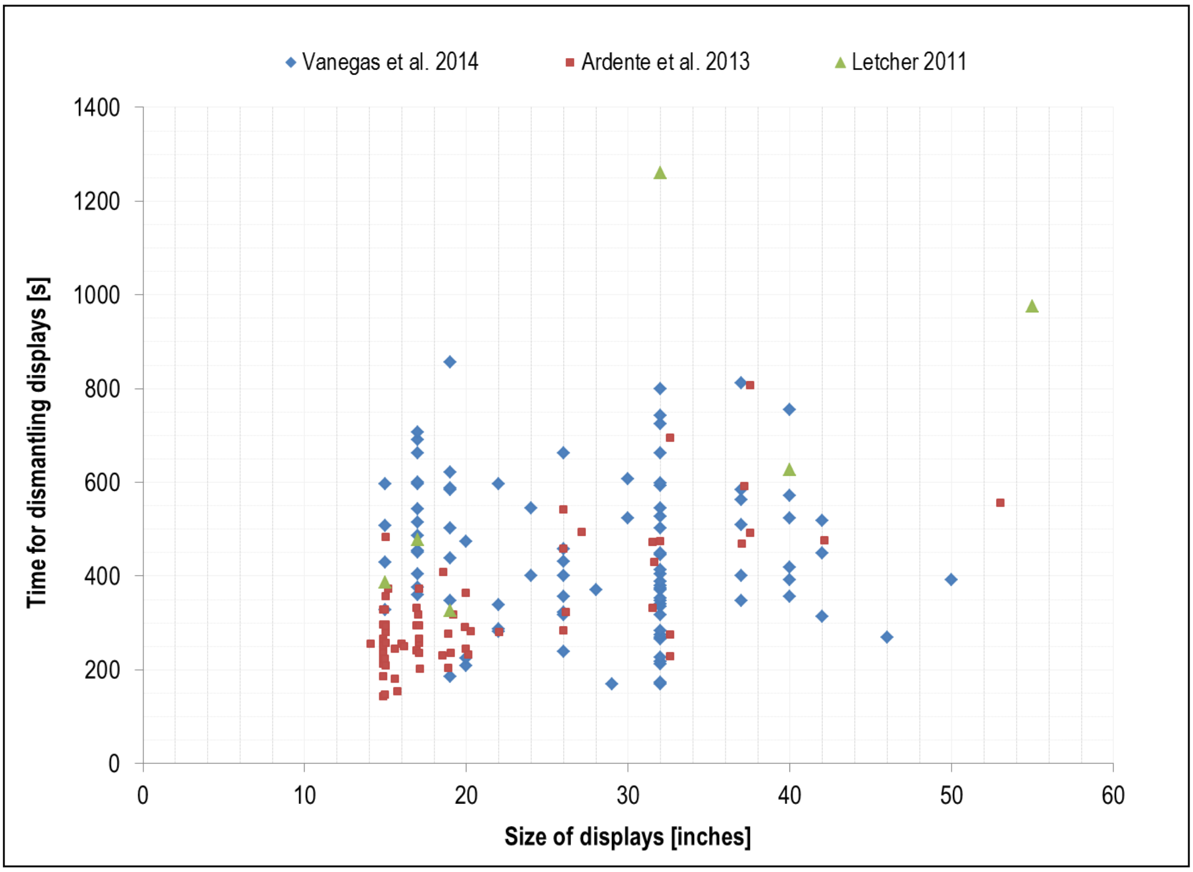

Figure 13. Time for dismantling PCBs, PMMA, and TFT panels in electronic displays with different sizes. Elaborated from (Letcher 2011; Ardente et al. 2013)[9].

Figure 14 assists in a more comprehensive understanding of the number of display already compliant on the market for certain time thresholds. The figure shows that the number of displays (vertical axis) have a time for dismantling of certain components below a certain threshold (horizontal axis). The results can be used to more precisely estimate possible thresholds on time for dismantling for defining mandatory and voluntary environmental policies for electronic displays.

Mandatory thresholds, aimed to avoid the worst environmental products on the market, can be defined based on 80 % compliance. For instance, the mandatory threshold for time for dismantling for EDs, as given in Figure 14, would be 490 seconds for sizes smaller than 25", 580 seconds for sizes between 25" and 40", and 620 seconds for EDs between 40" and 55".

On the contrary, the threshold for voluntary measures (such as the EU Ecolabel criteria) can be conceived to award products with the best environmental performance in the market. Thus, time thresholds for voluntary measures can be set as the time thresholds that are achieved by the best 30 % of the products. In this case, the time thresholds would be 260, 340, and 400

[9] Times for full dismantling given by Letcher 2011 and Vanegas et al. 2014 have been recalculated to include only the times for the extraction of PCBs, TFT, and PMMA, as measured by Ardente et al. 2013 (JRC-IES), and in order to harmonize the results.

seconds for EDs smaller than 25”, EDs between 25” and 40”, and EDs between 40” and 55”, respectively.

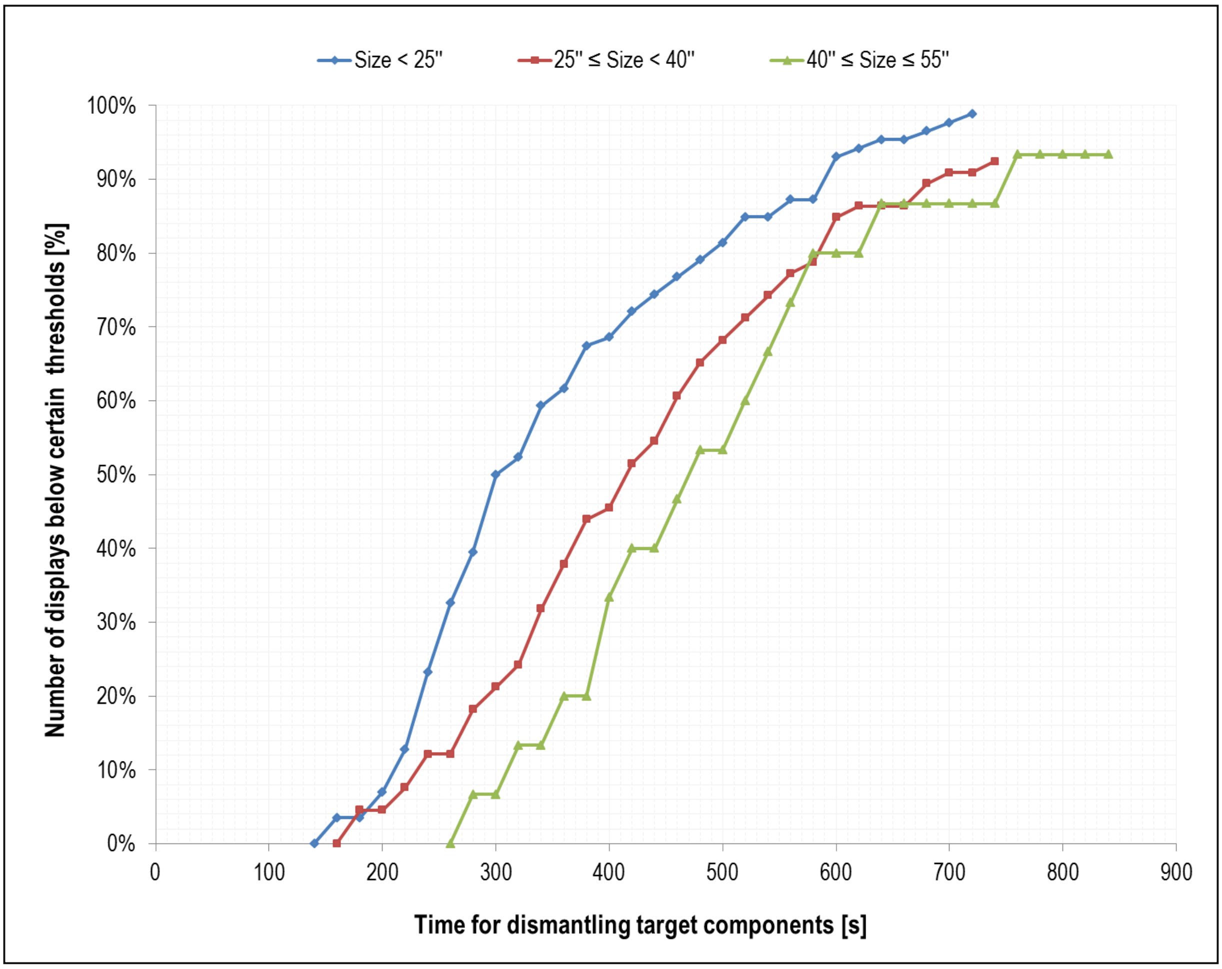

Figure 14. Percentage of displays with a time for dismantling PCBs (larger than 10 cm^2), PMMA, and TFT panels below certain thresholds.

Table 10 summarises the time threshold estimates to set mandatory and voluntary regulations for time for dismantling.

Table 10. Time for dismantling thresholds proposed for potential mandatory and voluntary regulation.

Size of display [inches]	< 25"	25"- 40"	≥ 40"- 55"
Times [seconds]	t_1	t_2	t_3
Mandatory (based on 80 % of displays compliant as in Figure 14)	490	580	620
Voluntary (based on 30 % of displays compliant as in Figure 14)	260	340	400

6.5.1.1. Draft criteria on design for dismantling

Based on these results, we suggest formulating an EU Ecolabel criterion about 'design for dismantling and recycling' as 'time for dismantling' of key components, in line with the requirement proposed for the Ecodesign for electronic displays.

For recycling purposes, electronic displays shall be designed so that:

(a) For the following components, manual disassembly by one person in a specialised company shall be possible to carry out using common commercially available tools (i.e. pliers, screw-drivers, cutters, and hammers as defined by ISO 5742, ISO 1174, ISO 15601):

(i) Printed Circuit Boards > 10 cm^2

(ii) Thin Film Transistor (TFT) unit > 100 cm^2 and film conductors

(iii) Polymethyl Methacrylate (PMMA) board light guide

These components should not be glued or welded to other parts.

(b) The time required to extract these components shall not exceed the following:

(i) 260 seconds (t1) for displays with a size smaller than 25 inches (diagonal screen size);

(ii) 340 seconds (t_2) for displays with a size greater than or equal to 25 inches and smaller than 40 inches (diagonal screen size);

(iii) 400 seconds (t_3) for displays with a size greater than or equal to 40 inches and smaller than 55 inches (diagonal screen size).

(c) At least one of the following optional components shall be possible to manually disassemble using common commercially available tools:

(i) LED backlight units

(ii) Speaker unit magnets (for display sizes greater than or equal to 25 inches)

(iii) HDD drive (if applicable in the case of smart devices)

This criterion is more detailed compared to the generic claim for the 'design for recycling' (as introduced in the 'Blue Angel' and 'Nordic' Swan labelling systems for televisions) and in line with the criteria set in the IEEE (2012) labelling. Furthermore, a criterion based on time thresholds leaves enough freedom to the manufacturers to decide the best design strategy to comply with.

The verification of this criterion should be based on the following procedure:

'Manufacturer shall provide a disassembly report (available online) indicating the location of the above mentioned target components, the fastening systems adopted and the disassembly sequence (steps, procedures and tools needed for the disassembly). Manufacturer shall also provide a video showing the extraction of the above mentioned target components, and the compliance to the time thresholds'.

6.5.2. *Recyclability of plastics parts*

The recyclability of plastic parts for electronic displays was analysed in more detail compared to the portable computers case study, as more information for this product group was available. In electronic displays, plastics represent about 40 % of the mass. The main types of plastics are polymethyl methacrylate (PMMA), and acrylic-styrene-acrylonitrile (ABS); however, there are still some unspecified plastic parts, as in the case of televisions (3 %).

One of the aspects analysed in further detail is the use of plastic parts containing flame retardants in electronic displays. The CENELEC EN 60065 regulation ‘Audio, video and similar electronic apparatus - Safety requirements’, approved in 2009, was later removed by the majority of delegates after further deliberations, as it remains unclear to which extent flame retardants, including brominated flame retardants, are truly necessary to safeguard certain electronic components and products, including televisions[10].

The use of certain brominated compounds is being regulated in diverse pieces of legislation. For instance, the directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic products (RoHS) says that member states shall ensure that new electrical and electronic equipment put on the market does not contain polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE) (European Parliament and of the Council 2003). According to scientific studies, these brominated flame retardant (BFR) substances have already been phased out (Peeters et al. 2014).

The directive 2012/19/EU on waste electrical and electronic equipment (WEEE) states in Annex VII that plastics containing brominated flame retardants have to be removed from any separately collected WEEE (European Commission 2012).

In 2014, Peeters et al. observed that the share of TVs at the recycling plant containing BFR in the housings is around 18 % (i.e. relevant but not dominant) (Peeters et al. 2014). In addition, a substantial share of the analysed TVs had a plastic marking not corresponding with the actual plastic composition. In that sense, setting up a criterion for marking brominated flame retardants would improve the reliability of marking allowing an effective separation, and later recycling, of plastics that do not containing brominated flame retardants. The presence of flame retardants can reduce the mechanical properties of the materials, requiring additional treatments and additives to compensate for the degradation of such properties, as well as reduce the value of the materials in the market, and consequently the economic feasibility of recycling (Dawson and Landry 2005).

[10] Flame retardant chemicals are added into plastics to avoid potential internally and externally initiated ignitions. However, the need to continue using such additives in televisions is doubtful being that internally-initiated fires have become more unlikely as result of the use of lower voltages (200 V) and power levels than older TVs using cathode ray tube technology (15 000 to 25 000 V); and improvements in lightness and thinness have influenced the positioning of TVs, which are usually hung on the wall now; thus, external ignition sources TVs are an unlikely source of ignition “Blum, A. (2014) "The case against candle resistant TVs." 1-19.”.

Based on such evidence, we propose to include a criterion for marking the presence of brominated flame retardants in plastic parts larger than 25 g, and the set of specific logos in the back cover of the display. The marking will improve the identification of BFR containing plastics recyclers and their effective separation, in line with WEEE Directive requirements. In this way, displays with BFR could be addressed to specific treatments so that the content of brominated flame retardants in other recyclable plastic fractions will be minimised, thus reducing the negative effect of impurities during plastic recycling processes.

The criterion for the EU Ecolabel for electronic displays is proposed to be refined accordingly, under the cluster 4 'End of Life management: design and material selection'.

6.5.2.1. Draft criteria for recyclability of plastic parts

Based on the findings described above, we propose to reformulate the criteria to be included in the EU Ecolabel for electronic displays as following:

Material selection and information to improve recyclability

(a) Recyclability of components
Assemblies made of materials mutually incompatible for recycling shall be separable
(b) Surface coating / metal inlays:

All plastic materials > 25 grams used for housings and enclosures shall have no surface coatings that are not reusable/or recyclable, or metal inlays.

(c) Material information to facilitate recycling:
Plastic parts with a mass greater than 25 grams shall be marked in accordance with ISO 11469 and ISO 1043, Sections 1-2. Plastic parts containing flame retardants shall be marked with the symbol >FR< Plastic markings may include additional information related to the content of the flame retardant (ISO 1043-4 code) and CAS number, and the marking of the plasticizers and fillers.

For plastic parts > 200 grams, the marking should be large enough and located in a visible position in order to be identified by workers of specialized recycling firms.

Exemptions are made in the following cases:

(i) where the marking would impact the performance or functionality of the plastic part, including optical plastics;

(ii) where parts cannot be marked because there is not enough available appropriate surface area for the marking to be of a legible size to be identified by a recycling operator;

(iii) where marking is technically not possible due to the moulding method; or

(iv) where the addition or location of marking causes unacceptable defect rates under quality inspection, leading to unnecessary wastage of materials.

7. Conclusion

Based on the technical analysis developed in this report and the discussions during the Ad-Hoc working group, criteria for the EU Ecolabel for televisions and computers were reshaped. The next sub-sections give the criteria included in the annex of the draft documents for the EU Ecolabel Act. Input from JRC IES has been used to draft the final version of criteria for both the product groups. These are represented by the paragraphs highlighted in bold and coloured in blue in the sections below.

Although the objective of this report was to propose material efficiency measures to be fed into the EU Ecolabel for both of the product groups analysed, the outcome of the study could also be used to further analyse the feasibility of turning those criteria into requirements to be implemented in Ecodesign regulations. To better understand such feasibility, both a more exhaustive study about their verification and an investigation on the potential benefits of reusing and recycling some key parts in both product groups would be desirable.

7.1. Personal and notebook computers

The tables below show the draft criteria for computers for clusters 3 and 4. Proposals from JRC-IES were taken on-board to formulate the criteria included in the annex of the draft documents for the EU Ecolabel Act (JRC-IPTS 2014).

Lifetime extension

Proposed revised criteria: 3(e) Upgradeability and Repairability
For the purpose of upgrading older components or undertaking repairs and replacements of worn out components or parts, the following criteria shall be fulfilled: **(a) Design for upgrades and repair: The following components of computers shall be easily accessible and exchangeable by the use of universal tools (i.e. widely used commercially available tools such as screwdrivers, spatulas, pliers, or tweezers):** **(i) HDD/SSD,** **(ii) Memory,** **(iii) Screen assembly and LCD backlight (where integrated),** **(iv) Keyboard and mouse pad (where used), and** **(v) Cooling fan.** **(b) Battery replacement: The battery shall be easy to extract by one person (either the user or repair service provider). The following specific requirements apply:** **(i) For all products, batteries shall not be glued or welded into a product;** **(ii) For notebooks and portable all-in-one computers it shall be possible for the user to extract the battery without tools;** **(iii) For sub-notebooks and ultrabooks, it shall be possible to extract the battery in a maximum of three steps using a screwdriver;**

(iv) **For tablets and two-in-one notebooks, it shall be possible to extract the battery in a maximum of four steps using a screwdriver and spudger;**

(v) **For sub-notebooks, ultrabooks, tablets, and two-in-one computers, simple instructions about how the battery packs are to be removed shall be marked on the base cover of the product.**

(c) **Repair manual: The applicant shall provide clear disassembly and repair instructions (e.g. hard or electronic copy, video) and make them publicly available, to enable a non-destructive disassembly of products for the purpose of replacing key components or parts for upgrades or repairs. Additionally, a diagram shall be provided on the inside of the casing of stationary computers showing the location of the components listed in (a) can be accessed and exchanged. For mobile computers a diagram showing that the location of the battery, data storage drives and memory shall be made available in pre-installed user instructions and via the manufacturers website.**

(d) Repair Service / Information: Information should be included in the user instructions or the manufacturer's website to let the user know where to go to obtain professional repairs and servicing of the computer, including contact details as appropriate. During the guarantee period referred to in (f) this may be limited to the applicant's Authorised Service Providers.

(e) Availability of spare parts: The applicant shall ensure that original or backward-compatible spare parts, including rechargeable batteries (if applicable), are publicly available for at least five years following the end of production for the model.

(f) Guarantee: The applicant shall provide, at no additional cost, a minimum of a three-year guarantee during which time they shall ensure the goods are in conformity with the contract of sale. This guarantee shall include a service agreement with pick-up and return.

Assessment and verification: The applicant shall declare the compliance of the product with these requirements to the competent body. Additionally, the applicant shall provide:

(i) A copy of the guarantee or service agreement

(ii) A copy of the repair manual and supporting diagrams

(iii) A copy of the user instructions

(iv) A description supported by photographs showing compliance for battery extraction

(v) A picture of the battery replacement instructions on the base of the product

Design, material selection, and end-of-life management

Proposed revised criteria: 4(a) Material selection and compatibility with recycling
a) Recyclability of plastics: (i) Parts with a weight greater than 25 grams shall consist of a single polymer or a polymer blend or alloy compatible with recycling; (ii) Parts with a weight greater than 25 grams shall not be painted or coated in such a form that it makes them incompatible with recycling; (iii) Casings, enclosures, and bezels shall not contain molded-in or glued on metal unless they are easy to remove with commonly available tools; (iv) Casings, enclosures, and bezels incorporating flame retardants shall be compatible with recycling. (v) Printed Wiring Boards greater than 10 cm^2 shall not contain aluminium-based flame retardants or additives. **b) Material information to facilitate recycling: Plastic parts with a mass greater than 25 grams shall be marked in accordance with ISO 11469 and ISO 1043, Sections 1-4. Plastic parts incorporating flame retardants may additionally be marked with the CAS number. For plastic parts greater than 100 grams, the markings should be large enough and located in a visible position in order to be easily identified.** Exemptions are made in the following cases: (i) Where the marking would impact the performance or functionality of the plastic part including optical plastics; (ii) Where parts cannot be marked because there is not enough available appropriate surface area for the marking to be of a legible size to be identified by a recycling operator; (iii)Where marking is technically not possible due to the moulding method; or (iv) Where the addition or location of marking causes unacceptable defect rates under quality inspection, leading to unnecessary wastage of materials. c) Recycled content: The product shall contain, on average, a minimum 10 % content postconsumer recycled plastic measured as a percentage of the total plastic (by weight) in the product excluding Printed Wiring Boards. Where the recycled content is greater than 25 %, a declaration may be made in the text box accompanying the Ecolabel (see Criterion 7(a)). Products with a metal casing are exempt from this sub-criterion. **Assessment and verification:** **The applicant shall provide the Competent Body with an exploded diagram of the computer in written or audiovisual format. This shall identify the plastic parts greater than 25 grams by their weight, their polymer composition, and their ISO 11469 and 1043 markings. The dimensions and positions of the marking(s) shall be illustrated and, where exemptions apply, technical justifications provided.** The applicant shall verify compatibility with recycling by providing evidence that the plastics, either individually or combined, do not impact the technical properties of the resulting recycled plastics in such a way that they cannot be used again in electronic products. This could include: - A declaration from an experienced plastics recycler or permitted treatment operation in accordance with Article 23 of Directive 2008/98/EC ('the Waste Framework Directive'); **- Test results from an independent laboratory or an experienced plastics recycler;** **- Peer and industry reviewed technical literature applicable to Europe.** The applicant shall provide third party verification and traceability for post-consumer recycled content.

Proposed revised criteria: 4(b) Design for dismantling and recycling

For recycling purposes, computers shall be designed so that target components and parts can be easily extracted from the product. A disassembly test shall be carried out according to the test procedure in Appendix 3. The test shall record the number of steps required and the associated tools and actions required to extract the target components and parts identified in (a) and (b).

(a) The following target components and parts, selected as relevant to the product, shall be extracted during the disassembly test:

All products

(i) Printed Wiring Boards relating to computing functions >10 cm²

Stationary computer products

(i) Internal Power Supply Unit

(ii) HDD drives

Portable computer products

(i) Rechargeable battery

Displays (where integrated into the product enclosure)

(i) Printed Circuit Boards >10 cm2

(ii) Thin Film Transistor unit and film conductors in display units >100 cm2

(iii) LED backlight units

(b) At least *two* of the following target components and parts, selected as relevant to the product, shall also be extracted during the test, following-on the test from those in (a):

(i) HDD drive (portable products)

(ii) Optical drives (where included)

(iii) Printed circuit boards ≤ 10 cm² and > 5 cm²

(iv) Speaker units (notebooks, integrated desktops and portable all-in-one computers)

(v) Polymethyl Methacrylate (PMMA) film light guide (where the screen size is >100 cm²)

Assessment and verification:

The applicant shall provide a 'disassembly test report' to the competent body detailing the adopted disassembly sequence, including a detailed description of the specific steps and procedures, for the target parts and components listed in (a) and (b), The disassembly test may be carried out by:

(i) The applicant, or a nominated supplier, in their own laboratory, or;

(ii) An independent third party testing body, or;

(iii) A specialised recycling firm that is a permitted treatment operation in accordance with Article 23 of the Waste Framework Directive.

7.2. Electronic displays

Material efficiency criteria based on the technical analysis of this report to award the EU Ecolabel to electronic displays are included under two main aspects: 'Lifecycle extension' and 'Design, material selection and end-of-life management'(JRC-IPTS 2014).

Lifetime extension

Proposed revised criteria: (a) Repairability
For the purpose of undertaking repairs and replacements of worn out components or parts, the following criteria shall be fulfilled: **(a) Design for repair: The following components of electronic displays shall be easily accessible and exchangeable by the use of universal tools (i.e. widely used commercially available tools such as screwdrivers, spatulas, pliers, or tweezers):** **(i) Screen assembly and LCD backlight,** **(ii) stands, and** **(iii) power and control circuit boards.** **(b) Repair manual: The applicant shall provide clear disassembly and repair instructions (e.g. hard or soft copy, video) and make them publicly available, to enable a non-destructive disassembly of products for the purpose of replacing key components or parts for upgrades or repairs.** (c) Repair Service / Information: Information should be included in the user instructions or the manufacturer's website to let the user know where to go to obtain professional repairs and servicing of the electronic display, including contact details as appropriate. During the guarantee period referred to in (e) this may be limited to the applicant's Authorized Service Providers. (d) Availability of spare parts: The applicant shall ensure that original or backward-compatible spare parts are publicly available for a certain time following the end of the model production: (i) Televisions: at least seven years (ii) Computer monitors: at least five years. (e) Guarantee: The applicant shall provide, at no additional cost, a minimum of a three-year guarantee during which time they shall ensure the goods are in conformity with the contract of sale. This guarantee shall include a service agreement with pick-up and return. ***Assessment and verification***: The applicant shall declare the compliance of the product with these requirements to the competent body. Additionally, the applicant shall provide: (i) A copy of the guarantee or service agreement. (ii) A copy of the repair manual (iii)A copy of the user instructions

Design, material selection and end-of-life management

Proposed revised criteria: (a) Material selection and information to improve recyclability
a) Recyclability of plastics: (i) Parts with a weight greater than 25 grams shall consist of a single polymer or a polymer blend or alloy compatible with recycling; (ii) Casings, enclosures, and bezels incorporating flame retardants shall be compatible with recycling. (iii) Parts with a weight greater than 25 grams shall not be painted or coated in a form that makes them incompatible with recycling; (iv) Casings, enclosures, and bezels shall not contain molded-in or glued on metal unless they are easy to remove with commonly available tools; (v) Casings, enclosures and bezels incorporating flame retardants shall be compatible with recycling. (vi) Printed Wiring Boards greater than 10 cm^2 shall not contain aluminium based flame retardants or additives. **b) Material information to facilitate recycling: Plastic parts with a mass greater than 25 grams shall be marked in accordance with ISO 11469 and ISO 1043, Sections 1-4. Plastic parts incorporating flame retardants may additionally be marked with the CAS number. For plastic parts greater than 100 grams, the markings should be large enough and located in a visible position in order to be easily identified.** Exemptions are made in the following cases: (i) Where the marking would impact the performance or functionality of the plastic part including optical plastics; (ii) Where parts cannot be marked because there is not enough available appropriate surface area for the marking to be of a legible size to be identified by a recycling operator; (iii)Where marking is technically not possible due to the moulding method; or (iv) Where the addition or location of marking(s) causes unacceptable defect rates under quality inspection, leading to unnecessary wastage of materials c) Recycled content: The product shall contain, on average, a minimum of 10 % post-consumer recycled plastic, measured as a percentage of total plastic (by weight) in the product excluding Printed Wiring Boards. Where the recycled content is greater than 25 %, a declaration may be made in the text box accompanying the Ecolabel (see Criterion 7(a)). Products with a metal casing are exempt from this sub-criterion. **Assessment and verification:** **The applicant shall provide the Competent Body with an exploded diagram of the electronic display in written or audiovisual format. This shall identify the plastic parts greater than 25 grams by their weight, their polymer composition, and their ISO 11469 and 1043 markings. The dimensions and positions of the marking shall be illustrated and, where exemptions apply, technical justifications provided.** The applicant shall verify compatibility with recycling by providing evidence in regard to the plastics. This section briefly revises the material efficiency criteria of two of the most renowned environmental labelling standards: Blue Angel and Nordic Swan. These labels are the oldest environmental labelling schemes in Europe, and also one of the most frequently used in Europe. As part of the revision, we decided to include the recently developed IEEE 1680 family of environmental standards, as they also propose novel environmental criteria for material efficiency which are potentially relevant and applicable to the case studies developed later on in this report.

Proposed revised criteria (b) Design for dismantling and recycling
For recycling purposes, electronic displays shall be designed so that the identified sub-assemblies and components are easily extracted from the product. A disassembly test shall be carried out according to the test procedure Appendix 2. The test shall record the time required to extract those components identified from sub-criterion (a), the number of steps required and the associated tools and actions required to extract those components identified from sub-criterion (a) and (c). (a) For the following components, as relevant to the product, a manual disassembly shall be carried out by one person using widely used commercially available tools (i.e. pliers, screw-drivers, cutters, and hammers as defined by ISO 5742, ISO 1174, ISO 15601): (i) Printed Wiring Boards >10 cm^2 (ii) Thin Film Transistor (TFT) unit >100 cm^2 and film conductors (iii) Polymethyl Methacrylate (PMMA) board light guide (b) The time required to extract these components shall not exceed the following: (i) 260 seconds for displays with a size smaller than 25 inches (diagonal screen size); (ii) 340 seconds for displays with a size greater than or equal to 25 inches and smaller than 40 inches (diagonal screen size); (iii) 480 seconds for displays with a size greater than or equal to 40 inches and smaller than 55 inches (diagonal screen size). (c) At least one of the following optional components shall also be possible to manually disassemble using common commercially available tools: (i) LED backlight units (ii) Speaker unit magnets (for display sizes greater than or equal to 25 inches) (iii) HDD drive (if applicable in the case of smart devices) **Assessment and verification:** The applicant shall provide a 'test disassembly report' to the competent body detailing the adopted disassembly sequence, including a detailed description of the specific steps and procedures, for the components listed in (a) and the optional components selected from (c), The tools used for the disassembly of each component shall additionally be specified The disassembly shall be carried out by: (i) The applicant, or a nominated supplier, in their own laboratory, or; (ii) An independent third party testing body, or; (iii) A specialised recycling firm that is a permitted treatment operation in accordance with Article 23 of the Waste Framework Directive.

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10. Annex

Table A1. List of product groups and work timeline for EU Ecolabel (European Commission 2014).

Product group	Current criteria adoption	Expiry date	Prolongation	Revision start date	Reg Com vote	Work timeline 2014	2015	2016	EC staff	Comments
Soaps, shampoos and hair conditioners	Jun 2007	Dec 2014	tbd	Jul 2011	July 2014 (Written vote)				SF	Name will be changed to "Rinse-off cosmetic products"
All-purpose cleaners and sanitary cleaners	Jun 2011	Jun 2015	Planned to Dec 2016	Jan 2014	Mar 2016				SF	All detergent product groups, the DID list and the laundry detergents protocol will be revised as a package. The validity of existing product groups (with the exception of "I&I laundry detergents" and "I&I automatic dishwasher detergents") will be prolonged until Dec 2016
Detergents for dishwashers	Apr 2011	Apr 2015	Planned to Dec 2016	Jan 2014	Mar 2016				SF	
Hand dishwashing detergents	Jun 2011	Jun 2015	Planned to Dec 2016	Jan 2014	Mar 2016				SF	
Laundry detergents	Apr 2011	Apr 2015	Planned to Dec 2016	Jan 2014	Mar 2016				SF	
I&I laundry detergents	Nov 2012	Nov 2016	Not foreseen	Jan 2014	Mar 2016				SF	
I&I automatic dishwasher detergents	Nov 2012	Nov 2016	Not foreseen	Jan 2014	Mar 2016				SF	
Textile products	Jun 2014	Jun 2018							JK	
Footwear	Jul 2009	Jun 2015	Planned to Dec 2015	Jul 2012	Apr 2015				JK	An extension of the scope to "leather products" is currently being assessed
Indoor paints and outdoor paints and varnishes	May 2014	May 2018								Criteria for indoor and outdoor paints and varnishes merged.
Imaging equipment	Dec 2013	Dec 2017	Not foreseen						JK	
Personal computers	Jun 2011	Dec 2015	Not foreseen	Dec 2012	Apr 2015				JK	These PGs are revised at the same time. Laptops are merged with PCs. TVs: transitional period for revised criteria should be shorter than 12 months.
Notebook computers	Jun 2011	Dec 2015	Not foreseen	Dec 2012	Apr 2015				JK	
Televisions	Mar 2009	Dec 2015	Not foreseen	Dec 2012	Apr 2015				JK	
Wooden floor coverings	Nov 2009	Dec 2015	Planned to Dec 2016	Dec 2013	Mar 2016				CP	

Product group	Current criteria adoption	Expiry date	Prolongation	Revision start date	Reg Com vote	Work timeline 2014	2015	2016	EC staff	Comments
Textile floor coverings	Nov 2009	Dec 2015	Planned to Dec 2017	tbd					JK	
Hard coverings	Jul 2009	Nov 2017	Not foreseen	tbd					CP	
Wooden furniture	Nov 2009	Dec 2015	Not foreseen	Dec 2012	Apr 2015				CP	The scope will be enlargedto Furniture. Transition period to be longer than 12 months (due to corrigendum).
Soil improvers	Nov 2006	Dec 2015	Not foreseen	Dec 2012	Apr 2015				CP	The two PGs will be merged and the scope broadened to Mulch.
Growing media	Nov 2006	Dec 2015	Not foreseen	Dec 2012	Apr 2015				CP	
Light sources	Jun 2011	Dec 2015	tbd	Jan 2012	Apr 2015				CP	Revision led by industry (Eco-Lighting Consortium).
Sanitary tapware	May 2013	May 2017	Not foreseen						CP	
Flushing toilets and urinals	Nov 2013	Nov 2017	Not foreseen						CP	
Heat pumps	Nov 2007	Dec 2016	Planned to Dec 2017	tbd					SF	Water-based heaters was removed from the scope, as those productsare now covered by the water-based heaters product group.
Water-based heaters	Jun 2014	Jun 2018	Not foreseen						SF	
Lubricants	Jun 2011	Jun 2015	Planned to Dec 2017	tbd					JK	
Bed mattresses	Jun 2014	Jun 2018							CP	
Copying and graphic paper	Jun 2011	Jun 2015	Planned to Dec 2017	tbd					MG	Criteria for copying and graphic paper and newsprint will be merged
Newsprint	Mar 2012	Jun 2015	Planned to Dec 2017	tbd					MG	
Printed paper	Mar 2012	Aug 2015	Planned to Dec 2017	tbd					MG	Amendment removing stationery paper products from the scope was adopted in June 2014
Tissue paper	Jul 2009	June 2015	Planned to Dec 2017	tbd					MG	
Converted paper	May 2014	May 2017	Not foreseen						MG	
Campsite services	Jul 2009	Nov 2015	Planned to Dec 2016	2013	Mar 2016				SF	Criteria for CS and TAS

Table A2. Additional audiovisual information of the dismantling of laptop computers.

Brand	Model	Link to audiovisual information
Acer	Aspire S3 and S5	http://www.youtube.com/watch?v=o53WxaR_BxA
	Aspire S7	http://www.thessdreview.com/hardware/notebooks/acer-aspire-s7-touch-screen-ultrabook-review-worlds-fastest-ultrabook-intros-new-ssd-form-factor/2/
	Aspire Ultra M5	http://www.youtube.com/watch?v=xdrUEGEV-os
Apple	MacBook Pro 13 core i7	http://www.youtube.com/watch?v=ds6lvrTE0yI
	MacBook Air	http://www.youtube.com/watch?v=Z7vWsMzMZKE
	MacBook Pro 15 retina	http://www.youtube.com/watch?v=pLhHSIej9fs
Asus	Zenbook UX31 and UX21	http://www.youtube.com/watch?v=nYL9PCGWT3g
Dell	XPS 13	http://www.youtube.com/watch?v=V9m8i4z7jqA
	XPS 15z	http://www.youtube.com/watch?v=R9xHa4UYlAQ
	Inspiron 14 z	http://www.youtube.com/watch?v=V3BoPid82a0
HP	EliteBook Folio 9470m	http://www.youtube.com/watch?v=mQdb5qGJtTE
	Envy 4	http://www.youtube.com/watch?v=vEesYDN_T8g
	Envy Pro	http://www.youtube.com/watch?v=AmyLGTbKk28
	Envy 6	http://www.youtube.com/watch?v=_4n78ipOeLs
	XPS14z	http://www.youtube.com/watch?v=-PoZipSbwTk
	Folio 13	http://www.youtube.com/watch?v=ks6aIzPIp2I
Lenovo	thinkPad yoga	http://www.youtube.com/watch?v=nj7azo6syQQ
	thinkPad yoga 2	http://www.youtube.com/watch?v=JqxPdv21_Mk
	IdeaPad u410	http://www.youtube.com/watch?v=1sGwQBiGw-Y
	IdeaPad u310	http://www.youtube.com/watch?v=UP057Eu56co
Samsung	Series 9	http://www.youtube.com/watch?v=C8qZhzo-iN8
	Series 5	http://www.youtube.com/watch?v=k7QncSWHpMs
Sony	Sony vaio t13	http://www.youtube.com/watch?v=mbqYdwuC7Dc
Vizio	Portege z830	http://www.youtube.com/watch?v=9GaC9NGpVtc
	Portege z831	http://www.youtube.com/watch?v=TSmEhiK3Njs

Table A3. Additional audiovisual information of the dismantling PC-tablets.

Brand	Model	Link to audiovisual information
Acer	Iconia Tab A500	http://www.youtube.com/watch?v=zFrXbrblcVU
	Iconia W700	http://www.youtube.com/watch?v=2WkDrJq5cc8
Asus	google nexus 7	http://www.youtube.com/watch?v=dDHLHn9fctU
	Memo ME301T	http://www.youtube.com/watch?v=zAjl09noang
	Transformer TF300	http://www.youtube.com/watch?v=KJihe-hpA4M
Huawei	media pad7	http://www.youtube.com/watch?v=U_NIAH6s5Pc
Kindle	Fire Hd	http://www.youtube.com/watch?v=iHT10MhpbpQ
Samsung	galaxy note 10.1	http://www.youtube.com/watch?v=I0HqtOBhzwU
	galaxy tab 2	http://www.youtube.com/watch?v=Ow5T93uqz9I
Sony	Xperia tablet S series	http://www.youtube.com/watch?v=zFrXbrblcVU
Toshiba	AT100 tablet	http://www.youtube.com/watch?v=UPw0EkzxvlY

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