Ecodesign preparatory study for product specific measures on scarce, environmentally relevant and critical raw materials and on recycled content

Study Report

Phase 2: Preparatory study

Personal Computers

Draft 14 April 2025

Prepared by Viegand Maagøe, Van Holsteijn en Kemna, Fraunhofer ISI and VITO

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Project:
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Contract Manager:
Jan Viegand, Viegand Maagøe

Authors:
Michael Scholand and Felice Alfieri, Viegand Maagøe

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DRAFT REPORT FOR PUBLIC COMMENT

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Acronyms

A	Allocation factor in the CFF
ABS	Acrylonitrile butadiene styrene
AEC	Annual Electricity Consumption
Ag	Silver
Au	Gold
BoM	Bill of Materials
CFF	Circular Footprint Formula
CR	Commission Regulation
CRM	Critical Raw Material
CRMA	Critical Raw Materials Act
Cu	Copper
EC	European Commission
EEE	Electric and Electronic Equipment
EEI	Energy Efficiency Index
EIA	Ecodesign Impact Accounting
EFSA	European Food Safety Authority
EoL	End-of-Life
EPR	Extended Producer Responsibility
EPREL	European Product Registry for Energy Labelling
Erec	Environmental impact of recycled raw material
ERT	EcoReportTool
ESPR	Ecodesign for Sustainable Products Regulation
Ev	Environmental impact of virgin raw material
FCA	Food Contact Article
FCM	Food Contact Material
GMP	Good Manufacturing Practice
GPPS	General Purpose PolyStyrene
GWP	Global Warming Potential
HIPS	High-Impact PolyStyrene
HIPS ESCR	high impact polystyrene with enhanced environmental stress cracking resistance
IA	Impact Assessment
MDI	Methylene diphenyl diisocyanate (used for PUR foam)
NIAS	Non-intentionally added substances
ODP	Ozone depletion
PCB	Printed Circuit Board
PCR	Post-consumer recycled
Pd	Palladium
PET	PolyEthylene Terephthalate
PP	PolyPropylene
PPWR	Packaging and Packaging Waste Regulation
Pt	Platinum
PU(R)	PolyUrethane (Rigid)
R1	Recycled content in the CFF (section 5.2)
R2	Recycling output rate in the CFF (section 5.2)
RC	Recycled Content
R&M	Repair and Maintenance
r-HIPS	Recycled HIPS
SAN	Styrene acrylonitrile resin
WEEE	Waste Electric and Electronic Equipment

1. MEErP Task 1, Scope

1.1. Scope

The product scope for this study is aligned with the scope proposed in the draft Impact Assessment of Personal Computers that is on-going at this time. The following products, powered both directly from the mains alternating current (AC) including via an external or internal power supply or by batteries (i.e. both desktops and mobiles):

- Desktop computers;
- Integrated desktop computers;
- Notebook computers (including tablet computers);
- Workstations;
- Thin clients;
- Small-scale servers.

1.2. Definitions of Personal Computers (EU No 617/2013)

Products and components that are within the scope of the existing ecodesign Regulation (617/2013) on computers and computer servers are defined as:

Computers: Computer means a device, which performs logical operations and processes data, is capable of using input devices and outputting information to a display, and normally includes a central processing unit (CPU) to perform operations. If no CPU is present, then the device must function as a client gateway to a computer server, which acts as a computational processing unit.

Computer servers: Computer server means a computing product that provides services and manages networked resources for client devices, such as desktop computers, notebook computers, desktop thin clients, internet protocol (IP) telephones, or other computer servers. A computer server is typically placed on the market for use in data centres and office/corporate environments. A computer server is primarily accessed via network connections, and not through direct user input devices, such as a keyboard or a mouse. A computer server has the following characteristics:

(a) is designed to support computer server operating systems (OS) and/or hypervisors, and targeted to run user-installed enterprise applications;

(b) supports error-correcting code (ECC) and/or buffered memory (including both buffered dual in-line memory modules (DIMMs) and buffered on board (BOB) configurations);

(c) is placed on the market with one or more AC-DC power supply(ies);

(d) all processors have access to shared system memory and are independently visible to a single OS or hypervisor.

Desktop computers: Desktop computer means a computer where the main unit is intended to be located in a permanent location and is not designed for portability and which is designed for use with an external display and external peripherals such as a keyboard and mouse.

Integrated desktop computers: Integrated desktop computer means a computer in which the computer and the display function as a single unit, which receives its AC power through a single cable. Integrated desktop computers come in one of two possible forms:

(1) a product where the display and the computer are physically combined into a single unit; or

(2) a product where the display is separated from the computer, but it is connected to the main chassis by a direct current (DC) power cord. An integrated desktop computer is intended to be located in a permanent location and is not designed for portability. Integrated desktop computers are not primarily designed for the display and reception of audio-visual signals.

Notebook computers (including tablet computers, slate computers and mobile thin clients):

- **Notebook computer** means a computer 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. Notebook computers utilise an integrated display, with a viewable diagonal screen size of at least 22.86 cm (9 inches) and are capable of operation on an integrated battery or other portable power source.
- **Tablet computer** means a product, which is a type of notebook computer that includes both an attached touch-sensitive display and an attached physical keyboard.
- **Slate computer** means a type of notebook computer that includes an integrated touch-sensitive display but does not have a permanently attached physical keyboard;
- **Mobile thin client** means a type of notebook computer that relies on a connection to remote computing resources (e.g. computer server, remote workstation) to obtain primary functionality and has no rotational storage media integral to the product. Products that would otherwise meet the definition of notebook computer but have idle state power demand of less than 6 W are not considered to be notebook computers for the purposes of this Regulation.

Desktop thin clients: Desktop thin client means a computer that relies on a connection to remote computing resources (e.g. computer server, remote workstation) to obtain primary functionality and has no rotational storage media integral to the product. The main unit of a desktop thin client must be intended for use in a permanent location (e.g. on a desk) and not for portability. Desktop thin clients can output information to either an external or, where included with the product, an internal display.

Workstations: Workstation means a high-performance, single-user computer primarily used for graphics, Computer Aided Design, software development, financial and scientific applications among other computer intensive tasks, and which has the following characteristics:

(a) has a mean time between failures (MTBF) of at least 15,000 hours;

(b) has error-correcting code (ECC) and/or buffered memory;

(c) meets three of the following five characteristics:

(1) has supplemental power support for high-end graphics (i.e. peripheral component interconnect (PCI)-E 6-pin 12 V supplemental power feed);

(2) its system is wired for greater than x4 PCI-E on the motherboard in addition to the graphics slot(s) and/or PCI-X support;

(3) does not support uniform memory access (UMA) graphics;

(4) includes five or more PCI, PCI-E or PCI-X slots;

(5) is capable of multi-processor support for two or more CPU (must support physically separate CPU packages/sockets, i.e. not met with support for a single multi core CPU).

Mobile workstation: Mobile workstation means a high-performance, single- user computer primarily used for graphics, Computer Aided Design, software development, financial and scientific applications among other compute intensive tasks, excluding game play, and which is 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. Mobile workstations utilise an integrated display and are capable of operation on an integrated battery or other portable power source. Most mobile workstations use an external power supply and most have an integrated keyboard and pointing device. A mobile workstation has the following characteristics:

(a) has a mean time between failures (MTBF) of at least 13,000 hours;

(b) has at least one discrete graphics card (dGfx) meeting the G3 (with FB Data Width > 128-bit), G4, G5, G6 or G7 classification;

(c) supports the inclusion of three or more internal storage devices;

(d) supports at least 32 GB of system memory.

Small-scale servers: Small-scale server means a type of computer that typically uses desktop computer components in a desktop form factor but is designed primarily to be a storage host for other computers and to perform functions such as providing network infrastructure services and hosting data/ media, and which has the following characteristics:

(a) is designed in a pedestal, tower, or other form factor similar to those of desktop computers such that all data processing, storage, and network interfacing is contained within one box;

(b) is designed to be operational 24 hours per day and 7 days per week;

(c) is primarily designed to operate in a simultaneous multi-user environment serving several users through networked client units;

(d) where placed on the market with an operating system, the operating system is designed for home server or low-end server applications;

(e) is not placed on the market with a discrete graphics card (dGfx) meeting any classification other than G1.

External power supply means a device, which has the following characteristics:

(a) is designed to convert alternating current (AC) power input from the mains power source input into lower voltage direct current (DC) or AC output;

(b) is able to convert to only one DC or AC output voltage at a time;

(c) is intended to be used with a separate device that constitutes the primary load;

(d) is contained in a physical enclosure separate from the device that constitutes the primary load;

(e) is connected to the device that constitutes the primary load via a removable or hard-wired male/female electrical connection, cable, cord or other wiring; and

(f) has nameplate output power not exceeding 250 Watts.

Internal power supply means a component designed to convert AC voltage from the mains to DC voltage(s) for the purpose of powering the computer or computer server and has the following characteristics:

(a) is contained within the computer or computer server casing but is separate from the main computer or computer server board;

(b) the power supply connects to the mains through a single cable with no intermediate circuitry between the power supply and the mains power; and

(c) all power connections from the power supply to the computer or computer server components, with the exception of a DC connection to a display in an integrated desktop computer, are internal to the computer casing.

Internal DC-to-DC converters used to convert a single DC voltage from an external power supply into multiple voltages for use by a computer or computer server are not considered internal power supplies.

Discrete Graphics Card (dGfx) means a discrete internal component containing one or more graphics processing units (GPUs) with a local memory controller interface and local graphics-specific memory and falling into one of the following categories:

(a) G1 (FB_BW ≤ 16);

(b) G2 (16 < FB_BW ≤ 32);

(c) G3 (32 <FB_BW ≤ 64);

(d) G4 (64 <FB_BW ≤ 96);

(e) G5 (96 <FB_BW ≤ 128);

(f) G6 (FB_BW > 128 (with FB Data Width < 192-bit));

(g) G7 (FB_BW > 128 (with FB Data Width ≥ 192-bit)).

Frame buffer bandwidth (FB _BW) means the amount of data that is processed per second by all GPUs on a dGfx, which is calculated using the following formula:

Frame buffer bandwidth = (Data Rate × Data Width)/(8 × 1 000)

Where:

(a) frame buffer bandwidth is expressed in GigaBytes/ second (GB/s);

(b) data rate is the effective memory data frequency in MHz;

(c) data width is the memory frame buffer (FB) data width, expressed in bits (b);

(d) ‘8’ converts the calculation into Bytes;

(e) dividing by 1 000 converts Megabytes into Gigabytes.

Internal storage means a component internal to the computer, which provides non-volatile storage of data.

Product type means desktop computer, integrated desktop computer, notebook computer, desktop thin client, workstation, mobile workstation, small-scale server, computer server, blade system and components, multi-node server, server appliance, game console, docking station, internal power supply or external power supply.

Relevant products that are defined in the Regulation, but not within scope include:

- **Game console** means a mains-powered standalone device, which is designed to provide video game playing as its primary function. A game console is typically designed to provide output to an external display as the main game-play display. Game consoles typically include a CPU, system memory and a graphics processing unit(s) (GPU), and may contain hard drives or other internal storage options, and optical drives. Game consoles typically utilise handheld controllers or other interactive controllers as their primary input device rather than an external keyboard or mouse. Game consoles do not typically include conventional personal computing operating systems but instead utilise console-specific operating systems. Handheld gaming devices, with an integrated display as the primary game-play display, and which primarily operate on an integrated battery or other portable power source rather than via a direct connection to an AC power source, are considered to be a type of game console.
- **Docking station** means a discrete product designed to be connected to a computer in order to perform functions such as expanding connectivity or consolidating connections to peripheral devices. Docking stations may also facilitate charging of internal batteries in the connected computer.

1.3. Definitions of Circularity Concepts

The list below provides the relevant terms and definitions from that a JRC report that looked at imaging equipment. (JRC, 2024) These definitions are universal, and would also apply to personal computers.

Durability - Ability to function as required, under defined conditions of use, maintenance and repair, until a limiting state is reached (EN45552:2020)

Reliability - Probability that a product functions as required under given conditions, including maintenance, for a given duration without limiting event (EN45552:2020)

Repair - Process of returning a faulty product to a condition where it can fulfil its intended use (EN45552:2020)

Upgrade - Process of enhancing the functionality, performance, capacity, or aesthetics (EN45552:2020)

Reuse - Process by which a product or its parts, having reached the end of their first use, are used for the same purpose for which they were conceived (EN45552:2020)

Remanufacturing and refurbishing - Industrial process which produces a product from used products or used parts where at least one change is made which influences the safety, original performance, purpose or type of the product. (EN45553:2020)

Note 1 to entry: The product created by the remanufacturing process may be considered a new product when placing on the market. Refer to the EU Blue Guide [1] for additional information.

Note 2 to entry: Refurbishing is a similar concept to remanufacturing except that it does not involve substantial modifications influencing safety, original performance, purpose or type of the product. It is not covered by this standard.

Recycling - Recovery operation of any kind, by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes excluding energy recovery (EN45555:2019)

Critical Raw Materials - Critical raw material CRM materials which, according to a defined classification methodology, are economically important, and have a high-risk associated with their supply (EN45558:2019)

Post-consumer recycled content - the amount of post-consumer recycled material that goes into the manufacturing of a new product (EN45557:2020)

Among the definitions listed above, it is important to highlight how product modification by refurbishing and remanufacturing processes can influence the consideration of products as legally as “new products” or as “second hand products”. This distinction has an effect on the applicability of ecodesign and energy labelling requirements, which are only applicable at the moment of placing products on the market.

1.4. Standards

The following is a sample of standards included in the JRC 2024 imaging equipment preparatory study and these are applicable to the personal computers being evaluated in this study.

IEC 60068-2-31:2008. Environmental testing - Part 2-31: Tests: Rough handling shocks, primarily for equipment-type specimens.

This standard establishes a test procedure for simulating the effects of rough handling shocks, primarily in equipment-type specimens, the effects of knocks, jolts and falls which may be received during repair work or rough handling in operational use. This procedure does not simulate the effects of impacts received during transportation as loosely constrained cargo and does not simulate the effects of shock applied to installed equipment.

EN 45552:2020. General method for the assessment of the durability of energy-related products.

This standard provides a comprehensive framework for assessing the durability of products, ensuring they meet the highest standards of quality and longevity. The standard establishes a general method for evaluating the durability of energy-related products. Durability not only affects the product's performance and reliability but also its environmental impact and cost-effectiveness. By adhering to the guidelines set forth in this standard, manufacturers can ensure that their products are designed to last, reducing waste and promoting sustainability.

EN 45553:2020. General method for the assessment of the ability to remanufacture energy-related products.

This standard provides a comprehensive framework for assessing the remanufacturability of energy-related products. The standard offers a structured approach to evaluate the potential for remanufacturing, ensuring that products can be reused, refurbished, and reintroduced into the market with minimal environmental impact. This not only helps in reducing waste but also in conserving resources, ultimately leading to cost savings and increased profitability.

EN 45554:2020. General methods for the assessment of the ability to repair, reuse and upgrade energy-related products.

This standard provides a comprehensive framework for assessing the ability to repair, reuse, and upgrade energy-related products. This standard is an essential tool for manufacturers, engineers, and sustainability experts who are committed to enhancing the lifecycle of their products while minimizing environmental impact. This standard outlines general methods for evaluating the repairability, reusability, and upgradability of energy-related products. It provides detailed guidelines and methodologies that help stakeholders in the energy sector to improve product design and lifecycle management.

EN 45555:2019. General methods for assessing the recyclability and recoverability of energy-related products.

This standard provides comprehensive guidelines and methodologies for evaluating the recyclability and recoverability of energy-related products, ensuring that they meet the necessary environmental standards and contribute to a circular economy. It helps to provide a structured approach to assess their potential for recycling and recovery. By following the guidelines in this standard, companies can ensure that their products are designed with end-of-life considerations in mind, promoting a more sustainable approach to product development.

EN 45557:2020. General method for assessing the proportion of recycled material content in energy-related products.

This standard provides a comprehensive methodology for assessing the proportion of recycled material content in energy-related products. It is an essential tool for companies aiming to enhance their environmental responsibility and transparency. The standard offers a structured approach to evaluate and report the recycled material content, thereby supporting manufacturers in their efforts to reduce the ecological footprint of their products. This standard not only aids in compliance with environmental regulations but also enhances the marketability of products by aligning them with consumer demand for sustainable solutions.

EN 45558:2019. General method to declare the use of critical raw materials in energy-related products.

This standard is intended to provide a means for information on the use of CRMs to be exchanged up and down the supply chain and with other relevant stakeholders. The standard is intended for use by any public, private or social enterprises involved in the production of energy-related products (including SMEs) and other organisations in the product supply chain. It is also relevant to European market surveillance and trade authorities as well as European policy makers. This standard is horizontal in nature, and can be applied directly to any type of energy-related product. This document sets out a standardised format for reporting use of CRMs in energy-related products.

prTS 50752:20YY Design for recycling guidelines for styrenics and polyolefins products and parts in electrical and electronic equipment, with focus on ABS, PP and PS

This draft technical specification describes the best practices and technical solutions that manufacturers of electrical and electronic equipment (EEE) can adopt during the design phase, to enable consistent and effective recycling of styrenics and polyolefins plastics composing the equipment, during the Waste of Electrical and Electronic Equipment (WEEE) management.

1.5. Legislation

1.5.1 Ecodesign Directive

The Ecodesign Directive **([1])** provides consistent EU-wide rules for improving the environmental performance of products placed on the EU market. The Directive's main aim is to provide a framework for reducing the environmental impacts of products throughout their entire life cycle. As many of the environmental impacts associated with products are determined during the design phase, the Ecodesign Directive aims to bring about improvements in environmental performance through mandating changes at the product design stage.

The Ecodesign Directive is a framework directive, not directly setting minimum requirements: the aims of the Directive are implemented through product-specific Regulations, directly applicable in all EU member states. For a product category to be covered by under the Ecodesign Directive it needs to ([2]):

- have a significant volume of sales (indicatively 200,000 units per year throughout the Union market)
- have a significant environmental impact
- present significant potential for improvement in environmental impact (without incurring excessive costs)

Increasing energy efficiency is an important objective of the EU policy ([3]). A crucial policy instrument for achieving the 2030 EU climate and energy targets is the setting of **minimum efficiency requirements for products –** through **ecodesign –**, in combination with **informing customers about their energy performance and durability –** through **energy labelling**.

Ecodesign and Energy Labelling regulations are key contributors in product policy supporting the Energy Union objectives and the transition to a Circular Economy. The Commission has flagged in the Ecodesign Working plan 2016-2019 that ecodesign implementing measures should cover resource efficiency aspects

([1]) http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0125&from=EN

([2]) Article 15.2 of Ecodesign Directive 2009/125/EC.

([3]) more information at https://ec.europa.eu/energy/en/topics/energy-efficiency where appropriate, to ensure greater durability, accessibility, design for disassembly and reparability of products entering the market and therefore contribute to the transition towards a more circular economy.

Since the coming into force of the first ecodesign directive in 2005, a variety of energy-consuming product groups such as washing machines, refrigerators, etc. have been covered by ecodesign and energy labelling regulations. Moreover, each ecodesign and energy labelling regulation contains provisions for its future evaluation and possible revision, taking into account the experience gained with their implementation and technological progress.

Actually computers where among the first product categories being subject to an Ecodesign Preparatory Study back in 2007 ([4]), but it took 6 years until adoption of Commission Regulation (EU) No 617/2013 of 26 June 2013, which set requirements on computers and computer servers. It was to be reviewed three and a half years after entry into force (i.e. by January 2017) and is part of the Ecodesign Working Plan 2016-2019. A review study (https://computerregulationreview.eu/) was completed only in 2018. The information and data evidence gathered within this study show a clear need of reviewing, updating and simplifying the Ecodesign requirements in force. However, the study could not provide a solution for one of the crucial objectives, i.e. identifying a testing method of the energy efficiency of computers while performing “relevant” work.

There are market barriers that hamper the introduction and uptake of more energy efficient and more long lasting products. It is desirable for policies to address these barriers since they lead, from the point of view of the consumer and society, to unrealised economically viable energy savings. Behavioural failures refer to the cognitive limitations and biases that prevent consumers and investors to appreciate rationally the benefits of energy efficiency ([5]). Market failures arise from the fact that many impacts and aspects of energy supply or resource use are not brought into market prices ([6]). Market barriers such as lack of information and awareness or financing challenges result in economically rational energy savings not being realised or more sustainable choices not being made.

The EU Ecodesign Directive aims to address these barriers by setting performance requirements to remove the worst performing products from the market. The assessment aims to ensure that the minimum requirements are set at the level of Least Life Cycle Cost (LLCC). These harmonised requirements have specifically addressed energy efficiency and have led to significant reductions in energy use of household and industrial products. Being set at EU level, they have avoided subjecting industry to multiple national rules.

Energy labelling rules complement ecodesign requirements. These provide information to potential users with the aim of encouraging them to purchase products that have a better energy performance than the minimum ([7]). This has helped consumers to reduce their energy bills by easily identifying and comparing more energy efficient appliances. Nearly 80 % of the EU public recognise the label and say it has influenced their purchase decision ([8]).

([4]) In reality energy efficiency aspects during the “use phase” had been tacked since the Energy Star Agreement with US EPA in 2001, as computers have been, for a number of years and in the lack of a suitable energy efficiency regulatory framework, the first an only product covered in the Agreement, endorsing in the EU the requirements set in the US Energy Star.

([5]) DellaValle N., Bertoldi P. (2021) “Toward a more situated energy efficiency policy agenda”.

([6]) E.g. impacts on air pollution, biodiversity, resource use, climate change and energy security

([7]) An upfront possibly higher purchase cost can be fully covered by savings over the product lifetime: the break-even point between different models and costs depends on subjective aspects such as the intensiveness of use,

([8])Special Eurobarometer 492. “Europeans’ attitudes on energy policy report. European Commission September 2019.

The impact of these measures are estimated through the Ecodesign Impact Accounting ([9]). It is estimated that in 2020 the combined ecodesign and energy labelling measures contributed a quarter of the energy savings and a third of the greenhouse gas emissions reductions to achieve the EU's 20-20-20 climate and energy policy goals.

EU Regulation 617/2013/EU - Ecodesign Requirements for Computers and Computer Servers ([10]) includes requirements on annual typical energy consumption (TEC), operational modes and power management enabling as well as energy efficiency requirements on internal power supply units. The Regulation applies to a range of computers including:

- desktop computers;
- integrated desktop computers;
- notebook computers (including tablet computers, slate computers and mobile thin clients);
- desktop thin clients;
- workstations;
- mobile workstations;
- small-scale servers;
- computer servers.

The ecodesign Regulation on computers entered into force on July 17, 2013 with some requirements applying from that date whilst other requirements were phased in over the following 18-months.

Regulation 617/2013 was deeply inspired by the Energy Star specifications Version 10, but that framework designed for a preliminary compliance verification, proved to be not suitable in the EU context, where random ex post verification is the compliance control strategy.

As in Energy Star, to which it is deeply inspired, Regulation 617/2017 only caps the energy use when the computer is in "idle" state, i.e. when doing no computation or activity. As in the Energy Star specifications, no requirements on reliability, durability or recyclability are set.

1.5.2 Related Legislation

EU Regulation 1275/2008/EC - Ecodesign requirements for Standby and off mode ([11]) sets mandatory power demand limits on low power modes (e.g. networked standby, sleep and off mode) and power management requirements for household and office electrical and electronic equipment. The EU Computer Regulation (617/2013/EU) explicitly pulls desktops, integrated desktops and some notebooks out of scope of the Standby Directive as the ecodesign regulation on computers includes more appropriate requirements on power management, sleep mode, off mode and lowest power state. Laptops that use less than 6W in idle or have displays with a diagonal length less than 22.86 cm (9 inches) remain within scope of the Standby Regulation.

Regulation (EU) 2019/1782 - Ecodesign requirements for External power supplies ([12]) includes no-load condition electric power demand and average active efficiency for all external power supplies (EPS) with an output of less than 250 W and supplying only one output voltage at a time. The EPS Regulation only applies to EPS that are intended to be used to power household and office electrical and electronic equipment.

([9]) Ecodesign impact accounting annual report 2020

([10]) http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2013:175:0013:0033:EN:PDF

([11]) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02008R1275-20210301

([12]) http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:093:0003:0010:EN:PDF

The EU Ecodesign Regulation (617/2013/EU) explicitly states that any EPS that are placed on the EU market with computers are covered by EU Regulation 2019/1782. The regulation is currently under revision with the goal to complement the amended Radio Equipment Directive (see next) as regards interoperability of external power supplies.

Directive (EU) 2022/2380 on radio equipment ([13]) sets requirements for the so-called common charger. From April 28, 2026 laptops are required to be compatible with USB-PD power supplies and an option to acquire a laptop without external power supply (unbundled) has to be offered to the consumer.

Regulation (EU) 2023/1717 ([14]) amends the Radio Equipment Directive and sets technical specifications for the charging receptacle and charging communication protocol for all the categories or classes of radio equipment capable of being recharged by means of wired charging, including laptops.

EU Regulation 1907/2006/EC - REACH Regulation ([15]) addresses chemicals, and their safe use, and aims to improve the protection of human health and the environment through a system of Registration, Evaluation, Authorisation and Restriction of Chemicals. The REACH Regulation places greater responsibility on industry to manage the risks from the chemicals they manufacture, import and market in the EU. Companies are required to demonstrate how substances can be used safely and risk management measures must be reported to users. The REACH Regulation also establishes procedures for collecting and assessing information on the properties and hazards of substances and requires that companies register their substances in a central database. The entries in the database are then assessed to determine whether the risks of the substances can be managed. The REACH Regulation allows for some chemicals to be determined “substances of very high concern (SVHC)” due to their large potential negative impacts on human health or the environment. The European Chemicals Agency must be notified of the presence of SVHCs in certain products and the use of SVHCs may then be subject to prior authorisation. Substances can also be banned were risks are deemed to be unmanageable. As such, REACH encourages substitution of the most dangerous chemicals when suitable alternatives have been identified.
As REACH applies to all chemical substances, in theory, it also covers the chemicals that are used in computers and associated products that are within scope of this review project.

EU Directive 2011/65/EU - RoHS Directive ([16]) aims to prevent the risks posed to human health and the environment related to the management of electronic and electrical waste. It does this by restricting the use of certain hazardous substances in products that can be substituted by safer alternatives. These restricted substances include heavy metals, flame retardants and plasticizers.

The RoHS Directive 2011/65/EU currently restricts the use of ten substances: lead, cadmium, mercury, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE), bis(2-ethylhexyl) phthalate (DEHP), butyl benzyl phthalate (BBP), dibutyl phthalate (DBP) and diisobutyl phthalate (DIBP). The RoHS Directive does contain some exemptions where it has been decided that it may not be possible to manufacture some products without the use of one or more of the banned substances.

([13]) Directive (EU) 2022/2380 of the European Parliament and of the Council of 23 November 2022 amending Directive 2014/53/EU on the harmonisation of the laws of the Member States relating to the making available on the market of radio equipment (Text with EEA relevance). Link: https://eur-lex.europa.eu/eli/dir/2022/2380/oj/eng

([14]) Commission Delegated Regulation (EU) 2023/1717 of 27 June 2023 amending Directive 2014/53/EU of the European Parliament and of the Council as regards the technical specifications for the charging receptacle and charging communication protocol for all the categories or classes of radio equipment capable of being recharged by means of wired charging (Text with EEA relevance) https://eur-lex.europa.eu/eli/reg_del/2023/1717/oj/eng

([15]) http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02006R1907-20140410&from=EN

([16]) Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast) (Text with EEA relevance), Link: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02011L0065-20250101

The RoHS Directive explicitly states that "IT and telecommunications equipment" are within scope and so the computers and associated products that are within scope of this review project are also within scope of the RoHS Directive.

Ecodesign requirements for computers could therefore be used to assist the RoHS Directive aims via the introduction of product design requirements that contribute to the reduction of the use of hazardous substances. This could include requirements such as labelling of hazardous materials that are subject to exemptions under the RoHS Directive.

Regulation (EU) 2023/1542 – Battery Regulation ([17]), aims to make batteries sustainable throughout their entire life cycle – from the sourcing of materials to their collection, recycling and repurposing. Products incorporating portable batteries shall be designed to ensure that those batteries are readily removable and replaceable by the end-user at any time during the lifetime of the product. A portable battery shall be considered readily removable by the end-user where it can be removed from a product with the use of commercially available tools, without requiring the use of specialised tools, unless provided free of charge with the product, proprietary tools, thermal energy, or solvents to disassemble the product. Furthermore, products incorporating portable batteries shall ensure that those products are accompanied with instructions and safety information on the use, removal and replacement of the batteries. Those instructions and that safety information shall be made available permanently online, on a publicly available website, in an easily understandable way for end-users. (Art. 11, paragraph 1). Other Union Law, such as ecodesign regulations, might set requirements ensuring a higher level of protection of the environment and human health relating to the removability and replaceability of portable batteries by end-users. Where appliances are specifically designed to operate primarily in an environment that is regularly subject to splashing water, water streams or water immersion, and that are intended to be washable or rinseable products incorporating portable batteries may be designed in such a way as to make the battery removable and replaceable only by independent professionals (Art. 11, paragraph 2).

The Cyber Resilience Act (EU) 2024/2847 ([18]) defines requirements on software security updates to fix identified vulnerabilities. When placing a product with digital elements on the market, and for the expected product lifetime or for a period of five years from the placing of the product on the market, whichever is shorter, manufacturers shall provide for mechanisms to securely distribute updates to ensure that exploitable vulnerabilities are fixed or mitigated in a timely manner, and shall ensure that, where security patches or updates are available to address identified security issues, they are disseminated without delay and free of charge, accompanied by advisory messages providing users with the relevant information, including on potential action to be taken (Art. 10 and Annex I, No. 2). Information to the use shall comprise, among others, the type of technical security support offered by the manufacturer and until when it will be provided, at the very least until when users can expect to receive security updates (Annex II). Given that the expected product lifetime of computers should not be expected to be less than 5 years, the minimum security update requirement for computers can be read to be 5 years according to the CRA. The CRA does not regulate functionality updates.

EU Directive 2014/30/EU - Electromagnetic Compatibility Directive ([19]) (EMC) ensures that electrical and electronic equipment, i.e., including computers, does not generate, or is not affected by, electromagnetic disturbance. The Directive requires that products must not emit unwanted electromagnetic interference and must be protected against a normal level of interference.

([17]) https://eur-lex.europa.eu/eli/reg/2023/1542/oj

([18]) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52022PC0454

([19]) http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32014L0030&locale=en

EU Directive 2014/35/EU - Low Voltage Directive ([20]) (LVD) covers health and safety risks on electrical equipment operating with an input or output voltage of between 50 and 1000 V for alternating current, and 75 and 1500 V for direct current. It applies to a wide range of electrical equipment for both consumer and professional usage.

Regulation (EU) 2023/988 - General Product Safety Regulation ([21]) (GPSR) requires all products on the EU market to be safe, irrespective of their sale channel or country of origin. This means manufacturers must make sure that the products they place on the market are safe by design and comply with EU product safety rules. A product is considered safe if – when used normally or as intended (including the length of time it is used) – it does not pose any risk or only presents minimal risks acceptable for its use. To meet the general safety requirement under the GPSR, the manufacturer must conduct a risk analysis of the product. This analysis, also known as a risk assessment, evaluates the potential risks to consumer health and safety and also takes into account all relevant aspects of the product. The manufacturer should draw up technical documentation describing all potential risks of the product and how they have been eliminated or mitigated.

US-EPA Energy Star programme focusses on the energy efficiency of a variety of products including many types of computers. The programme has also been adopted in several other countries including Australia, Canada and Japan. Although this legislation is not relevant in the EU, Energy Star has a significant influence in the market place because the specifications behind the programme are de-facto mandatory considerations in US central government procurement contracts. Given its large influence in the marketplace, the corresponding databases and use of established test procedures, Energy Star is often used as the basis for regulatory measures on computer energy efficiency. Although the Energy Star does not make use of a testing method really assessing the energy efficiency of computers, but simply capping energy use while the computer is not performing relevant work, some alignment in minimal requirements of EU Regulations and Energy Star specifications may reduce burden on manufacturers exporting the same computer models to the EU an US market.. The European Union (EU) and the United States of America (US) signed an Energy Star * agreement in 2001, the aim of which was to implement in the EU a ready-made programme, on a voluntary basis. The Energy Star initially only covered computers and was later extended to a few more ([22]). The current Ecodesign Regulation on computers is heavily inspired to the Energy Start specifications version 5.2, of 2009.

A specific clause in the EU-US agreement was inhibiting the EU from introducing a labelling program on the products in the scope of the Agreement. As the EU-Energy Star board gave priority to an EU labelling scheme, would it be introduced, it meant that the product group had to exit the EU-US Agreement. The agreement expired in 2018 ([23]).

There are some parallel Ecodesign and Energy Labelling Regulations, which need to be taken into account:

Regulation (EU) 2019/2021 laying down ecodesign requirements for electronic displays ([24]) includes in the scope computer monitors and signage displays and sets in particular, material efficiency requirements, such as design for dismantling, recycling and recovery, Marking of plastic components, Halogenated flame retardants and Design for repair and reuse. Considering that in most cases an integrated desktop computer, aka All-in-One (AiO) is not easily distinguishable from a computer monitor

([20]) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32014L0035

([21]) https://eur-lex.europa.eu/eli/reg/2023/988/oj

([22]) computer monitors and signage displays, imaging products, servers, and unimpterruptible power supplies

([23]) Would the Agreement not expire, computer monitors and signage displays had to be expluded fro Energy Star when they were included in the scope of the Electronic Display Regulation. Similarly would have happened if labelling was proposed for Enterprise servers and con Computers, leaving no product part of the agreement.

([24]) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32019R2021 or from a small/medium signage monitor, once sorted at WEEE plants that process electronic displays ([25]), the same material efficiency requirements should also apply to AiO computers.

EU Directive 2012/19/EU on Waste Electrical and Electronic Equipment (WEEE Directive) implements the principle of "extended producer responsibility” where producers of EEE are expected to take responsibility for the environmental impact of their products at the end of life. As such, the WEEE Directive aims to reduce environmental impacts through setting targets for the separate collection, reuse, recovery, recycling and environmentally sound disposal of WEEE.

The WEEE Directive (Directive 2012/19/EU) lays down measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste from electrical and electronic equipment (WEEE) and by reducing overall impacts of resource use and improving the efficiency of such use in accordance with Articles 1 and 4 of Directive 2008/98/EC (the ‘general’ waste directive).

Article 4 of this Directive refers to the Ecodesign Directive 2009/125/EC for more efficiently tacking upstream what would be cumbersome downstream: Ecodesign requirements facilitating the re-use, dismantling and maximizing the yield of recoverable materials should be laid down in the framework of measures implementing the Ecodesign Directive in order to optimise re-use and recovery since the product design, thus taking into account the whole product life cycle.

As EEE, computers and many associated products fall under the scope of the WEEE Directive. Ecodesign requirements for computers could therefore be used to assist the WEEE Directive aims via the introduction of product design requirements that enhance reuse, material recovery and effective recycling.

1.5.3 Critical Raw Materials Act

Annex I of the Critical Raw Materials Act [8] lists the strategic raw materials, and Annex II the critical raw materials. The list is presented in the table below.

Table 1: List of strategic and critical raw materials (source: Critical Raw Materials Act [8], annex I and II)

Raw Material / Element	Critical Raw Material	Strategic Raw Material
Antimony	x	
Arsenic	x	
Bauxite/alumina/aluminium	x	x
Baryte	x	
Beryllium	x	
Bismuth	x	x
Boron	x	x (metallurgy grade)
Cobalt	x	x

([25]) An AiO computer may be also be regarded as a computer monitor with integrated computer and , expecally an old model, is unlikely to be recognized and differently treated by automated machinery or even by workers.

Raw Material / Element	Critical Raw Material	Strategic Raw Material
Coking coal	x	
Copper	x	x
Feldspar	x	
Fluorspar	x	
Gallium	x	x
Germanium	x	x
Hafnium	x	
Helium	x	
Heavy rare earth elements [26]	x	
Light rare earth elements [27]	x	
Rare earth elements for permanent magnets (Nd, Pr, Tb, Dy, Gd, Sm, & Ce)		x
Lithium	x	x (battery grade)
Magnesium	x	x (metal)
Manganese	x	x (battery grade)
Graphite	x	x (battery grade)
Nickel – battery grade	x	x
Niobium	x	
Phosphate rock	x	
Phosphorus	x	
Platinum group metals [28]	x	x
Scandium	x	
Silicon metal	x	x
Strontium	x	
Tantalum	x	

[26] The CRM Act does not further define this, but heavy rare earth elements should include Y (Yttrium), Gd (Gadolinium), Tb (Terbium), Dy (Dysprosium), Ho (Holmium), Er (Erbium), Tm (Thulium), Yb (Ytterbium), and Lu (Lutetium)

[27] The CRM Act does not further define this, but light rare earth elements should include La (Lanthanum), Ce (Cerium), Pr (Praseodymium), Nd (Neodymium), Pm (Promethium), Sm (Samarium) and Eu (Europium).

[28] The CRM Act does not further define this, but platinum group metals (PGM) should include: Pd (Palladium), Pt (Platinum), Rh (Rhodium), Ru (Ruthenium), Ir (Iridium) and Os (Osmium).

Raw Material / Element	Critical Raw Material	Strategic Raw Material
Titanium metal	x	x
Tungsten	x	x
Vanadium	x	

Among the provisions of the CRM Act there are two which are directly relevant for this study on personal computers[29]:

Paragraph (52)

(52) Member States retain important competences in the field of circularity, for example in the area of waste collection and treatment systems. Those competences should be used to increase collection and recycling rates for waste streams with a high potential for recovery of critical raw materials, including electronic waste, making use for example of financial incentives such as discounts, monetary rewards or deposit-refund systems while preserving the integrity of the internal market. With a view to increasing the use of secondary critical raw materials, this could also include differentiated producer responsibility fees, provided such fees exist in national law, to benefit products containing a larger share of secondary critical raw materials recovered from waste recycled in accordance with environmental standards established in Union law. Such secondary critical raw materials recovered from waste should include recovery carried out in accordance with third-country standards that offer an equivalent protection to Union standards. Member State authorities should also make a difference as buyers of critical raw materials and of products containing them, and national research and innovation programmes provide significant resources to increase the state of knowledge and technology for critical raw materials circularity as well as material efficiency. Finally, Member States should promote the recovery of critical raw materials from extractive waste by improving the availability of information and by addressing legal, economic and technical barriers. A possible solution that Member States should look into are risk-sharing mechanisms between operators and the Member State to promote recovery from closed waste facilities. The Board should also facilitate the exchange of best practices between Member States, on the design and implementation of their national programmes.

- ***Article 26, National measures on circularity***

  1. Each Member State shall, […], adopt […] measures designed to:

  […]

  (c) increase the collection, sorting and processing of waste with relevant critical raw materials recovery potential [30], including metal scraps, and ensure their introduction into the appropriate recycling system, with a view to maximising the availability and quality of recyclable material as an input to critical raw material recycling facilities.

[29] The following are extracts or summaries of the legal text. See the act itself for the precise text. Link: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L_202401252

[30] The Commission has to define by May 2025 which products, components and waste streams shall at least be considered as having a relevant critical raw materials recovery potential.

(d) increase the use of secondary critical raw materials, including through measures such as taking recycled content into account in award criteria related to public procurement or financial incentives for the use of secondary critical raw materials.

(e) increase the technological maturity of recycling technologies for critical raw materials and promote circular design, materials efficiency and substitution of critical raw materials in products and applications, at least by including support actions to that effect under national research and innovation programmes.

5. *Member States shall identify separately, and report, the quantities of components containing relevant amounts of critical raw materials removed from waste electrical and electronic equipment and the quantities of critical raw materials recovered from such equipment.*

2. MEErP Task 2, Markets

This section offers a very brief look at the market data estimates for personal computers, derived from the Ecodesign Impact Accounting (EIA) study. This EIA gathers data from all products regulated by Ecodesign and Energy Labelling regulations. It provides estimates of sales, stock, volumes, efficiencies, electricity consumption, GHG emissions, prices, costs, business revenues and jobs.

EIA data are based on EU28 data from the 2019 Impact Assessment [5], the 2016 review study [4] and the underlying Excel file, converted to EU27 by applying Brexit factors (see the EIA annual report). The data until 2015-2018 [31] can be considered 'historical', while data for later years are projections made at the time of the last study.

2.1. Computers Sales and Stock

Table 2 presents the estimated sales of personal computers in five-year increments from 2010 through 2050. These data are presented in thousands of units and show anticipated sales growth over time. Between 2025 and 2050, overall sales are projected to increase by 39%. Within that time period, notebook computers are expected to grow by 55% and integrated desktops by 45%. Workstations grow by 40% and desktop computers by 12%, with all other categories having 0 to 1% growth.

Table 2. EU27 Sales of Personal Computers by Type, EIA 2024 (BAU, thousands of units)

Type	2010	2015	2020	2025	2030	2035	2040	2045	2050
Desktop	24,091	12,744	14,255	19,669	20,969	21,725	21,979	22,063	22,091
Integrated Desktop	964	510	570	787	960	1,079	1,121	1,136	1,140
Notebook	48,278	42,570	42,464	56,033	70,666	81,151	84,953	86,242	86,669
Tablet (non-slate)	503	8,736	7,500	7,667	7,667	7,667	7,667	7,667	7,667
Thin client	1,347	1,308	1,381	1,394	1,403	1,408	1,409	1,410	1,410
Integrated Thin Cli.	135	131	138	139	140	141	141	141	141
Small-scale Server	133	168	170	171	172	173	173	173	173
Workstation	646	795	908	1,087	1,301	1,445	1,495	1,512	1,518
TOTAL	**76,097**	**66,962**	**67,386**	**86,947**	**103,278**	**114,787**	**118,939**	**120,344**	**120,809**

Table 3 presents the estimated installed stock of personal computers in five-year increments between 2010 and 2050. These data are presented in thousands of units, and show a projected growth in the installed stock. Between 2025 and 2050, the overall stock is expected to increase by 52%. Within that time period, the stock of notebook computers are expected to grow by 71% and integrated desktops by 68%. Workstations grow by 54% and desktop computers by 30%, with all other categories having 1 to 2% growth, except for tablet computers (non-slate) which are forecast to have slightly negative (-1%) change in stock.

[31] The 2016 review study used data available in 2015. The 2019 impact assessment used these data but may have updated some of the data up to 2018.

Table 3. Stock (EU-27) of Personal Computers by Type, EIA 2024 (BAU, thousands of units)

Type	2010	2015	2020	2025	2030	2035	2040	2045	2050
Desktop	156,355	110,524	81,096	101,772	121,914	128,400	131,222	132,163	132,473
Integrated Desktop	6,255	4,423	3,244	4,071	5,241	6,163	6,618	6,777	6,830
Notebook	184,321	224,187	212,868	253,027	324,064	388,748	418,749	429,189	432,678
Tablet (non-slate)	1,499	30,138	36,874	38,733	38,333	38,333	38,333	38,333	38,333
Thin client	6,750	6,607	6,765	6,944	6,997	7,032	7,045	7,049	7,051
Integrated Thin Cli.	677	662	677	693	698	702	703	704	704
Small-scale Server	813	1,029	1,178	1,195	1,202	1,207	1,209	1,210	1,210
Workstation	4,358	4,956	5,876	6,871	8,215	9,551	10,267	10,520	10,604
TOTAL	**361,027**	**382,525**	**348,578**	**413,307**	**506,664**	**580,136**	**614,147**	**625,945**	**629,884**

2.2. Electricity Consumption of Computers in the EU-27

Table 4 presents the estimated electricity consumption of the installed stock of personal computers in five-year increments between 2010 and 2050. These data are presented in terawatt-hours per annum, for the business as usual scenario. Although there is a 52% increase in stock, the expectation is that the power consumption will be approximately the same in real terms. The projected power consumption in 2025 for personal computers is 20.3 TWh and in 2050 it is 20.1 TWh, even though there are over 200 million more computers expected to be in service in 2050. On a per unit (computer) energy consumption basis, this represents a reduction of 35% over that time period in the business as usual case. Please note too that this calculation is only about actual electricity consumption by computers, it does not take into account the calculation power or performance of computers in 2050 vs. 2025.

Table 4. Electricity Consumption of Computers, EU27 Stock, by Type, EIA 2024 (BAU, Terawatt-hours per year)

Type	2010	2015	2020	2025	2030	2035	2040	2045	2050
Desktop	20.80	13.93	8.82	9.79	10.84	10.61	10.23	9.68	9.08
Integrated Desktop	0.89	0.60	0.41	0.53	0.69	0.80	0.82	0.80	0.77
Notebook	7.26	8.26	6.72	7.33	7.70	7.82	8.09	7.96	7.68
Tablet (non-slate)	0.05	0.72	0.72	0.52	0.38	0.38	0.37	0.37	0.36
Thin client	0.52	0.39	0.29	0.28	0.27	0.26	0.25	0.25	0.24
Integrated Thin Cli.	0.12	0.09	0.07	0.06	0.06	0.06	0.06	0.06	0.05
Small-scale Server	0.11	0.13	0.13	0.12	0.11	0.10	0.09	0.09	0.08
Workstation	1.36	1.45	1.55	1.67	1.89	2.07	2.07	1.97	1.83
TOTAL	**31.11**	**25.55**	**18.72**	**20.30**	**21.95**	**22.10**	**21.99**	**21.16**	**20.09**

3. MEErP Task 3, Product usage

In this task, the review study would look at how much the product being evaluated is used. However, for the purposes of the work being conducted in this study of critical raw materials, recycled content and recyclability, the usage of the product is less relevant.

The upcoming review study on personal computers will provide updates on product usage in their analysis, it is therefore not included in this report.

4. MEErP Task 4, Technologies

In this task, the review study would assess both current and anticipated technological improvements in the product being evaluated. For the purposes of the work being conducted in this study, apart from product re-design to incorporate recycled content, development of more efficient personal computers are outside of scope. Thus, for this study on critical raw materials, recycled content and recyclability, the degree of technological innovation of personal computers is less relevant.

The upcoming review study on personal computers will provide updates on technological innovation in their analysis, and this is therefore not included in this report.

5. MEErP Task 5, Environment and Economics

5.1. Bill-of-Materials for base cases

In the review of personal computers, seven basecase representative models are being developed for analysis:

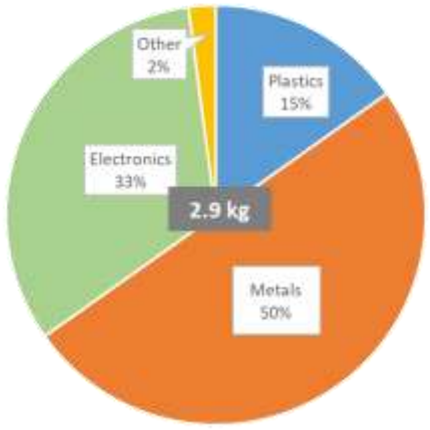
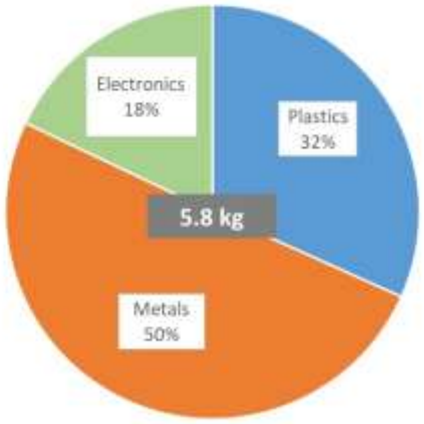
- BC1: Tablet computers
- BC2: (all other) laptops
- BC3: Laptops with browser-based applications (i.e, Chromebooks)
- BC4: Integrated desktop computers
- BC5: Desktop computers
- BC6: Desktop with registered memory (i.e., "workstations")
- BC7: Small scale servers

For the CRM and recycled content analysis, the team selected two of the seven base case models: BC-2 (all other) laptops and BC5 Desktop computers as these are among the most common computers and have two different formats – i.e., the notebook being portable and incorporating a screen while the desktop being designed not to be moved and without a screen. The definitions of these two product types are given below:

> **Desktop computer** means a computer where the main unit is intended to be located in a permanent location and is not designed for portability and which is designed for use with an external display and external peripherals such as a keyboard and mouse.
>
> **Notebook computer** means a computer 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. Notebook computers utilise an integrated display, with a viewable diagonal screen size of at least 22.86 cm (9 inches) and are capable of operation on an integrated battery or other portable power source.

The table below provides a high-level breakdown / comparison between the different material types found in the two representative models selected for these two product groups.

Table 5: Materials Weight Allocation for the two Basecase Models Evaluated for Computers

BC2 Laptop (Notebook) Computer	BC5 Desktop Computer
	
For the laptop computer (BC2), the total weight of the computer is 2.9 kg, excluding packaging material used in shipping. Breaking down the computer into groups of material types, metals represent 50% of the mass (1.4 kg), electronics are 33% (0.9 kg), plastics are 15% (0.4 kg) and other materials are 2% (0.06 kg).	For the desktop computer (BC5), the total weight of the computer is 5.8 kg, excluding any packaging material used in shipping. Breaking down the computer into its material types, the largest share is metals, which represents 50% of the mass (2.9 kg), followed by plastics at 32% (1.8 kg) and electronics at 18% (1.0 kg).

This study uses the new 2024 EcoReportTool (ERT)[32], developed for use in assessing products under the Ecodesign for Sustainable Products Regulation (ESPR). A representative model of a product group is selected, and the bill of materials associated with that representative model is matched with items within the ERT. The matched items have unit environmental impacts provided which are part of the assessment, and recycled material options available. In the new ERT, there is virgin material (V) and recycled material (R), each with their own dataset of unit environmental impacts. Table 6 and Table 7 present the BoM for the laptop computers and desktop computers, respectively. For the factors R1 (recycled content), R2 (recyclability or recycling output rate) and A (allocation factor), see section 5.2.

Table 6: Bill of Materials for base case 2 (BC2) Laptop Computer and corresponding entries in the EcoReportTool

Laptop (BC2) Component	Weight (grams)	Material Category	Virgin material dataset	Recycled material dataset	R1	R2	A
Membrane foil	0.01	Plastics	12-Polyethylene terephthalate (PET), petrochemical based polymerisation of ethylene glycol and terephthalic acid production mix, at plant petrochemical based	34-Polyethylene terephthalate (PET), recycled, semi-mechanical, post-consumer washing, drying, shredding, pelletizing production mix, at plant Erec/ErecEoL, efficiency 80%	0%	0%	50%
Light guide panel	10	Plastics	13-Polymethyl methacrylate (PMMA) granulate bulk polymerisation, from methyl methacrylate production mix, at plant 1.18 g/cm3	40-Recycling of post-consumer waste polypropylene (PP) collection, sorting, transport, washing, granulation, pelletization production mix, at plant 48,9% recycling rate	0%	0%	50%

[32] MEErP _Ecoreport tool_v1.7.xlsx; European Commission, Joint Research Centre, Eynard, U., Ardente, F., Gama Caldas, M., Spiliotopoulos, C. and Mathieux, F., Ecoreport tool - Manual, Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/473257, JRC133597.

Laptop (BC2) Component	Weight (grams)	Material Category	Virgin material dataset	Recycled material dataset	R1	R2	A
Plastic housing	8	Plastics	14-Polycarbonate (PC) granulate Technology mix, dipenyl carbonate route and phosgene route production mix, at plant 1.20–1.22 g/cm3	33-Polycarbonate (PC), recycled, post-consumer chemical recycling, depolymerisation, hydrolysis production mix, at plant Erec/ErecEoL, efficiency 80%	0%	0%	50%
fan, blades etc.	10	Plastics					
Back housing (PC+ABS)	21.38	Plastics					
Bezel	25	Plastics					
keys	35	Plastics					
Casing, various parts	300	Plastics					
Front housing (PC+ABS)	22.95	Plastics	1-Acrylonitrile Butadiene Styrene (ABS) emulsion polymerisation, bulk polymerisation or combined processes production mix, at plant	36-Recycling plastic Acrylonitrile-butadiene-styrene (ABS), waste management, technology mix	0%	0%	50%
Plastic adhesive	0.05	Plastics	20-Polyurethane flexible foam reaction of toluene diisocyanate (TDI) with long-chain polyether polyol and foaming production mix, at plant 18- 53 kg/m3	not available	0%	0%	50%
Rubber sealings	2.5	Plastics	26-Silicone, high viscosity hydrolysis and methanolysis of dimethyldichloro silane production mix, at plant >30 000 centi Poise	not available	0%	0%	50%
heat pipe / heat sink	40	Metals	46-Aluminium ingot (copper main solute) primary production, aluminium casting and alloying single route, at plant 2.7 g/cm3	117-Secondary aluminium ingot (copper main solute) secondary production, aluminium casting and alloying single route, at plant 2.7 g/cm3	30%	85%	20%
aluminum	0.6	Metals	52-Aluminium ingot mix (high purity) primary production, aluminium casting single route, at plant 2.7 g/cm3, >99% Al	123-Recycling of aluminium into aluminium ingot - from post-consumer collection, transport, pretreatment, remelting production mix, at plant aluminium waste, efficiency 90%	30%	85%	20%
thermal paste	4	Metals					
mechanical parts	80	Metals					
Casing, various parts	300	Metals					
Casing, machining losses aluminum	600	Metals					
Screws	5	Metals	55-Brass anode furnace and casting, from copper and zinc, primary production single route, at plant 8.41- 8.86 g/cm3	99-Brass, recycled, post-consumer die casting, from copper and zinc, primary production production mix, at plant 8.41- 8.86 g/cm3	n.a.	n.a.	20%
connectors	20	Metals					
copper	0.1	Metals	61-Copper Concentrate (Mining, mix technologies); copper ore mining and processing; single route, at plant; Copper - gold - silver - concentrate (28% Cu; 22.3 Au gpt; 37.3 Ag gpt)	124-Recycling of copper from clean scrap; collection, transport, pretreatment; production mix, at plant; copper content in input scrap 90%, copper losses 1%	0%	0%	20%
fan, motor	5	Metals					
Copper coil	6	Metals					
Copper foils and shields	15	Metals					
Coils	15	Metals	68-Ferrite (iron ore) iron ore mining and processing production mix, at plant 5.00 g/cm3	not available	0%	0%	20%
coils	15	Metals					
Gold bond wires (0,5mg)	0	Metals	75-Gold (primary route) primary route, underground mining and leaching production mix, at plant 19.32 g/cm3	102-Gold, recycled, pre-consumer collection, transport, dismantling, shredding, separation, remelting production mix, at plant 19.32 g/cm3, recycling efficiency 98%	n.a.	n.a.	20%
other IC gold (entered as 5 mg)	0.01	Metals					
SoC, RAM, NAND gold (entered as 20 mg)	0.02	Metals					
Casing, mid-frame, Magnesium	200	Metals	77-Magnesium Pidgeon Process, primary production production mix, at plant 1.74 g/cm	106-Magnesium, recycled (pre consumer, remelting)	n.a.	n.a.	20%

Laptop (BC2) Component	Weight (grams)	Material Category	Virgin material dataset	Recycled material dataset	R1	R2	A
Magnet	10	Metals	83-Rare earth concentrate mining, concentration, roasting, refining production mix, at plant concentrated	not available	n.a.	n.a.	20%
steel	0.2	Metals	85-Stainless steel cold rolled hot rolling production mix, at plant stainless steel	126-Secondary steel slab electric arc furnace route, from steel scrap, secondary production single route, at plant carbon steel	0%	85%	20%
Screws	5	Metals					
Metal cover	10	Metals					
on board steel sheets (EMI shields)	15	Metals					
Steel parts, EMC shielding	30	Metals					
Metal clips	0.56	Metals	86-Stainless steel hot rolled hot rolling production mix, at plant stainless steel	126-Secondary steel slab electric arc furnace route, from steel scrap, secondary production single route, at plant carbon steel	0%	85%	20%
fan, motor housing	15	Metals					
Hinge	40	Metals					
cable	48	Electronics	133-Cable, three-conductor cable technology mix production mix, at plant three-conductor cable, 1m, 60 g/m	177-End of life of cable, three-conductor cable Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
passive components on flex	0.06	Electronics	134-Capacitor ceramic technology mix production mix, at plant capacitor, mlcc, 6 mg	178-End of life of capacitor ceramic Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
passive components (SMD)	0.11	Electronics					
Passive components	12	Electronics					
passive components	12	Electronics					
Capacitors	9.5	Electronics	136-Capacitor, electrolyte technology mix production mix, at plant electrolyte, hight <2 cm, 9.5 g	180-End of life of Capacitor, electrolyte Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
tantalum capacitors	5	Electronics	138-Capacitor, Tantalum technology mix production mix, at plant tantalum capacitor, 0.5 g	182-End of life of Capacitor, Tantalum Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
various connectors, incl. board-to-board connectors, SO-DIMM, USB	50	Electronics	139-Connector for printed wiring board (PWB) technology mix production mix, at plant 1 PWB connector, 0.005kg	183-End of life of Connector for printed wiring board (PWB) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
USB Connector	1.79	Electronics	140-Connector Peripheral Component Interconnect (PCI) bus technology mix production mix, at plant 1 PCI bus connector, 0.00255 kg	184-End of life of Connector Peripheral Component Interconnect (PCI) bus Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
Plugs	3.83	Electronics					

Laptop (BC2) Component	Weight (grams)	Material Category	Virgin material dataset	Recycled material dataset	R1	R2	A
Sensor chip, 0,1cm³	0.03	Electronics	141-Controller board	206-Recycling of controller board	0%	50%	50%
Control IC's	0.62	Electronics	141-Controller board	206-Recycling of controller board	0%	50%	50%
small ICs	1.54	Electronics	141-Controller board	206-Recycling of controller board	0%	50%	50%
Battery	3.08	Electronics	141-Controller board	206-Recycling of controller board	0%	50%	50%
diodes	0.36	Electronics	143-Diode Metal electrode leadless face (mMELF) front-end and back-end processing of the wafer, including Czochralski method of silicon growing production mix, at plant 40 mg	186-End of life of Diode Metal electrode leadless face (mMELF) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
keyboard backlights	0.59	Electronics	153-Light Emitting Diode (LED), low power front-end and back-end processing of the wafer, including Czochralski method of silicon growing production mix, at plant 59 mg	192-End of life of Light Emitting Diode (LED), low power Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
LED backlights	7.08	Electronics	153-Light Emitting Diode (LED), low power front-end and back-end processing of the wafer, including Czochralski method of silicon growing production mix, at plant 59 mg	192-End of life of Light Emitting Diode (LED), low power Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
Display 14" (16:9, 539 cm2), LCD	421.8	Electronics	154-Liquid Crystal Display (LCD)	204-End of life of TFT LCD display panel, color Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
PCB, THT/SMD, single-sided (18cm²)	2.38	Electronics	164-Printed wiring board (PWB) (2-layer) via the subtractive method (as opposed to additive method) production mix, at plant 2-layer, 1.32 kg	195-End of life of Populated Printed wiring board (PWB) (2-layer) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
Flex boards (30cm²)	39.6	Electronics	164-Printed wiring board (PWB) (2-layer) via the subtractive method (as opposed to additive method) production mix, at plant 2-layer, 1.32 kg	195-End of life of Populated Printed wiring board (PWB) (2-layer) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
PCB, flex board	52.8	Electronics	164-Printed wiring board (PWB) (2-layer) via the subtractive method (as opposed to additive method) production mix, at plant 2-layer, 1.32 kg	195-End of life of Populated Printed wiring board (PWB) (2-layer) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
PCB, 6-layers; flex included above	0.09	Electronics	165-Printed wiring board (PWB) (8-layer) via the subtractive method (as opposed to additive method) production mix, at plant 8-layer, 3.08 kg	196-End of life of Populated Printed wiring board (PWB) (8-layer) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
Battery PCB	0.46	Electronics	165-Printed wiring board (PWB) (8-layer) via the subtractive method (as opposed to additive method) production mix, at plant 8-layer, 3.08 kg	196-End of life of Populated Printed wiring board (PWB) (8-layer) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
CPU substrate	1.23	Electronics	165-Printed wiring board (PWB) (8-layer) via the subtractive method (as opposed to additive method) production mix, at plant 8-layer, 3.08 kg	196-End of life of Populated Printed wiring board (PWB) (8-layer) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
Display PCB	3.08	Electronics	165-Printed wiring board (PWB) (8-layer) via the subtractive method (as opposed to additive method) production mix, at plant 8-layer, 3.08 kg	196-End of life of Populated Printed wiring board (PWB) (8-layer) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
PCB	30.8	Electronics	165-Printed wiring board (PWB) (8-layer) via the subtractive method (as opposed to additive method) production mix, at plant 8-layer, 3.08 kg	196-End of life of Populated Printed wiring board (PWB) (8-layer) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
PCB substrate, 10-layers, 0.0675m2	207.9	Electronics	165-Printed wiring board (PWB) (8-layer) via the subtractive method (as opposed to additive method) production mix, at plant 8-layer, 3.08 kg	196-End of life of Populated Printed wiring board (PWB) (8-layer) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
Coil	11.6	Electronics	167-SMD coil technology mix production mix, at plant 1 piece of Coil miniature wound SDR1006 (1.16g) D9.8 x 5.8	198-End of life of SMD coil Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
solder on flex	0.4	Electronics	168-Solder Paste (SnAg3.5Cu0.7) technology mix production mix, at plant 1 kg of solder paste	199-End of life of Solder paste Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-	0%	50%	50%
solder	3	Electronics	168-Solder Paste (SnAg3.5Cu0.7) technology mix production mix, at plant 1 kg of solder paste	199-End of life of Solder paste Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95-	0%	50%	50%

<table>
<tr><th>Laptop (BC2) Component</th><th>Weight (grams)</th><th>Material Category</th><th>Virgin material dataset</th><th>Recycled material dataset</th><th>R1</th><th>R2</th><th>A</th></tr>
<tr><td>solder</td><td>3</td><td>Electronics</td><td></td><td>98% efficiency, scrap incineration: 11.0 MJ/kg NCV</td><td></td><td></td><td></td></tr>
<tr><td>CPU SoC (1,7cm² die size)</td><td>3.36</td><td>Electronics</td><td>300-IC SoC</td><td>not available</td><td>n.a.</td><td>n.a.</td><td>50%</td></tr>
<tr><td>RAM 16GB (2cm² die size)</td><td>0.0004</td><td>Electronics</td><td rowspan="2">302-IC, DRAM (50% of SoC)</td><td rowspan="2">303-Recycled IC, DRAM (50% of SoC)</td><td rowspan="2">n.a.</td><td rowspan="2">n.a.</td><td rowspan="2">50%</td></tr>
<tr><td>SSD 512GB (10cm² total die size)</td><td>0.002</td><td>Electronics</td></tr>
<tr><td>Graphics CPU/SoC</td><td>0.0003</td><td>Electronics</td><td rowspan="3">306-Generic IC</td><td rowspan="3">307-Recycled Generic IC</td><td rowspan="3">n.a.</td><td rowspan="3">n.a.</td><td rowspan="3">50%</td></tr>
<tr><td>ICs</td><td>0.001</td><td>Electronics</td></tr>
<tr><td>other ICs (10cm² total die size)</td><td>0.002</td><td>Electronics</td></tr>
<tr><td>Cover glass</td><td>6</td><td>Others</td><td>222-glass fiber technology mix production mix, at plant 1 kg</td><td>not available</td><td>n.a.</td><td>n.a.</td><td>50%</td></tr>
</table>

Table 7: Bill of Materials for base case 5 (BC5) Desktop Computer and corresponding entries in the EcoReportTool

Desktop (BC5) Component	Weight (grams)	Material Category	Virgin material dataset	Recycled material dataset	R1	R2	A
Casing, various parts	800	Plastics	14-Polycarbonate (PC) granulate Technology mix, dipenyl carbonate route and phosgene route production mix, at plant 1.20–1.22 g/cm3	33-Polycarbonate (PC), recycled, post-consumer chemical recycling, depolymerisation, hydrolysis production mix, at plant Erec/ErecEoL, efficiency 80%	0%	0%	50%
fan, blades etc.	30	Plastics					
Back housing (PC+ABS)	100	Plastics					
Casing, various parts	800	Plastics	1-Acrylonitrile Butadiene Styrene (ABS) emulsion polymerisation, bulk polymerisation or combined processes production mix, at plant	36-Recycling plastic Acrylonitrile-butadiene-styrene (ABS), waste management, technology mix	0%	0%	50%
Front housing (PC+ABS)	100	Plastics					
Casing, various parts	800	Metals	52-Aluminium ingot mix (high purity) primary production, aluminium casting single route, at plant 2.7 g/cm3, >99% Al	123-Recycling of aluminium into aluminium ingot - from post-consumer collection, transport, pretreatment, remelting production mix, at plant aluminium waste, efficiency 90%	30%	85%	20%
Casing, Machining losses aluminum	100	Metals					
thermal paste	8	Metals					
Screws	5	Metals	55-Brass anode furnace and casting, from copper and zinc, primary production single route, at plant 8.41- 8.86 g/cm3	99-Brass, recycled, post-consumer die casting, from copper and zinc, primary production production mix, at plant 8.41- 8.86 g/cm3	n.a.	n.a.	20%
connectors	20	Metals					
Copper foils and shields	15	Metals	61-Copper Concentrate (Mining, mix technologies); copper ore mining and processing; single route, at plant; Copper - gold - silver - concentrate (28% Cu; 22.3 Au gpt; 37.3 Ag gpt)	124-Recycling of copper from clean scrap; collection, transport, pretreatment; production mix, at plant; copper content in input scrap 90%, copper losses 1%	0%	0%	20%
fan, motor	10	Metals					
heat pipe / heat sink	100	Metals					
coils	30	Metals	68-Ferrite (iron ore) iron ore mining and processing production mix, at plant 5.00 g/cm3	not available	0%	0%	20%
Coils	30	Metals					
SoC, RAM, NAND gold (entered as 50 mg)	0.05	Metals	75-Gold (primary route) primary route, underground mining and leaching production mix, at plant 19.32 g/cm3	102-Gold, recycled, pre-consumer collection, transport, dismantling, shredding, separation, remelting production mix, at plant 19.32 g/cm3, recycling efficiency 98%	n.a.	n.a.	20%
other IC gold (entered as 10 mg)	0.01	Metals					
Steel parts, EMC shielding	1500	Metals	85-Stainless steel cold rolled hot rolling production mix, at plant stainless steel	126-Secondary steel slab electric arc furnace route, from steel scrap, secondary production single route, at plant carbon steel	0%	85%	20%
on board steel sheets (EMI shields)	50	Metals					

Desktop (BC5) Component	Weight (grams)	Material Category	Virgin material dataset	Recycled material dataset	R1	R2	A
Metal casing	200	Metals					
Screws	5	Metals					
fan, motor housing	30	Metals	86-Stainless steel hot rolled hot rolling production mix, at plant stainless steel	126-Secondary steel slab electric arc furnace route, from steel scrap, secondary production single route, at plant carbon steel	0%	85%	20%
Metal clips	0.56	Metals					
cable	150	Electronics	133-Cable, three-conductor cable technology mix production mix, at plant three-conductor cable, 1m, 60 g/m	177-End of life of cable, three-conductor cable Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
passive components	15	Electronics	134-Capacitor ceramic technology mix production mix, at plant capacitor, mlcc, 6 mg	178-End of life of capacitor ceramic Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
passive components on flex	0.06	Electronics					
Passive components	15	Electronics					
passive components (SMD)	0.18	Electronics					
Capacitors	28.50	Electronics	136-Capacitor, electrolyte technology mix production mix, at plant electrolyte, hight <2 cm, 9.5 g	180-End of life of Capacitor, electrolyte Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
tantalum capacitors	5	Electronics	138-Capacitor, Tantalum technology mix production mix, at plant tantalum capacitor, 0.5 g	182-End of life of Capacitor, Tantalum Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
various connectors, incl. board-to-board connectors, SO-DIMM, USB	100	Electronics	139-Connector for printed wiring board (PWB) technology mix production mix, at plant 1 PWB connector, 0.005kg	183-End of life of Connector for printed wiring board (PWB) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
Plugs	3.83	Electronics			0%	50%	50%

Desktop (BC5) Component	Weight (grams)	Material Category	Virgin material dataset	Recycled material dataset	R1	R2	A
USB Connector	1.79	Electronics	140-Connector Peripheral Component Interconnect (PCI) bus technology mix production mix, at plant 1 PCI bus connector, 0.00255 kg	184-End of life of Connector Peripheral Component Interconnect (PCI) bus Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV			
diodes	1.2	Electronics	143-Diode Metal electrode leadless face (mMELF) front-end and back-end processing of the wafer, including Czochralski method of silicon growing production mix, at plant 40 mg	186-End of life of Diode Metal electrode leadless face (mMELF) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
Hard disk drive	315	Electronics	148-Hard disk drive, for desktop computer technology mix production mix, at plant 1 piece of HDD	189-End of life of Hard disk drive, for desktop computer Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
Flex boards ($30cm^2$)	39.6	Electronics	164-Printed wiring board (PWB) (2-layer) via the subtractive method (as opposed to additive method) production mix, at plant 2-layer, 1.32 kg	195-End of life of Populated Printed wiring board (PWB) (2-layer) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
PCB, THT/SMD, single-sided ($18cm^2$)	6.6	Electronics					
PCB substrate, 10-layers, $595m^2$ (MicroATX)	183.37	Electronics	165-Printed wiring board (PWB) (8-layer) via the subtractive method (as opposed to additive method) production mix, at plant 8-layer, 3.08 kg	196-End of life of Populated Printed wiring board (PWB) (8-layer) Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
PCB, SO-DIMM (1x SO-DIMM Form Factor)	6.25	Electronics					
PCB	30.8	Electronics					
CPU substrate	1.23	Electronics					
Coil	23.2	Electronics	167-SMD coil technology mix production mix, at plant 1 piece of Coil miniature wound SDR1006 (1.16g) D9.8 x 5.8	198-End of life of SMD coil Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
solder	5	Electronics	168-Solder Paste (SnAg3.5Cu0.7) technology mix production mix, at plant 1 kg of solder paste	199-End of life of Solder paste Recycling of copper and precious metals (Ag, Au, Pd, Pt) from electronics production mix, at plant recycling processes: 95- 98% efficiency, scrap incineration: 11.0 MJ/kg NCV	0%	50%	50%
solder on flex	0.4	Electronics					
solder	5	Electronics					

Desktop (BC5) Component	Weight (grams)	Material Category	Virgin material dataset	Recycled material dataset	R1	R2	A
CPU SoC (2cm² die size)	4	Electronics	300-IC SoC	not available	n.a.	n.a.	50%
ICs	1	Electronics					
Graphics CPU/SoC	0.0003	Electronics					
RAM 16GB (8cm² die size)	16	Electronics	302-IC, DRAM (50% of SoC)	303-Recycled IC, DRAM (50% of SoC)	n.a.	n.a.	50%
SSD 512GB (10cm² total die size)	20	Electronics	304-IC, NAND (60% of SoC)	305-Recycled IC, NAND (60% of SoC)	n.a.	n.a.	50%
other ICs (15cm² total die size)	30	Electronics	306-Generic IC	307-Recycled Generic IC	n.a.	n.a.	50%
small ICs	2	Electronics					
Battery (BIOS)	25	Electronics	308-LCO battery	309-Recycled LCO battery	n.a.	n.a.	50%

5.2. Recycling parameters for the EcoReportTool

5.2.1 Simplified Circular Footprint Formula

The 2024 ERT calculates the environmental impacts of raw materials, excluding the end-of-life (EoL) phase, using a simplified version of the Circular Footprint Formula (CFF) [33] [34]:

(1-R1) x Ev + R1 x (A x Erec + (1-A) x Ev).

The impacts at end-of-life due to material recycling are computed from:

(1-A) x R2 x Erec.

The benefits at end-of-life due to material recycling (avoidance of virgin material use) are computed from:

For non-electronics: - (1-A) x R2 x Ev

For electronics: - CF x Amount x (1-A) x R2 x SUM (Credits for Cu, Au, Pd, Pt, Ag)

where:

Ev the virgin material impact for the environmental parameter, computed as the total input material mass (kg) multiplied by the unit impact for the applicable virgin material dataset for the environmental parameter (impact/kg).

[33] MEErp _Ecoreport tool_v1.7.xlsx
European Commission, Joint Research Centre, Eynard, U., Ardente, F., Gama Caldas, M., Spiliotopoulos, C. and Mathieux, F., Ecoreport tool - Manual, Publications Office of the European Union, Luxembourg, 2024, https://data.europa.eu/doi/10.2760/473257, JRC133597.

[34] The ERT does not consider the impacts from incineration (with or without heat recovery), nor of landfilling, fugitive, or missing masses at EoL.

Erec — the recycled material impact for the environmental parameter, computed as the total input material mass (kg) multiplied by the unit impact for the applicable recycled material dataset for the environmental parameter (impact/kg).

R1 — (recycled content): the proportion of material in input to the production that has been recycled from a previous system.

R2 — (recycling output rate): the proportion of the material in the product that will be recycled in a subsequent system. R2 considers the efficiencies in the collection and recycling processes. R2 shall be measured at the output of the recycling plant.

A — the allocation factor apportions the burdens and credits between supplier and user of recycled materials. The “A” factor in the CFF allocates impacts and/or benefits between use of recycled materials as input (i.e. recycled content) and recycling at the end-of-life (i.e. recycling output rate). It avoids a situation of potential double counting due to recycled materials coming from these products being subsequently used in other products, or vice versa.

For electronics, a more complex formula is used to compute recycling benefits:

- For electronics, the amount of material in input to the production is often defined in square metres, linear metres or items. A conversion factor CF is used to convert the amount to a mass in kg.
- Each virgin material dataset for electronics has material credits defined for copper (Cu), gold (Au), palladium (Pd), platinum (Pt) and silver (Ag). These credits can be interpreted as mass shares. E.g. for dataset 133 (cable), the credit for copper is 0.195.
- Each material credit is multiplied by the unit impact for the considered parameter in the virgin material dataset for Cu (61), Au (75), Pd (81), Pt (82) or Ag (84), and the sum is multiplied by the recycled mass share CF x Amount x (1-A) x R2.
- Hence, for electronics, the recycling benefit is not related to e.g. avoided virgin cables, PWBs or LEDs, but to avoided virgin Cu, Au, Pd, Pt and Ag.

The ERT provides default values for R1, R2 and A that the user can accept or overwrite. The values for these parameters are discussed in the following sections. The values used are shown in Table 6 and Table 7.

5.2.2 Allocation factor A

The current study uses the default values for allocation factor A, which are 20% for metals and 50% for all other material types. Hence, for recycling of metals, only 20% of the benefits are assigned to the production phase, and 80% to the EoL phase. For plastic, electronics, and other materials the allocation is 50% production and 50% EoL.

5.2.3 Factor R1, recycled content

Plastics

For plastics, the ERT default value for factor R1 (recycled content) is 0%. PlasticsEurope [35] states that EEE products consumed 3.1 Mt of plastics in 2022, of which 3.2% (0.1 Mt) came from post-consumer recycled plastic. It is uncertain if this share would also be representative for personal computers, although

[35] https://plasticseurope.org/wp-content/uploads/2024/11/PE_TheFacts_24_digital-1pager.pdf
https://plasticseurope.org/knowledge-hub/the-circular-economy-for-plastics-a-european-analysis-2024/

many of the major brands are working on developing pioneering computer models that incorporate post-consumer recycled plastic (e.g., Acer, Apple, Dell).

For the base case laptop (notebook) computer, plastics constitute 15% or about 440 grams of the total mass of the machine. Table 8 provides a breakdown by type of plastic, including mass in grams, percentage of total plastic mass and percentage of total mass of all materials. Of these, polycarbonate (PC) is the common plastic, representing 92% of the plastic mass at 399.4 grams. Acrylonitrile Butadiene Styrene (ABS) is the second most common, at 5.3% of the mass and 23 grams. Polymethyl methacrylate (PMMA) is the third most common, at 2.3% and 10 grams. The other three plastics – silicone, polyethylene terephthalate (PET) and polyurethane flexible foam reaction of toluene diisocyanate (TDI) – are all less than 1%. For four of the plastics selected (PC, ABS, PMMA and PET), the default assumption is 0% recycled plastic content, which when viewed across the whole industry seems reasonable and thus has been used as the reference scenario. For two of the plastics (Silicone and TDI), there are no recycled plastic options available in the database, thus the default assumption is 0%.

Table 8. Plastics used in the basecase laptop computer (BC2) mass and percentages

Plastic Type	Mass of Plastic [grams]	Percent Total Plastic Mass of Laptop	Percent of Total Mass of Laptop
Polycarbonate (PC)	399.4	92%	13.9%
Acrylonitrile Butadiene Styrene (ABS)	23.0	5.3%	0.8%
Polymethyl methacrylate (PMMA)	10.0	2.3%	0.3%
Silicone	2.5	0.6%	0.1%
Polyurethane flexible foam reaction of toluene diisocyanate (TDI)	0.05	0.0%	0.0%
Polyethylene terephthalate (PET)	0.01	0.0%	0.0%

For the base case desktop computer, plastics constitute 32% of the total mass of the machine, or approximately 1.83 kilograms. Of these, polycarbonate (PC) is the common plastic, representing 51% of the plastic mass at 930 grams. Acrylonitrile Butadiene Styrene (ABS) is the second most common, at 49% of the mass and 900 grams. For both plastics, (PC and ABS), the default assumption is 0% recycled plastic content, which when viewed across the whole industry seems reasonable and thus has been used as the reference scenario.

Table 9. Plastics used in the basecase desktop computer (BC5) mass and percentages

Plastic Type	Mass of Plastic [grams]	Percent Total Plastic Mass of Desktop	Percent of Total Mass of Desktop
Polycarbonate (PC)	930.0	51%	16%
Acrylonitrile Butadiene Styrene (ABS)	900.0	49%	16%

In ECO scenarios, differing percentages of recycled plastic content (R1) were considered, with the percentages increased (i.e., 10%, 30%, 100%) and the differences in environmental impacts were recorded.

Metals

For the base case laptop (notebook) computer, metals constitute 50% or about 1.430 kilograms of the total mass of the machine. Of these, aluminium is the most common metal, with 1025 grams or about 72% of the metal content. Magnesium is the second most common at 200 grams or 14% of total mass of metals. Next is stainless steel, at 116 grams or about 8%. Ferrite (iron ore) is the fourth most common metal at 30 grams or about 2% of the metals. Copper is the next, at 26 grams and 2%, followed closely by brass at 25 grams and 2%. There are 10 grams of rare earths (1%) and 30 milligrams of gold, at 0.002% of the total mass of metals. In the basecase (reference) scenario, it is estimated that 30% of the aluminium is derived from recycled sources. All other metals are either 0% recycled (i.e., magnesium, stainless steel, copper, gold) or do not have a recycled option (i.e., ferrite (iron ore) and rare earths).

For the base case desktop computer, metals constitute 50% of the total mass of materials at 2.90 kilograms. Of the various types of metal in this computer, the largest quantity is stainless steel at approximately 1.78 kilograms or 62% of the total mass of metals. Aluminium is the second most common metal at 908 grams or 31.6%. Copper is the third most common metal, at 125 grams and 4.3% of total mass of metal. Ferrite (iron ore) is fourth at 35 grams and 1.2% of mass. Finally, brass and gold are the last two metals in the bill of materials, with 25 grams (0.9%) and 60 milligrams (0.002%), respectively.

In the ECO scenarios analysed for this study, adjustments were made to the recycled content of the metals (R1 values). Eurostat (End-of-Life Recycling Input Rates (EOL-RIR))[36] publishes estimates of rate at which certain materials are incorporating recycled content. The report doesn't cover all the materials of interest, however it does cover some of the important ones. The published value of recycled content (R1) in the Eurostat report for 2019 and 2022 (the most recent year available) are shown in the table below. The ERT had default values for copper, iron and magnesium as 0%, even though Eurostat found that these metals did incorporate recycled content. The table below presents the Eurostat values for 2019 and 2022, the default values for the ERT analytical tool, and finally the values that were used in this analysis for personal computers: 30% for aluminium, copper and iron and 10% for magnesium.

Table 10. End-of-life recycling input rates, Eurostat, EcoReport Tool and Personal Computers

Metal	Eurostat estimate for 2019	Eurostat estimate for 2022	EcoReport Tool v.1.7 default values	Personal Computers (R1 values used)
Aluminium	12%	32%	30%	30%
Copper	17%	55%	0%	30%
Iron	32%	31%	0%	30%
Magnesium	13%	13%	0%	10%

Electronics

Computers contain a lot of electronic parts and components. The bill of materials for the base case models of the laptop and desktop computers are discussed below.

For the base case laptop (notebook) computer, the electronics are approximately 33% of the mass, or 940 grams. Of all the electronic parts, the liquid crystal display on the laptop is the heaviest, constituting 45%

[36] Eurostat, 2023. "Contribution of recycled materials to raw materials demand - end-of-life recycling input rates (EOL-RIR)", online data code: cei_srm010 DOI: 10.2908/cei_srm010; last updated 11/05/2023. Accessed February 2025. Link: https://ec.europa.eu/eurostat/databrowser/view/cei_srm010$defaultview/default/table?lang=en

of the total mass of the electronics (422 grams). Printed wiring boards (PWB) are the next heaviest component, representing 36% of the mass of electronics (338 grams). Third most heavy are connectors for printing wiring boards, which are around 5.9% of the mass (56 grams). Cables are the next most significant component, at 5.1% (48 grams), followed by capacitors at 4.1% (39 grams). A SMD coil is next at 1.2% (11.6 grams). The remaining components are each less than 1% of the total mass of electronics, including diodes, solder paste, a controller board, and IC chips.

For the base case desktop computer, the electronics are the lightest component constituting 18% of the mass (1040 grams). Of all the electronic parts in this basecase desktop computer, the hard disk drive is the heaviest, constituting 30% of the total mass of the electronics, or 315 grams. Printed wiring boards are the second heaviest electrical item, at 26% of the electronics, or 268 grams. Next is cables at 14.5% or 150 grams, followed by 106 grams of connectors (10.2%). Integrated circuit chips are the next heaviest item at 73 grams or 7% of mass, followed by capacitors at 6% and 64 grams. Internal batteries are next, at 25 grams (2.4%), followed by an SMD coil at 23 grams and 2.2% of the mass of electronics.

For both laptop computers and desktop computers, the working assumption is that all the electronics being incorporated into the computers are new, therefore the R1 recycled content is set to 0% for all components on both basecase computers. This is a reasonable assumption, as new machines placed on the market are built with new components.

5.2.4 Factor R2, recycling output rate

The ERT specifies that the value for R2 (recycling output rate) shall take into account the efficiencies in the collection and recycling processes. The default values incorporated into the ERT were not adjusted for this analysis of personal computers.

<u>Plastics</u>

Based on bill of materials for the two base case model computers (i.e., laptop and desktop), the most popular plastics used in personal computers are polycarbonate (PC) and Acrylonitrile Butadiene Styrene (ABS). Beyond these two types of plastic, there is some use of Polymethyl methacrylate (PMMA), but in our analysis, that was only found in the laptop model, not the desktop. In the ERT, all three of these plastic types have their recycling output rates (R2) set to 0%. In the absence of any evidence to the contrary, this was the value used for all three plastic types. The other plastic types that are used are only found in trace amounts and thus it would not seem worthwhile to separate them at end of life, thus these are also assumed to have nothing recycled, i.e., R2=0%.

<u>Metals</u>

Based on the bill of materials, the most important metals in laptop computers are aluminium, magnesium, and stainless steel. On a mass of metal basis, the remaining metals are 2% or less. For a desktop computer, the most important metals are stainless steel, aluminium and copper. The remaining metals are 1.2% or less of the mass of metal.

For aluminium and steel, the ERT gives a default value of the recovered (recycled) output rate, R2, of 85%. The ERT's default R2 values for magnesium is "n.a." for not available and for copper it is set to 0%. However, it should be noted that if a computer is being recycled to recover the metals, the recycler would also work to recover the copper – which has a good value - so this assumption is incorrect.

For computers – both laptops and desktops – in our reference scenario, we have therefore set the recycling rate (R2) for these four metal types, aluminium, copper, magnesium and stainless steel to 50% which is aligned with the ERT recovery rate (R2) for electronics.

<u>Electronics</u>

For all electronics, the ERT establishes a default value of recovery of electronics (R2) at 50%. This includes the LCD display, printed wiring boards, connectors, cables, capacitors, SMD coils and other parts. This default collection rate (R2) in the ERT seems reasonable for the sector and therefore has not been adjusted.

5.3. Mass distributions for the baseline

Figure 1 shows the distribution of masses over all the material types for the laptop computer, BC2, based on the bill of materials presented in section 5.1.

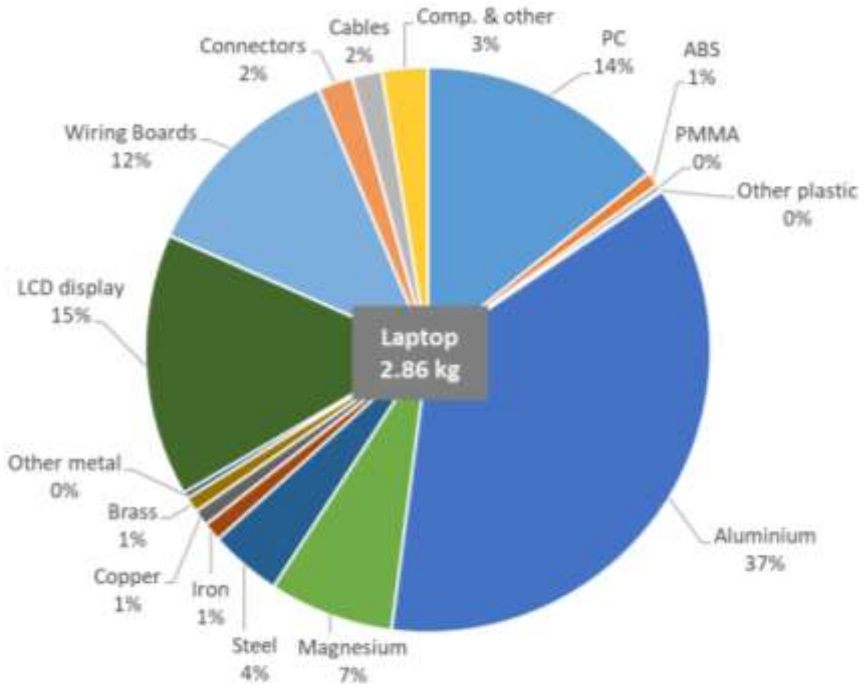


Figure 1: Percentage of total mass per material type for laptop (notebook) computer, BC2

Applying the baseline factors R1 (recycled content) of section 5.2.3 to laptop computers (BC2), approximately 0.4 kilograms, or about 14% of the materials in the laptop are derived from recycled sources, all from metals. Figure 2 shows the proportions of virgin (blue) and recycled (orange) materials used in the laptop computer.

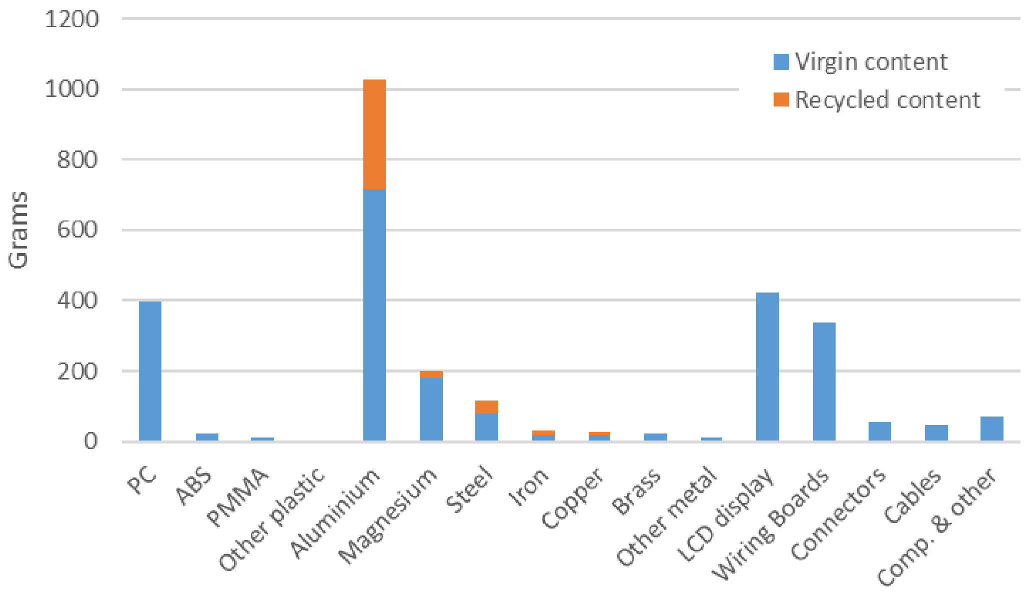


Figure 2: Virgin and recycled material in input, baseline, laptop computer BC2

Applying the baseline factors R2 (recycled at end of life) of section 5.2.4, approximately 1.2 kilograms, or about 42% of the materials in the laptop, are recovered at end of life. Figure 3 presents the total material inputs (purple) to the recycling outputs (green). The main sources of recycling output are aluminium, LCD display, wiring boards, magnesium and steel.

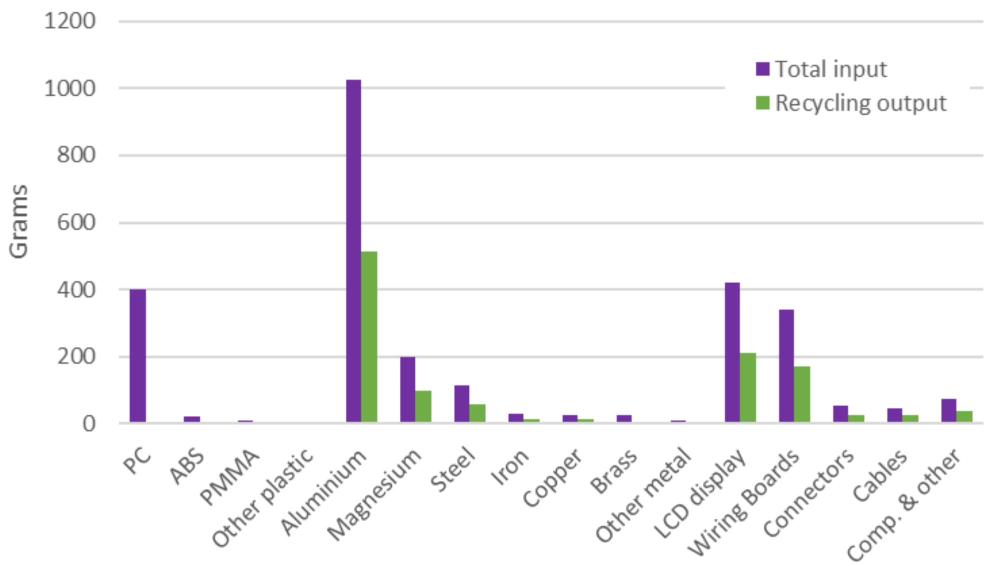


Figure 3: Total material input and recycled material output, baseline, laptop computer (BC2)

Figure 4 shows the distribution of masses over all the material types for the base case desktop computer, BC5, based on the bill of materials presented in section 5.1.

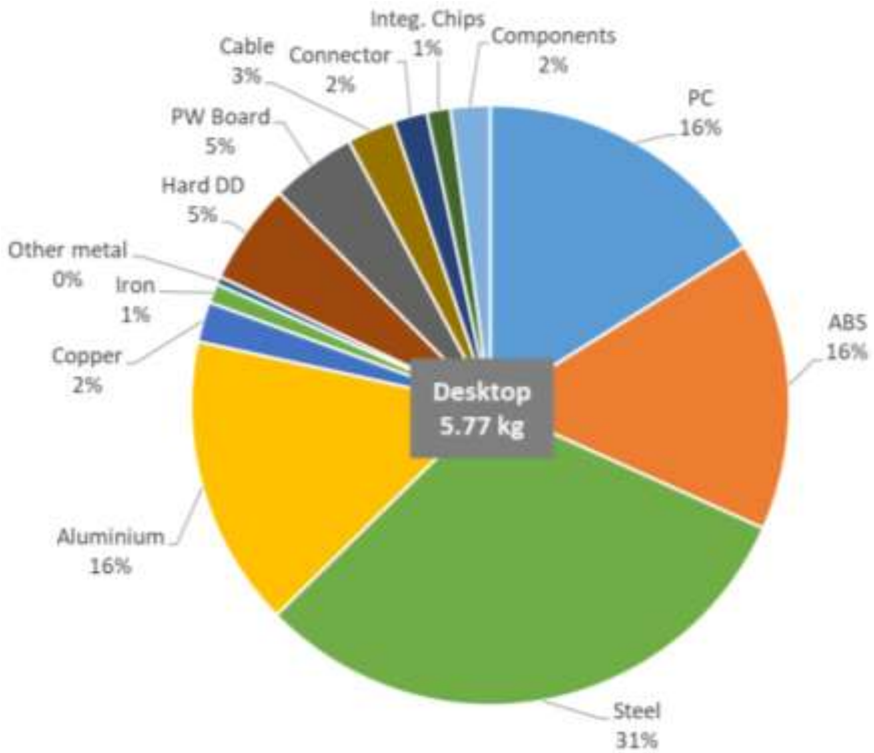


Figure 4: Percentage of total mass per material type for the base case desktop computer, BC5

Applying the baseline factors R1 (recycled content) of section 5.2.3 to base case desktop computers (BC5), approximately 0.86 kilograms, or about 15% of the materials in the desktop are derived from recycled sources, all from metals. Figure 5 shows the proportions of virgin (blue) and recycled (orange) materials used in the desktop computer.

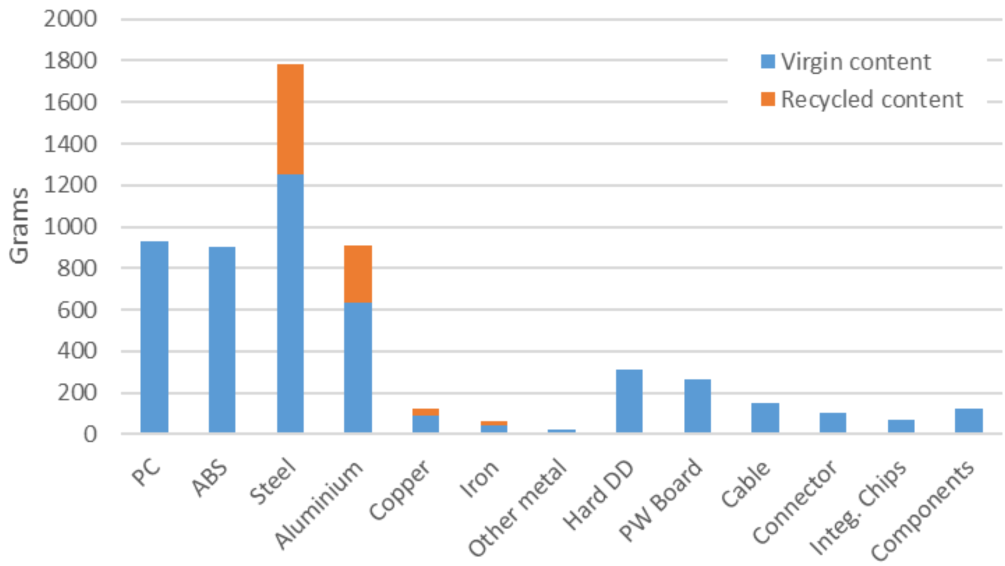


Figure 5: Virgin and recycled material in input, baseline, base case desktop computer BC5

Applying the baseline factors R2 (recycled at end of life) of section 5.2.4, approximately 2.0 kilograms, or about 34% of the materials in the desktop computer, are recovered at end of life. Figure 6 presents the total material inputs (purple) to the recycling outputs (green). The main sources of recycling output are steel, aluminium, hard disk drive, printed wiring board and cables.

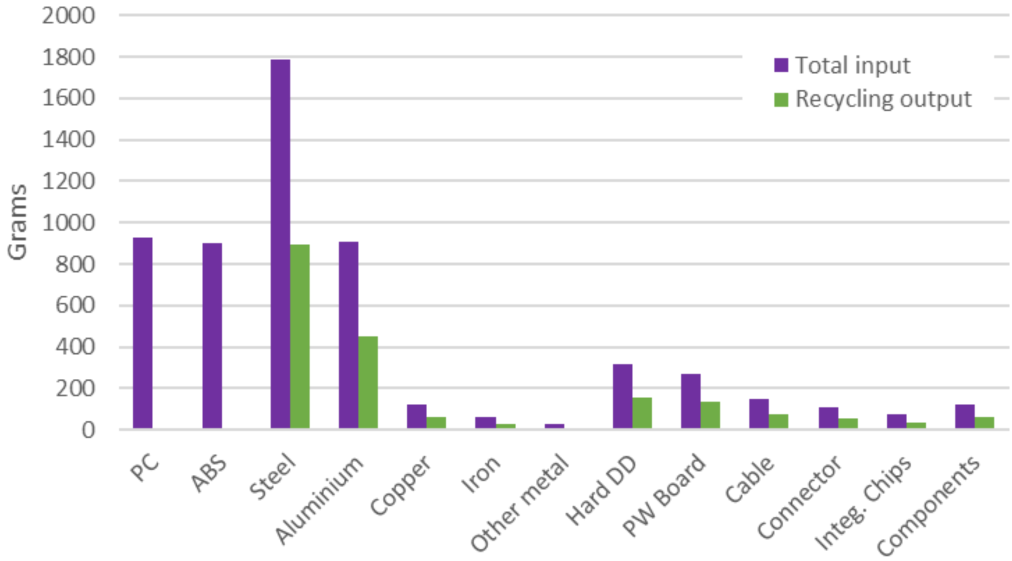


Figure 6: Total material input and recycled material output, baseline, base case desktop computer (BC5)

5.4. Environmental impacts for the baseline models

5.4.1 Laptop computer

The baseline environmental impacts for base case laptop computer (BC2) are given below. These results have been calculated using the 2024 EcoReportTool version 1.7. They are based on the BoM and factors R1, R2 and A of Table 6. Only impacts from raw materials and end-of-life impacts and credits have been considered [37].

Figure 7 provides the shares of each material category in the environmental impacts for raw materials and end-of-life impacts and credits for the reference scenario. Although electronic components (PCBs, cables, LED) represent approximately one-third of the weight of the laptop computer, they have the highest environmental impact shares for most parameters (green shaded bars). The two exceptions are 'ozone depletion' (primarily from other, which is glass), and 'land use' (primarily from metals). For 'land use' the impact from electronics is reported as negative which is considered an error, so it has been zeroed out.

[37] The current study focuses on material aspects. The impacts from manufacturing, distribution, use and repair and maintenance will be added later in the ongoing review study. They are assumed not to change due to requirements on recycled material content.

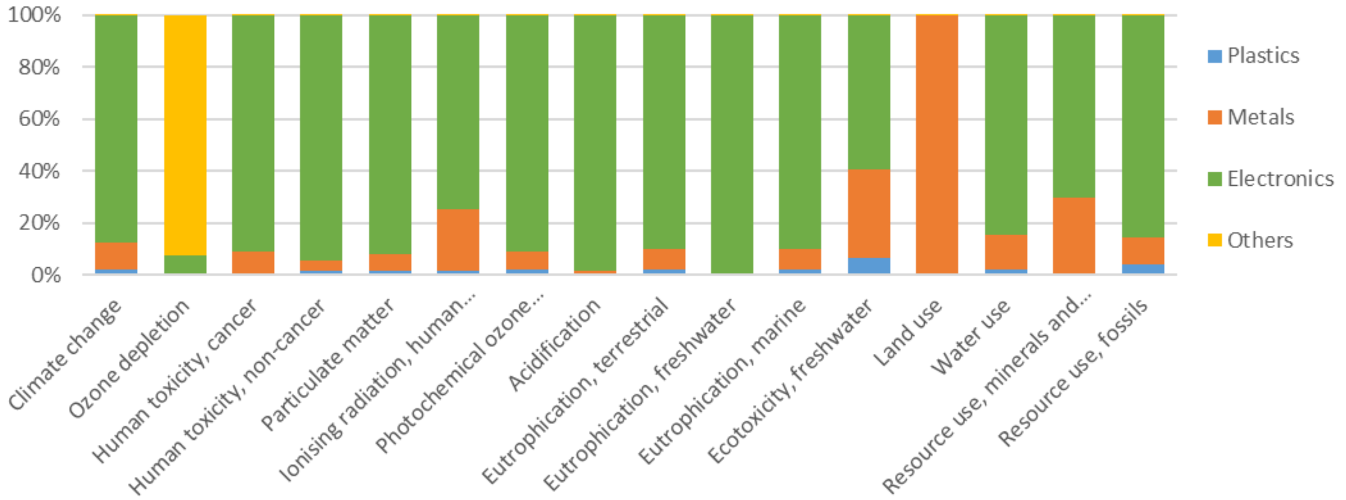


Figure 7: Shares of environmental impacts by material category, for laptop computer (BC2)

To provide more detail (i.e., with absolute values in the relevant units) on these impacts, the results are presented in tabular form below with the percentages of impact directly underneath the values. Due to the number of environmental indicators, the results are divided into two parts. The first part gives the mass and the impacts for the first 8 environmental parameters; the second part gives the impacts for the remaining 8 parameters [38]. Table 11 shows the total impacts, i.e. the sum of raw material impact, EoL impact and EoL credit for virgin material avoidance (negative impact), and the impact shares, per material category. Impact shares larger than 50% have been shaded in light blue.

[38] Impacts for 'primary energy consumption' are not shown, because here they are the same as for 'resource use, fossil'.

Table 11: Reference Environmental impacts for basecase laptop computer (BC2), computed using 2024 ERT, including impacts from raw materials and end-of-life impacts and benefits

Material	Mass	Climate change, total	Ozone depletion	Human toxicity, cancer	Human toxicity, non-cancer	Particulate matter	Ionising radiation, human health	Photo-chemical ozone formation, human health	Acidifi-cation
Units	*kg*	*kg CO2 eq*	*kg CFC-11 eq*	*CTUh*	*CTUh*	*disease incidence*	*kBq U235 eq*	*kg NMVOC eq*	*mol H+ eq*
Plastics	0.43	1.882	0.000	0.000	0.000	0.000	0.059	0.007	0.008
share	14.8%	1.9%	0.0%	0.7%	1.4%	1.5%	1.5%	2.1%	0.2%
Metals	1.52	12.461	0.000	0.000	0.000	0.000	1.378	0.027	0.058
share	51.6%	12.5%	1.1%	9.6%	5.4%	7.3%	35.0%	8.0%	1.4%
Electronics	0.92	85.481	0.000	0.000	0.000	0.000	2.489	0.301	4.103
share	31.5%	85.5%	6.9%	89.6%	93.1%	91.2%	63.2%	89.8%	98.4%
Others	0.06	0.111	0.000	0.000	0.000	0.000	0.011	0.000	0.000
share	2.0%	0.1%	92.0%	0.0%	0.1%	0.1%	0.3%	0.1%	0.0%
Total	**2.93**	**99.935**	**0.000**	**0.000**	**0.000**	**0.000**	**3.938**	**0.336**	**4.170**

Material	Eutrophication, terrestrial	Eutrophication, freshwater	Eutrophication, marine	Ecotoxicity, freshwater	Land use	Water use	Resource use, minerals and metals	Resource use, fossils
Units	*mol N eq*	*kg P eq*	*kg N eq*	*CTUe*	*pt*	*m3 water eq. of deprived water*	*kg Sb eq*	*MJ*
Plastics	0.023	0.000	0.002	29.662	1.660	0.359	0.000	43.392
share	2.2%	0.5%	2.2%	4.9%	0.5%	1.9%	0.0%	3.8%
Metals	0.096	0.000	0.009	292.205	409.509	3.521	0.002	148.552
share	9.0%	0.3%	8.8%	48.6%	113.8%	18.3%	29.7%	12.9%
Electronics	0.941	0.001	0.089	278.680	0.000	15.276	0.004	961.466
share	88.7%	99.0%	89.0%	46.4%	0.0%	79.6%	70.3%	83.3%
Others	0.001	0.000	0.000	0.643	0.171	0.035	0.000	1.500
share	0.1%	0.2%	0.1%	0.1%	0.0%	0.2%	0.0%	0.1%
Total	**1.06**	**0.001**	**0.10**	**601.19**	**359.74**	**19.19**	**0.006**	**1154.9**

5.4.1 Desktop computer

Figure 8 gives the shares of each material category in the environmental impacts for raw materials and end-of-life impacts and credits for the desktop computer (BC5) reference scenario. Although electronic components (PCBs, cables, LED) represent less than one-fifth of the total materials weight of the desktop computer, they have the highest environmental impact shares for most parameters (green shaded bars). The four exceptions are ‘human toxicity, cancer’, ‘ecotoxicity, freshwater’, ‘land use’ and ‘resource use, minerals and metals’ where the impact of metals dominate the impact in the reference case. For ‘land use’ the impact from electronics and for ‘water use’ the impact from plastics is reported as negative which is considered an error, so these two results have been zeroed out.

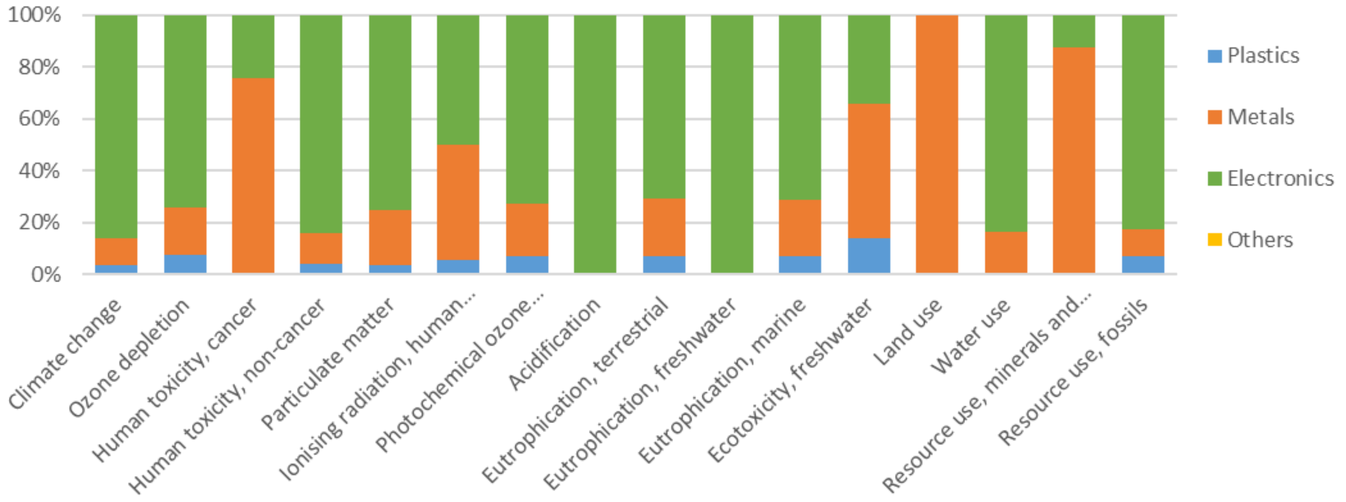


Figure 8: Shares of environmental impacts by material category, for desktop computer (BC5)

To provide more detail (i.e., with absolute values in the relevant units) on these impacts, the results are presented in tabular form below with the percentages of impact directly underneath the values. On the following page, Table 12 shows the total impacts, i.e. the sum of raw material impact, EoL impact and EoL credit for virgin material avoidance (negative impact), and the impact shares, per material category. Impact shares larger than 50% have been shaded in light blue.

Table 12: Reference Environmental impacts for basecase desktop computer (BC5), computed using 2024 ERT, including impacts from raw materials and end-of-life impacts and benefits

Material	Mass	Climate change, total	Ozone depletion	Human toxicity, cancer	Human toxicity, non-cancer	Particulate matter	Ionising radiation, human health	Photo-chemical ozone formation, human health	Acidifi-cation
Units	*kg*	*kg CO2 eq*	*kg CFC-11 eq*	*CTUh*	*CTUh*	*disease incidence*	*kBq U235 eq*	*kg NMVOC eq*	*mol H+ eq*
Plastics	1.83	6.867	0.000	0.000	0.000	0.000	0.232	0.022	0.025
share	31.9%	4.7%	2.0%	0.6%	5.4%	4.8%	7.9%	9.2%	0.1%
Metals	2.87	15.326	0.000	0.000	0.000	0.000	1.275	0.048	0.152
share	50.2%	10.4%	19.1%	75.1%	11.9%	20.7%	43.3%	20.0%	0.3%
Electronics	1.03	124.815	0.000	0.000	0.000	0.000	1.436	0.169	45.238
share	17.9%	84.9%	78.9%	24.3%	82.6%	74.5%	48.8%	70.8%	99.6%
Others	0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
share	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	5.73	147.008	0.000	0.000	0.000	0.000	2.942	0.239	45.415

Material	Eutrophication, terrestrial	Eutrophication, freshwater	Eutrophication, marine	Ecotoxicity, freshwater	Land use	Water use	Resource use, minerals and metals	Resource use, fossils
Units	*mol N eq*	*kg P eq*	*kg N eq*	*CTUe*	*pt*	*m3 water eq. of deprived water*	*kg Sb eq*	*MJ*
Plastics	0.073	0.000	0.007	100.634	7.480	-1.224	0.000	168.590
share	9.7%	0.2%	9.7%	18.5%	0.6%	-5.0%	0.0%	9.4%
Metals	0.163	0.000	0.015	266.973	1263.175	4.189	0.004	183.128
share	21.5%	0.1%	20.8%	49.1%	106.8%	17.0%	87.6%	10.2%
Electronics	0.522	0.013	0.049	176.034	0.000	21.662	0.001	1440.4
share	68.9%	99.8%	69.5%	32.4%	0.0%	88.0%	12.3%	80.4%
Others	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
share	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	0.758	0.013	0.070	543.6	1183.3	24.626	0.005	1792.1

5.5. Material costs for virgin vs. recycled plastic

According to information gathered during stakeholder interviews (see Figure 9) the difference between virgin and post-consumer recycled plastic has varied over the last five years. Virgin plastic is linked to the global price of oil while recycled plastic is linked to plastic recovery rates from waste streams and capacity within the recycling industry to process and prepare recyclates. Figure 9 provides the virgin and post-consumer recycled resin price for Acrylonitrile Butadiene Styrene (ABS) and High Impact Polystyrene (HIPS). The graph shows that by the end of 2024, the differences between virgin and post-consumer recycled ABS and HIPS material costs were small.

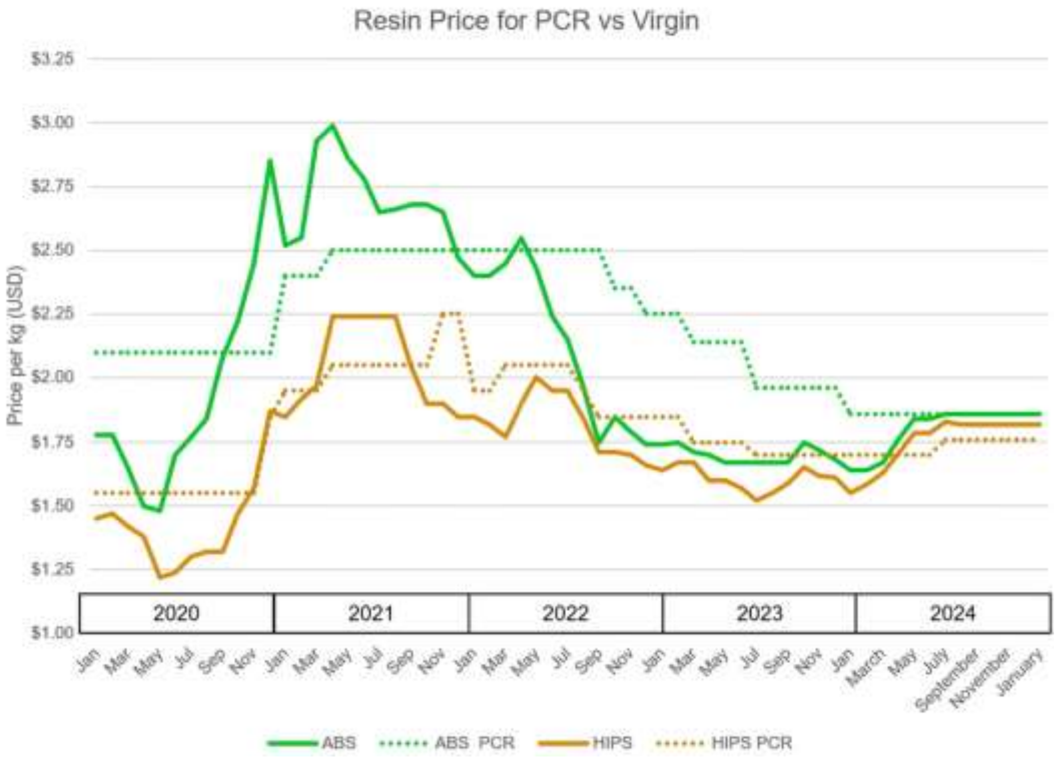


Figure 9: Comparison of prices for virgin and post-consumer recycled HIPS and ABS plastics

Figure 10 provides a comparison of four different plastics between the recycled price and the virgin price, presented in Euros per tonne for December 2024. For HDPE, injection moulding quality, the recycled plastic is €970 Euros/tonne while the virgin material is €1690 Euros/tonne. This represents a 42% reduction per tonne for the post-consumer recycled HDPE per tonne when compared to virgin HDPE.

Figure 10: Comparison of prices for virgin and post-consumer recycled plastics

Additional pricing information on virgin and recycled plastics was gathered from [Plastics Information Europe](#) (PIE) and [Market Report Plastics](#) (MRT). These data confirmed the price differences shown in Figure 10. Table 13 provides a comparison of the virgin and post-consumer prices for recycled plastics in the EU from February 2025. Where comparisons can be made, the cost per ton is lower for recycled material.

For polystyrene (PS), the Plastics Information Europe (PIE) price of virgin material ranges from 2090 to 2250 Euro, whereas the recycled price is from 1020 to 1150 Euro, representing a reduction of approximately 50% per ton when comparing recycled to virgin material. According to Market Report Plastics (MRP), polystyrene ranges from 1660 to 1810 Euro per ton, while the recycled polystyrene is 610 to 840 Euro, or approximately 60% less expensive per ton.

For polypropylene (PP), the MRP price of virgin material ranges from 1380 to 1510 Euro per ton, while the recycled is 240 to 870 per ton, a cost per ton reduction of 60-80%, depending on which one is selected.

For polyvinylchloride (PVC), the MRP price of virgin material ranges from 1110-1340 Euro per ton, while the recycled is priced at 290 to 410 Euro per ton, for PVC-P regrind and PVC-U regrind, respectively. This represents a savings of 67-76% when comparing the price of virgin plastic with recycled.

Table 13 Comparison of prices for virgin and post-consumer recycled plastics, February 2025
Source: Plastics Information Europe (PIE) and Market Report Plastics (MRP)

Prices in EUR/ton Jan/Feb 2025	PIE [39] , virgin	MRP [40], virgin	PIE, recycled	MRP, recycled
Polystyrene (PS)	€ 2090-2140 (GPPS)	€ 1660-1710 (PS crystal clear)		€ 610 (regrind)
	€ 2160-2240 (HIPS injection)	€ 1790-1810 (HIPS)	€ 1020-1150 (black rHIPS)	€ 840 (granulate)
	€ 2180-2250 (HIPS film/sheet)			
Polypropylene (PP)		€ 1380-1460 (homopolymer)		€ 240 (bale goods)
		€ 1430-1510 (copolymer)		€ 550 (regrind)
				€ 870 (granulate)
Acrylonitrile Butadiene Styrene (ABS)			€ 1620-1690 (industrial, black)	€ 650 (regrind)
				€ 1220 (regranulates)
Polyvinylchloride (PVC)		€ 1110-1210 (tube grade)		€ 290 (PVC-P regrind)
		€ 1240-1340 (film/cables)		€ 410 (PVC-U regrind)

During the interviews with manufacturers who are designing new consumer electronics to incorporate post-consumer recycled plastic, one of the engineers said their company was motivated to incorporate PCR plastic into their product lines for two principal reasons: (1) it helps with marketing their products to environmentally concerned consumers; and (2) it reduces their bill of materials since recycled plastic is less expensive per tonne. The engineer also commented on some of the differences in quality between virgin and recycled plastic that can occur, particularly for lighter shades of plastic including potential colour shifts or speckles of darker plastic. One solution to that issue was to use inks to dye the plastic to a dark shade such that any impurities causing colour variation in the recycled plastic are no longer visible to the end-user. Another engineer indicated that they were studying the potential to apply a thin layer of virgin plastic over parts made from PCR, and thereby avoiding any aesthetic issues associated with unwanted variability in the appearance of PCR.

Manufacturers are invited to comment on these prices and the costs associated with designing new personal computers incorporating post-consumer recycled plastic as opposed to designing new computers incorporating virgin plastic.

[39] Plastics Information Europe (PIE), website visited April 2025: https://pieweb.plasteurope.com/default.aspx?pageid=200

[40] Plasticker, the home of Plastics, website visited April 2025: https://plasticker.de/preise/marktbericht_en.php

5.6. Critical Raw Materials

The most recent list of Critical Raw Materials (CRMs) and Strategic Raw Materials (SRMs) were amended most recently by Regulation (EU) 2024/1252. The CRM list consists of raw materials meeting the requirements according to the published EU criticality methodology, while the Strategic Raw Materials (SRM) are primarily relevant for the green and digital transition as well as defence and aerospace applications. The updated list of CRMs and SRMs is given below. All materials listed are CRMs and those marked with a star ("*") are also SRMs:

> Antimony; arsenic; bauxite/alumina/aluminium; baryte; beryllium; bismuth*; boron*; cobalt*; coking coal; copper*; feldspar; fluorspar; gallium*; germanium*; hafnium; helium; heavy rare earth elements*; light rare earth elements*; lithium*; magnesium; manganese*; graphite*; nickel — battery grade*; niobium; phosphate rock; phosphorus; platinum group metals*; scandium; silicon metal*; strontium; tantalum; titanium metal*; tungsten* and vanadium.

Other non-CRM materials with high environmental impacts are e.g. gold, lead, molybdenum, rhenium, selenium, silver, tellurium and zinc.

The prioritization scores for environmental impacts have been examined for all materials together and separately per material category (plastics, ferrous metals, non-ferrous metals, coating / plating, electronics and miscellaneous).

For personal computers, the Phase 1 analysis identified the top five CRMs in this order:

- Tantalum
- Cobalt
- Palladium
- Bauxite/Aluminium
- Magnesium

Computers have most of their CRMs contained in the materials used on printed circuit boards (PCBs) inside the machines. However, PCBs are challenging to recycle because of the variety of materials they contain, including precious metals (e.g., gold, silver, and palladium), base metals (e.g., copper, aluminum, and tin), and hazardous substances (e.g., lead, mercury, epoxy resin containing brominated flame retardants)[41] Corroborating these findings. Other researchers[42] found that PCBs contain the following:

- Antimony: found in some lead-containing solders;
- Beryllium: small amounts found in connectors using as a copper-beryllium alloy (typically 98% copper, 2% beryllium);
- Cadmium: small amounts used in plated contacts and switches;
- Chlorine and/or Bromine: brominated and inorganic flame retardants may be in the PCBs; and
- Lead: found in solder and some electronic components.

Researchers found that mechanical treatment and separation of PCBs is essential for effective resource recovery and recycling, for both economic viability and environmental protection.[43] According to one study that looked at material composition, waste PCBs contained approximately 30% metallic material, 40%

[41] Hosseini, Pooya; Klauson, Artur; Hendrickx, Brent; Goljandin, Dmitri; Duflou, Joost R. (2024): Sustainable e-waste recycling: environmental impact assessment of novel waste PCBs separation. In: 2024 19th Biennial Baltic Electronics Conference (BEC): IEEE, S. 1–7.

[42] Tsydenova, Oyuna & Bengtsson, Magnus. (2009). Environmental and Human Health Risks Associated with the End-of-Life Treatment of Electrical and Electronic Equipment; Institute for Global Environmental Strategies (IGES), Integrated Waste Management and Resource Efficiency Project, 2108-11 Kamiyamaguchi, Hayama, Kanagawa, 240-0115, Japan. Link: https://www.researchgate.net/publication/281368370_Environmental_and_Human_Health_Risks_Associated_with_the_End-of-Life_Treatment_of_Electrical_and_Electronic_Equipment

[43] Hosseini, Pooya; Klauson, Artur; Hendrickx, Brent; Goljandin, Dmitri; Duflou, Joost R. (2024): Sustainable e-waste recycling: environmental impact assessment of novel waste PCBs separation. In: 2024 19th Biennial Baltic Electronics Conference (BEC): IEEE, S. 1–7.

organic resin materials and about 30% glass fibers used to reinforce the boards.[44] Of these, the metallic material consists of metals bound up in the circuitry (mainly copper), solder and lead frames (tin, iron and lead) and integrated circuits (gold, silver and palladium).[45] As an illustration of this, one paper found that a waste PCB from a computer contains 20% copper as well as 250 grams of gold and 110 grams of palladium per ton of waste PCBs.[46]

At this point in time two CRMs - namely, copper and aluminum, are regularly recovered from waste streams and re-introduced to the supply chain, offsetting virgin (mined) copper and aluminum. A number of research projects have been looking at recovery of CRMs from waste PCBs, and in particular, the recovery of palladium and antimony. Indeed, there specialist recycling companies who have started to recover palladium, as it can be collected as a by-product of the copper recovery process without significant extra cost. Therefore, beyond copper and aluminum which are already recovered, a third CRM that might be promoted by policy measures that support its recovery and reuse is palladium.

[44] Ionela Birloaga, Ida De Michelis, Francesco Ferella, Mihai Buzatu, Francesco Vegliò; Study on the influence of various factors in the hydrometallurgical processing of waste printed circuit boards for copper and gold recovery; Waste Management, Volume 33, Issue 4,, 2013, Pages 935-941, ISSN 0956-053X, https://doi.org/10.1016/j.wasman.2013.01.003.

[45] Ibid.

[46] Martinez-Ballesteros, Guadalupe; Valenzuela-García, Jesus Leobardo; Gómez-Alvarez, Agustin; Encinas-Romero, Martin Antonio; Mejía-Zamudio, Flerida Adriana; Rosas-Durazo, Aaron de Jesús; Valenzuela-Frisby, Roberto (2021): Recovery of Ag, Au, and Pt from Printed Circuit Boards by Pressure Leaching. In: Recycling 6 (4), S. 67. https://doi.org/10.3390/recycling6040067

6. MEErP Task 6, Design Options

6.1. Introduction and Timeline

This chapter describes the design options, linked to potential future Ecodesign requirements, for:

- Recycled plastic content in personal computers;
- Recyclability of personal computers at end of life; and
- Critical Raw Materials used in personal computers

This mini study on recycled content, recyclability and CRM for personal computers had a limited schedule and budget, therefore it relied primarily on interviews with stakeholders, preliminary data collection and EcoReport Tool analyses that will be handed over to the review study team working on personal computers for DG Energy. It is expected that the review study team will conduct further investigations into these and other policy options, conduct additional data collection and analysis, and address any comments received from this stakeholder consultation, incorporating the final recommendations into the Commission's Working Document for a new regulation on personal computers.

6.2. Design options for recycled plastic content in products/parts

In order to support the development of a circular economy, it is desirable to require that recycled plastics used in new products are derived from post-consumer recycled (PCR) sources. Requiring the use of PCR plastic is likely to stimulate post-consumer waste collection and investment in recycling capacity by increasing demand for recycled materials. Pre-consumer waste recovery practices are not expected to benefit from additional requirements. This analysis has focused on post-consumer recycled plastics and is aligned with article 7 of the packaging and packaging waste regulation (PPWR) [47] and article 29 of the Critical Raw Materials Act [48].

If they have not already done so, recyclers would have to set up and maintain an accounting system of incoming waste materials, such that they could provide documentation on the traceability of the origins of recycled material from post-consumer waste streams. Such traceability would be important for market surveillance authorities later when recycled plastic requirements are in place and need to be verified.

6.2.1 Policy Options for recycled plastic content requirements

There are a few different policy options that can be used to set out requirements on recycled plastic content of personal computers. The following are four potential approaches:

1. Based on the total mass of the finished product;
2. Based on the total mass of plastic in the finished product;
3. Based on the total mass of plastic in a specific component or part in the product; or
4. Based on specific type(s) of plastic used in the finished product.

[47] REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on packaging and packaging waste, amending Regulation (EU) 2019/1020 and Directive (EU) 2019/904, and repealing Directive 94/62/EC, Brussels, 4 December 2024, PE-CONS 73/24

[48] Critical Raw Materials Act: REGULATION (EU) 2024/1252 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 11 April 2024 establishing a framework for ensuring a secure and sustainable supply of critical raw materials and amending Regulations (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1724 and (EU) 2019/1020, OJ 3.5.2024

Examples of each of these options requiring the use of recycled plastic content are presented below, assuming there would be one date and one level of recycled content required. These same options could also be given in two or more stages of a regulatory measure if the requirements were drafted to phase-in gradually over time. The phrase “new personal computer models” was selected to reflect the fact that the requirements shall apply to new models that are first placed on the market on or after the date given. In other words, the requirement(s) would not apply to products that were first placed on the market before that date and are still offered for sale.

Option 1: Based on the total mass of the finished product

For this option, the requirements could be drafted to read as follows:

> Starting on 1 January 20XX, any new personal computer models placed on the market shall contain at least XX% of recycled plastic recovered from post-consumer waste. This percentage of recycled plastic shall be calculated as the mass of post-consumer recycled plastic contained in the product divided by the total mass of the product as sold, excluding packaging.

Option 2: Based on the total mass of plastic in the finished product

For this option, the requirements could be drafted to read as follows:

> Starting 1 January 20XX, any new personal computer models placed on the market shall contain at least XX% of recycled plastic recovered from post-consumer waste. This percentage of recycled plastic shall be calculated as the mass of post-consumer recycled plastic contained in the product divided by the total mass of plastic (both virgin and recycled) contained in the product as sold, excluding packaging.

Option 3: Based on the total mass of plastic in a specific component or part in the product;

For this option, the requirements could be drafted to read as follows:

> Starting 1 January 20XX, any new personal computer models placed on the market that have a plastic casing shall contain at least XX% of recycled content in the plastic used for that casing.

Option 4: Based on specific type(s) of plastic used in the finished product

For this option, the requirements could be drafted to read as follows:

> Starting 1 January 20XX, any new personal computer models placed on the market shall contain at least the following percentages of recycled content recovered from post-consumer waste, for the plastic types indicated, if they are present in the product:
>
> - Polystyrene (PS), any type XX%
> - Polypropylene (PP) YY%
> - Acrylonitrile butadiene styrene (ABS) ZZ%
>
> The percentage recycled content shares shall be computed as the mass of post-consumer recycled plastic contained in the product for the plastic type concerned divided by the total plastic mass contained in the product as placed on the market, for the plastic type concerned, excluding packaging.

6.2.2 Impact reduction due to recycled content

This section discusses the reduction in environmental impacts for a unit product when the post-consumer recycled content (factor R1) for plastics is raised from 0% (baseline) to 10% and to 30%. These levels have been selected as being representative of realistic levels for recycled content for computers. Data are for a unit product of base case laptop computer (BC2) and desktop computer (BC5) with the BoM presented earlier in this chapter. As the reduction increases linearly with the recycled content, these data can later be multiplied by a factor to simulate the effect of higher recycled content requirements (see chapter 7 on scenario analysis).

Like the previously reported impacts for the baseline, only impacts from input materials, EoL impacts and EoL benefits are considered (no manufacturing, distribution, use, repair and maintenance). Please see section 7.1 in this report for a comparison of the material and EoL impacts relative to energy-in-use.

Compared to the baseline, only the factors R1 for recycled content have been changed. Factors R2 (recycling output) and A (allocation factor) remain the same. This implies that EoL impact and EoL benefit do not change compared to the baseline: only the impact of materials in input to the production changes with R1. Table 14 provides the top-level reduction of environmental impacts compared to the reference case, when 10% and 30% recycled content (instead of 0%) is used for plastics. As before, the table is split in two parts, showing results for different impact categories.

The total mass of the laptop is 2.93 kg, of which about 15% is plastic. When the plastic in that computer is replaced with 10% and 30% post-consumer recycled plastic, the environmental impacts per laptop reduce by tenths of a percent. The reason for this limited impact is due to the small quantity of plastic in the base case reference laptop and the high environmental impact of the electronics.

Table 14: Summary of the reduction of environmental impacts compared to the baseline, when using 10% and 30% recycled content in input to the production for plastics for laptop computer (BC2)

Material	Climate change, total	Ozone depletion	Human toxicity, cancer	Human toxicity, non-cancer	Particulate matter	Ionising radiation, human health	Photochemical ozone formation, human health	Acidification
Units	*kg CO2 eq*	*kg CFC-11 eq*	*CTUh*	*CTUh*	*disease incidence*	*kBq U235 eq*	*kg NMVOC eq*	*mol H+ eq*
10% recycled plastic (R1)								
Change:	0.07	-0.00	0.00	0.00	0.00	0.00	0.00	0.00
Reference	99.93	0.00	0.00	0.00	0.00	3.94	0.34	4.17
% change	0.07%	-0.02%	0.03%	0.03%	0.06%	0.11%	0.10%	0.01%
30% recycled plastic (R1)								
Change:	0.20	-0.00	0.00	0.00	0.00	0.01	0.00	0.00
Reference	99.93	0.00	0.00	0.00	0.00	3.94	0.34	4.17
% change	0.20%	-0.07%	0.10%	0.09%	0.18%	0.32%	0.30%	0.03%

Material	Eutrophication, terrestrial	Eutrophication, freshwater	Eutrophication, marine	Ecotoxicity, freshwater	Land use	Water use	Resource use, minerals and metals	Resource use, fossils
Units	*mol N eq*	*kg P eq*	*kg N eq*	*CTUe*	*pt*	*m3 water eq. of deprived water*	*kg Sb eq*	*MJ*
10% recycled plastic (R1)								
Change:	0.00	-0.00	0.00	1.45	-0.01	0.01	-0.00	2.19
Reference	1.06	0.00	0.10	601.19	359.74	19.19	0.01	1,154.91
% change	0.10%	-0.04%	0.10%	0.24%	0.00%	0.07%	0.00%	0.19%
30% recycled plastic (R1)								
Change:	0.00	-0.00	0.00	4.35	-0.02	0.04	-0.00	6.56
Reference	1.06	0.00	0.10	601.19	359.74	19.19	0.01	1,154.91
% change	0.31%	-0.13%	0.30%	0.72%	-0.01%	0.22%	-0.01%	0.57%

Table 15 provides the top-level reduction of environmental impacts compared to the reference case, when 10% and 30% recycled content (instead of 0%) is used for plastics. As before, the table is split in two parts, showing results for different impact categories.

The total mass of the desktop is 5.73 kg, of which about 32% is plastic. When the plastic in that computer is replaced with 10% and 30% post-consumer recycled plastic, the environmental impacts per desktop reduce by a few percentage points. The reason for this limited impact is due to the small quantity of plastic in the base case reference laptop and the high environmental impact of the electronics.

Table 15: Summary of the reduction of environmental impacts compared to the baseline, when using 10% and 30% recycled content in input to the production for plastics for desktop computer (BC5)

Material	Climate change, total	Ozone depletion	Human toxicity, cancer	Human toxicity, non-cancer	Particulate matter	Ionising radiation, human health	Photochemical ozone formation, human health	Acidification
Units	*kg CO2 eq*	*kg CFC-11 eq*	*CTUh*	*CTUh*	*disease incidence*	*kBq U235 eq*	*kg NMVOC eq*	*mol H+ eq*
10% recycled plastic (R1)								
Change:	0.27	-0.00	0.00	0.00	0.00	0.01	0.00	0.00
Reference	147.01	0.00	0.00	0.00	0.00	2.94	0.24	45.41
% change	0.18%	-1.02%	0.02%	0.25%	0.19%	0.38%	0.42%	0.00%
30% recycled plastic (R1)								
Change:	0.81	-0.00	0.00	0.00	0.00	0.03	0.00	0.00
Reference	147.01	0.00	0.00	0.00	0.00	2.94	0.24	45.41
% change	0.55%	-3.05%	0.07%	0.74%	0.58%	1.15%	1.27%	0.01%

Material	Eutrophication, terrestrial	Eutrophication, freshwater	Eutrophication, marine	Ecotoxicity, freshwater	Land use	Water use	Resource use, minerals and metals	Resource use, fossils
Units	*mol N eq*	*kg P eq*	*kg N eq*	*CTUe*	*pt*	*m3 water eq. of deprived water*	*kg Sb eq*	*MJ*
10% recycled plastic (R1)								
Change:	0.00	-0.00	0.00	4.92	0.15	-0.07	-0.00	8.23
Reference	0.76	0.01	0.07	543.64	1,183.28	24.63	0.00	1,792.09
% change	0.45%	-0.01%	0.45%	0.90%	0.01%	-0.30%	-0.01%	0.46%
30% recycled plastic (R1)								
Change:	0.01	-0.00	0.00	14.75	0.46	-0.22	-0.00	24.70
Reference	0.76	0.01	0.07	543.64	1,183.3	24.63	0.00	1,792.09
% change	1.34%	-0.02%	1.35%	2.71%	0.04%	-0.89%	-0.04%	1.38%

6.3. Design options for recyclability

Another measure to support the development of a circular economy in Europe is to promote design options that facilitate recyclability of products at the end of life. This includes techniques such as designing products to be easily disassembled, for parts and materials to be individually marked to facilitate sorting, and for any critical raw materials (CRMs) to be easily identified to maximise the potential for recovery.

The overall recyclability calculation for the EU market is based on two key factors – the collection rate of used personal computers and the percentage of that recovered used equipment that can ultimately be separated, sorted and recycled. In the EcoReport Tool, the percentage recyclability referenced only takes into consideration the second of these factors – namely, the amount of material that can be recovered from a unit at the end of life. The levels discussed in Chapter 5 contemplate 10% and 30% recyclability, meaning that 10% or 30% of the material contained in the finished product at end of life is recovered for reuse.

For personal computers, recyclers generally separate before shredding mainly on economic grounds. If a component or material is valuable and easy to access and separate, this will be done, otherwise it will be shredded together with the rest, and the materials will be recovered from post-shredder separation processes. The advantage to separating before shredding is that it enables the recycler to isolate or increase the concentration of a desired material as opposed to having it diluted with all the other material of the product. Another reason to separate before shredding can be that a component could cause problems in the shredder (e.g. high-energy Li-ion batteries can cause a fire in the shredder).

Product separation of parts such as PCB boards or metal frames can be useful especially if the separated components or materials are subsequently processed on separate recycling lines or sold to a specialist recycler. If the separated components are processed in-house, additional parallel processing lines may be necessary, or the main processing lines would alternately have to process the different material types.

To address recyclability of the product at end of life, Table 16 sets out a system by which products can be designed for disassembly. This is a point scoring system based on an approach similar to the one used in the study for a potential photovoltaic and inverters recyclability index. Policy options on recyclability could be based around either a minimum value, a mandatory point score or to make it an information requirement with a view to making it mandatory in the next review.

Table 16. Overview of approaches to address recyclability at end of life for personal computers

Type	#	Parameter	Principle	Notes
Service-related Parameters	1	Information on presence (or absence) of substances of concern	Scoring based on presence of clear and durable information on presence (or absence) of substances of concern	Easy ID of substances that might hinger recycling or need special care
	2	Dismantling information and condition for access	Scoring based on information provided (e.g., a dismantling map, step-by-step instructions for priority parts)	Manufacturer facilitates dismantling and further recovery of materials
	3	Information on composition	Scoring based on disclosure of material composition of the product; points based on percentage of mass of product disclosed	Recyclers get valuable information regarding expected yield
	4	Information on CRMs and SRMs	Scoring based on disclosure of the quantity and location of CRMs and SRMs in the product	Recyclers get valuable information regarding expected yield
Dismantling Related Parameters	5	Number of steps for the dismantling of priority parts (dismantling depth)	Scoring based on the number of dismantling steps (N) to reach and remove specific priority parts	Number of steps to dismantle a component can be a proxy of the disassembly complexity
	6	Type of tools needed to dismantle priority parts	Level of complexity in terms of tools needed for dismantling a priority part, from low to high complexity. No tools, basic tools, commercial tools, proprietary tools.	Tools needed to dismantle a component can be a proxy of the disassembly complexity
Material based parameters	7	Level of concentration of hazardous substances and other substances affecting the recycling process	Scoring based on different concentration levels of substances (e.g. Antimony or F-containing materials, brominated flame retardants). Scores from maximum in case of total avoidance to lower scores based on the level of presence.	Avoid / reduce the cost and risks linked to depollution activities
	8	Selection of materials based on recyclability complexity	Score based on positive design for recyclability / easiness to be recycled.	Materials that by themselves are easy to recycle and reduce costs at the end of life
	9	Combination of materials used / homogeneity	Scoring based on the way different materials are combined in single parts and aims to award design based on homogeneous or separable materials	Different materials in a component can mean more difficult material separation for recycling

The design options considered are intended to facilitate the recovery of materials at the end of life – including critical raw materials (CRMs) – and thereby achieve the targets modelled in in the EcoReport Tool for the assumed recyclability rates.

Measures for consideration include:

- Design for disassembly – enable the separation of different material types used in a single part or component;
- Require marking the different types of plastic to facilitate sorting (similar to what is done for packaging);
- PCBs larger than 10 cm^2 and boards containing batteries or wet capacitors should be easily removable for recyclers;

- Forbid the use of halogenated flame retardants, and require a marking for plastics containing flame retardants, like the regulation for electronic displays

Recyclers seem to be in favour of measures that facilitate the identification and separation of components before shredding. Recyclers may support this approach because it will afford them more options in the future, and could increase the economic viability of further process automation.

6.3.1 Impact reduction due to recyclability of plastic

This section discusses the reduction in environmental impacts for a unit product when the recyclability at end of life (factor R2) for plastics is raised from 0% (baseline) to 10% and to 30%. Data are for a unit product of base case laptop computer (BC2) and desktop computer (BC5) with the BoM presented earlier in this chapter. As the reduction increases linearly with the recycled content, these data can later be multiplied by a factor to simulate the effect of higher recycled content requirements (see chapter 7 on scenario analysis).

Like the previously reported impacts for the baseline, only impacts from input materials, EoL impacts and EoL benefits are considered (no manufacturing, distribution, use, repair and maintenance).

Compared to the baseline, only the factors R2 for recyclability have been changed. Factors R1 (recycled content) and A (allocation factor) remain the same. Table 17 provides the top-level reduction of environmental impacts compared to the reference case, when 10% and 30% recyclability (instead of 0%) is used for plastics. As before, the table is split in two parts, showing results for different impact categories.

The total mass of the basecase laptop is 2.93 kg, of which about 15% is plastic. When the plastic in that computer is recovered at the end of life, the environmental impacts per laptop reduce by a few tenths of a percent. The reason for this very small change is due to the small quantity of plastic in the base case reference laptop and the high environmental impact of the electronics.

Table 17: Summary of the reduction of environmental impacts compared to the baseline, when the recyclability of plastics is increased to 10% and 30% by mass for a laptop computer (BC2)

Material	Climate change, total	Ozone depletion	Human toxicity, cancer	Human toxicity, non-cancer	Particulate matter	Ionising radiation, human health	Photochemical ozone formation, human health	Acidification
Units	*kg CO2 eq*	*kg CFC-11 eq*	*CTUh*	*CTUh*	*disease incidence*	*kBq U235 eq*	*kg NMVOC eq*	*mol H+ eq*
10% recyclability of plastic (R2)								
Change:	0.0674	-0.0000	0.0000	0.0000	0.0000	0.0041	0.0003	0.0004
Reference	99.9349	0.0000	0.0000	0.0000	0.0000	3.9377	0.3356	4.1697
% change	0.07%	-0.02%	0.03%	0.03%	0.06%	0.11%	0.10%	0.01%
30% recyclability of plastic (R2)								
Change:	0.2021	-0.0000	0.0000	0.0000	0.0000	0.0124	0.0010	0.0012
Reference	99.9349	0.0000	0.0000	0.0000	0.0000	3.9377	0.3356	4.1697
% change	0.20%	-0.07%	0.10%	0.09%	0.18%	0.32%	0.30%	0.03%

Material	Eutrophication, terrestrial	Eutrophication, freshwater	Eutrophication, marine	Ecotoxicity, freshwater	Land use	Water use	Resource use, minerals and metals	Resource use, fossils
Units	*mol N eq*	*kg P eq*	*kg N eq*	*CTUe*	*pt*	*m3 water eq. of deprived water*	*kg Sb eq*	*MJ*
10% recyclability of plastic (R2)								
Change:	0.0011	-0.0000	0.0001	1.4511	-0.0079	0.0138	-0.0000	2.1872
Reference	1.0606	0.0014	0.0997	601.1903	359.7403	19.1912	0.0057	1,154.9
% change	0.10%	-0.04%	0.10%	0.24%	0.00%	0.07%	0.00%	0.19%
30% recyclability of plastic (R2)								
Change:	0.0033	-0.0000	0.0003	4.3534	-0.0238	0.0414	-0.0000	6.5616
Reference	1.0606	0.0014	0.0997	601.19	359.74	19.1912	0.0057	1,154.91
% change	0.31%	-0.13%	0.30%	0.72%	-0.01%	0.22%	-0.01%	0.57%

Table 18 provides the top-level reduction of environmental impacts compared to the reference case, when 10% and 30% recyclability of plastics (instead of 0%) is used. As before, the table is split in two parts, showing results for different impact categories.

The total mass of the desktop is 5.73 kg, of which about 32% is plastic. When the plastic in that computer is recovered at end of life at two different levels - 10% and 30% - the environmental impacts per desktop reduce by a few percentage points. The reason for this very small change is due to the small quantity of plastic in the base case reference laptop and the high environmental impact of the electronics.

Table 18: Summary of the reduction of environmental impacts compared to the baseline, when the recyclability of plastics is increased to 10% and 30% by mass for a desktop computer (BC5)

Material	Climate change, total	Ozone depletion	Human toxicity, cancer	Human toxicity, non-cancer	Particulate matter	Ionising radiation, human health	Photochemical ozone formation, human health	Acidification
Units	*kg CO2 eq*	*kg CFC-11 eq*	*CTUh*	*CTUh*	*disease incidence*	*kBq U235 eq*	*kg NMVOC eq*	*mol H+ eq*
10% recyclability of plastic (R2)								
Change:	0.27	-0.00	0.00	0.00	0.00	0.01	0.00	0.00
Reference	147.01	0.00	0.00	0.00	0.00	2.94	0.24	45.41
% change	0.18%	-1.02%	0.02%	0.25%	0.19%	0.38%	0.42%	0.00%
30% recyclability of plastic (R2)								
Change:	0.81	-0.00	0.00	0.00	0.00	0.03	0.00	0.00
Reference	147.01	0.00	0.00	0.00	0.00	2.94	0.24	45.41
% change	0.55%	-3.05%	0.07%	0.74%	0.58%	1.15%	1.27%	0.01%

Material	Eutrophication, terrestrial	Eutrophication, freshwater	Eutrophication, marine	Ecotoxicity, freshwater	Land use	Water use	Resource use, minerals and metals	Resource use, fossils
Units	*mol N eq*	*kg P eq*	*kg N eq*	*CTUe*	*pt*	*m3 water eq. of deprived water*	*kg Sb eq*	*MJ*
10% recyclability of plastic (R2)								
Change:	0.00	-0.00	0.00	4.92	0.15	-0.07	-0.00	8.23
Reference	0.76	0.01	0.07	543.64	1,183.28	24.63	0.00	1,792.09
% change	0.45%	-0.01%	0.45%	0.90%	0.01%	-0.30%	-0.01%	0.46%
30% recyclability of plastic (R2)								
Change:	0.01	-0.00	0.00	14.75	0.46	-0.22	-0.00	24.70
Reference	0.76	0.01	0.07	543.64	1,183	24.63	0.00	1,792.09
% change	1.34%	-0.02%	1.35%	2.71%	0.04%	-0.89%	-0.04%	1.38%

6.4. Impact reduction from both recycled content and recyclability of plastic

This section discusses the combined reduction in environmental impacts for a unit product when both the recycled content (R1) factor and the recyclability at end of life (R2) factor for plastics are increased from 0% (baseline) to 10%, 30% and 100%. Like the previously reported impacts for the baseline, only impacts from changing the material inputs (i.e., plastic) and the EoL impacts and the EoL benefits are considered (no manufacturing, distribution, use, repair and maintenance). Compared to the baseline, both factors R1 and R2 have been adjusted. The A (allocation factor) remains the same.

Figure 11 presents the results for two of the fifteen environmental indicators, Climate change and Ecotoxicity, Freshwater. Plastic only constitutes 15% of the total mass of the laptop, therefore the impacts of increasing recycled content and recyclability have a limited effect on the overall environmental impact of the materials used in this laptop.

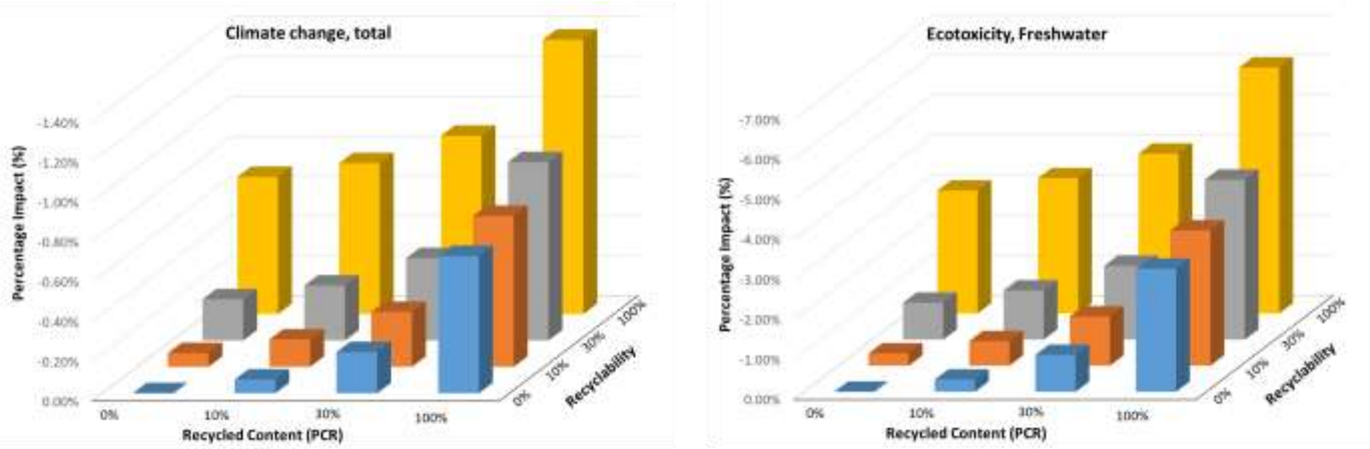


Figure 11: Impact Improvement of Climate Change and Ecotoxicity (Freshwater) for increasing recycled content and recyclability of the basecase laptop computer (BC2)

Table 19 presents the numerical results for all environmental indicators for the basecase laptop computer. The range of impacts varies from slightly more environmentally damaging (e.g., ozone depletion, resource use, minerals and metals) to being more environmentally friendly (e.g., ecotoxicity, freshwater, or resource use, fossils). In general, however, most of the environmental indicators indicate very modest changes with the increasing quantities of recycled plastic and higher levels of recyclability.

Table 19: All environmental indicators for recycled / recyclability plastic for a laptop computer (BC5)

PEF Impact categories	Content 0%, recyclability 0%	Content 10%, recyclability 0%	Content 30%, recyclability 0%	Content 100%, recyclability 0%	Content 0%, recyclability 10%	Content 10%, recyclability 10%	Content 30%, recyclability 10%	Content 100%, recyclability 10%	Content 0%, recyclability 30%	Content 10%, recyclability 30%	Content 30%, recyclability 30%	Content 100%, recyclability 30%	Content 0%, recyclability 100%	Content 10%, recyclability 100%	Content 30%, recyclability 100%	Content 100%, recyclability 100%
Climate change, total	0.0%	-0.1%	-0.2%	-0.7%	-0.1%	-0.1%	-0.3%	-0.8%	-0.2%	-0.3%	-0.4%	-0.9%	-0.7%	-0.8%	-0.9%	-1.4%
Ozone depletion	0.0%	0.0%	0.1%	0.2%	0.0%	0.0%	0.1%	0.3%	0.1%	0.1%	0.1%	0.3%	0.2%	0.3%	0.3%	0.5%
Human toxicity, cancer	0.0%	0.0%	-0.1%	-0.3%	0.0%	-0.1%	-0.1%	-0.4%	-0.1%	-0.1%	-0.2%	-0.4%	-0.3%	-0.4%	-0.4%	-0.7%
Human toxicity, non-can	0.0%	0.0%	-0.1%	-0.3%	0.0%	-0.1%	-0.1%	-0.3%	-0.1%	-0.1%	-0.2%	-0.4%	-0.3%	-0.3%	-0.4%	-0.6%
Particulate matter	0.0%	-0.1%	-0.2%	-0.6%	-0.1%	-0.1%	-0.2%	-0.7%	-0.2%	-0.2%	-0.4%	-0.8%	-0.6%	-0.7%	-0.8%	-1.2%
Ionising radiation, huma	0.0%	-0.1%	-0.4%	-1.2%	-0.1%	-0.2%	-0.5%	-1.4%	-0.4%	-0.5%	-0.7%	-1.6%	-1.2%	-1.4%	-1.6%	-2.5%
Photochemical ozone fo	0.0%	-0.1%	-0.3%	-1.0%	-0.1%	-0.2%	-0.4%	-1.1%	-0.3%	-0.4%	-0.6%	-1.3%	-1.0%	-1.1%	-1.3%	-2.0%
Acidification	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	-0.1%	-0.1%	-0.1%	-0.1%	-0.1%	-0.2%
Eutrophication, terrestri	0.0%	-0.1%	-0.3%	-1.0%	-0.1%	-0.2%	-0.4%	-1.1%	-0.3%	-0.4%	-0.6%	-1.3%	-1.0%	-1.1%	-1.3%	-2.1%
Eutrophication, freshwat	0.0%	0.0%	0.1%	0.4%	0.0%	0.1%	0.2%	0.5%	0.1%	0.2%	0.3%	0.5%	0.4%	0.5%	0.5%	0.8%
Eutrophication, marine	0.0%	-0.1%	-0.3%	-1.0%	-0.1%	-0.2%	-0.4%	-1.1%	-0.3%	-0.4%	-0.6%	-1.3%	-1.0%	-1.1%	-1.3%	-2.0%
Ecotoxicity, freshwater	0.0%	-0.3%	-0.9%	-3.1%	-0.3%	-0.6%	-1.2%	-3.4%	-0.9%	-1.2%	-1.8%	-4.0%	-3.1%	-3.4%	-4.0%	-6.1%
Land use	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Water use	0.0%	-0.1%	-0.2%	-0.8%	-0.1%	-0.2%	-0.3%	-0.8%	-0.2%	-0.3%	-0.5%	-1.0%	-0.8%	-0.8%	-1.0%	-1.5%
Resource use, minerals a	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.1%	0.1%
Resource use, fossils	0.0%	-0.2%	-0.6%	-1.9%	-0.2%	-0.4%	-0.8%	-2.1%	-0.6%	-0.8%	-1.2%	-2.5%	-1.9%	-2.1%	-2.5%	-3.9%

For the representative desktop computer (BC5), Figure 12 presents the results for two of the fifteen environmental indicators, Climate change and Ecotoxicity, Freshwater. Plastic constitutes 32% of the total materials mass of the desktop, thus the impacts of increasing recycled content and recyclability have more impact than the laptop basecase model.

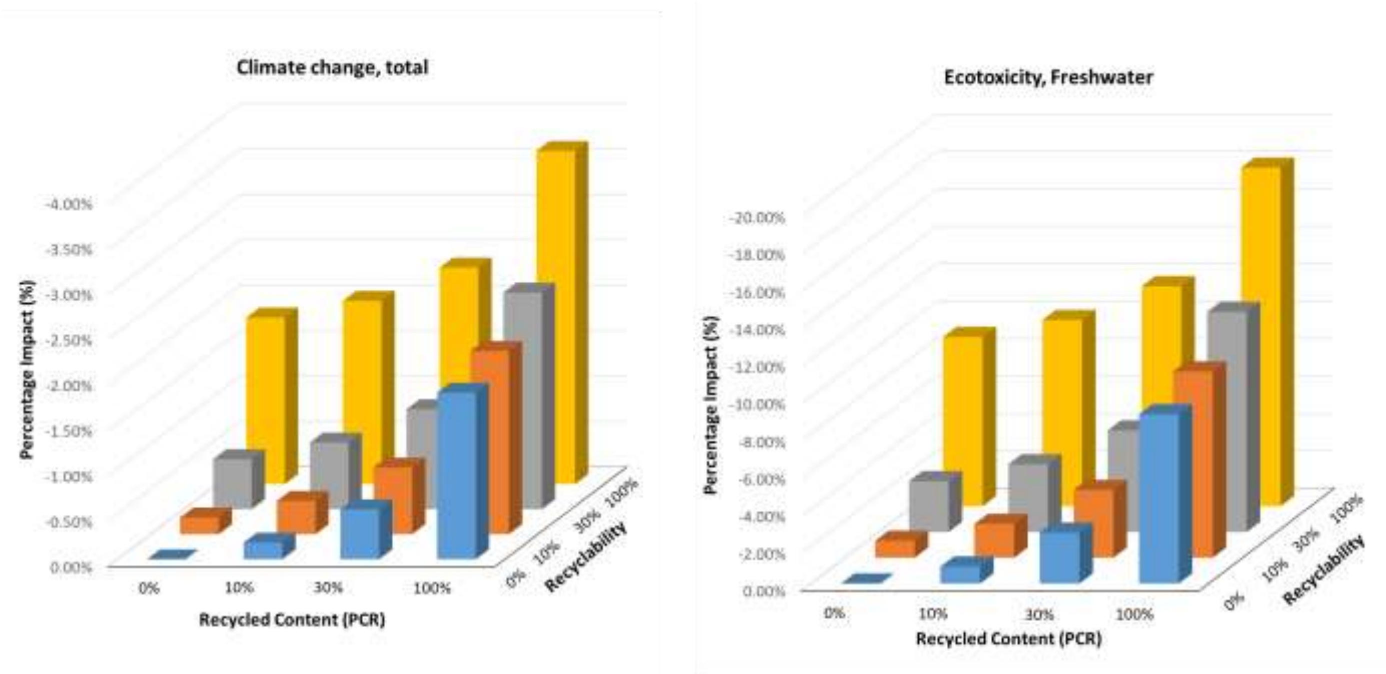


Figure 12: Impact Improvement of Climate Change and Ecotoxicity (Freshwater) for increasing recycled content and recyclability of the basecase desktop computer (BC5)

Table 20 presents the numerical results for all environmental indicators for the basecase laptop computer. The range of impacts varies from more environmentally damaging (e.g., Ozone depletion, Water use) to being more environmentally friendly (e.g., Ecotoxicity freshwater; Photochemical ozone formation; Eutrophication, terrestrial and marine). In general, however, most of the environmental indicators indicate very modest changes with the increasing quantities of recycled plastic and higher levels of recyclability.

Table 20: All environmental indicators for recycled / recyclability plastic for a laptop computer (BC5)

PEF Impact categories	Content 0%, recyclability 0%	Content 10%, recyclability 0%	Content 30%, recyclability 0%	Content 100%, recyclability 0%	Content 0%, recyclability 10%	Content 10%, recyclability 10%	Content 30%, recyclability 10%	Content 100%, recyclability 10%	Content 0%, recyclability 30%	Content 10%, recyclability 30%	Content 30%, recyclability 30%	Content 100%, recyclability 30%	Content 0%, recyclability 100%	Content 10%, recyclability 100%	Content 30%, recyclability 100%	Content 100%, recyclability 100%
Climate change, total	0.0%	-0.2%	-0.6%	-1.8%	-0.2%	-0.4%	-0.7%	-2.0%	-0.6%	-0.7%	-1.1%	-2.4%	-1.8%	-2.0%	-2.4%	-3.7%
Ozone depletion	0.0%	1.0%	3.0%	10.2%	1.0%	2.0%	4.1%	11.2%	3.0%	4.1%	6.1%	13.2%	10.2%	11.2%	13.2%	20.3%
Human toxicity, cancer	0.0%	0.0%	-0.1%	-0.2%	0.0%	0.0%	-0.1%	-0.3%	-0.1%	-0.1%	-0.1%	-0.3%	-0.2%	-0.3%	-0.3%	-0.5%
Human toxicity, non-cancer	0.0%	-0.2%	-0.7%	-2.5%	-0.2%	-0.5%	-1.0%	-2.7%	-0.7%	-1.0%	-1.5%	-3.2%	-2.5%	-2.7%	-3.2%	-4.9%
Particulate matter	0.0%	-0.2%	-0.6%	-1.9%	-0.2%	-0.4%	-0.8%	-2.1%	-0.6%	-0.8%	-1.2%	-2.5%	-1.9%	-2.1%	-2.5%	-3.9%
Ionising radiation, human health	0.0%	-0.4%	-1.2%	-3.8%	-0.4%	-0.8%	-1.5%	-4.2%	-1.2%	-1.5%	-2.3%	-5.0%	-3.8%	-4.2%	-5.0%	-7.7%
Photochemical ozone formation,	0.0%	-0.4%	-1.3%	-4.2%	-0.4%	-0.8%	-1.7%	-4.6%	-1.3%	-1.7%	-2.5%	-5.5%	-4.2%	-4.6%	-5.5%	-8.4%
Acidification	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Eutrophication, terrestrial	0.0%	-0.4%	-1.3%	-4.5%	-0.4%	-0.9%	-1.8%	-4.9%	-1.3%	-1.8%	-2.7%	-5.8%	-4.5%	-4.9%	-5.8%	-8.9%
Eutrophication, freshwater	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.1%	0.1%	0.1%	0.1%	0.2%
Eutrophication, marine	0.0%	-0.5%	-1.4%	-4.5%	-0.5%	-0.9%	-1.8%	-5.0%	-1.4%	-1.8%	-2.7%	-5.9%	-4.5%	-5.0%	-5.9%	-9.0%
Ecotoxicity, freshwater	0.0%	-0.9%	-2.7%	-9.0%	-0.9%	-1.8%	-3.6%	-9.9%	-2.7%	-3.6%	-5.4%	-11.8%	-9.0%	-9.9%	-11.8%	-18.1%
Land use	0.0%	0.0%	0.0%	-0.1%	0.0%	0.0%	-0.1%	-0.1%	0.0%	-0.1%	-0.1%	-0.2%	-0.1%	-0.1%	-0.2%	-0.3%
Water use	0.0%	0.3%	0.9%	3.0%	0.3%	0.6%	1.2%	3.3%	0.9%	1.2%	1.8%	3.9%	3.0%	3.3%	3.9%	5.9%
Resource use, minerals and meta	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.1%	0.1%	0.0%	0.1%	0.1%	0.2%	0.1%	0.1%	0.2%	0.3%
Resource use, fossils	0.0%	-0.5%	-1.4%	-4.6%	-0.5%	-0.9%	-1.8%	-5.1%	-1.4%	-1.8%	-2.8%	-6.0%	-4.6%	-5.1%	-6.0%	-9.2%

6.4.1 Analysis of the Impacts of Different Types of Plastic

This section conducts a comparison of the different types of plastic to understand which types are the most important for personal computers according to the actual amount of plastic in the two basecase models analysed.

Table 21 shows the types of plastic that are used in the two basecase models analysed, the laptop and desktop computer. Both computers have a majority of polycarbonate (PC), the laptop significantly so. For both computers, Acrylonitrile Butadiene Styrene (ABS) is the second most common plastic – for these desktop computers have much more than laptops, both in terms of quantity and percentage of overall plastic.

Table 21: Types of plastic used in the base case laptop (BC2) and desktop (BC5) computers

Types of Plastic	**Laptop [grams]**	**Laptop (% plastics)**	**Desktop [grams]**	**Desktop (% plastics)**
Polycarbonate (PC)	399.4 g	91.8%	930 g	51%
Acrylonitrile Butadiene Styrene (ABS)	23.0 g	5.3%	900 g	49%
Polymethyl methacrylate (PMMA)	10.0 g	2.3%	--	--
Silicone	2.5 g	0.6%	--	--
Toluene diisocyanate (TDI)	0.05 g	0.01%	--	--
Polyethylene terephthalate (PET)	0.01 g	0.002%	--	--
TOTAL:	**434.9 g**	**100%**	**1830.0 g**	**100%**

Given that the laptop computer had more types of plastic, this one was analysed to assess the impact across the different types of plastic. However, two of the plastics – Silicone and TDI – both do not have recycled options and are not recyclable, so they were simply entered as “n/a” in the table.

Two scenarios that were analysed with the ERT v.1.7:

- Scenario 1: 30% post-consumer recycled plastic and 30% recyclability at end of life (see Table 22)
- Scenario 2: 100% post-consumer recycled plastic and 100% recyclability at end of life (see Table 23)

As before, the results table is split in two parts, showing all the results across the various impact categories. If a particular metric increased instead of decreasing, it was given an “n/a” for not applicable. The percentages shown for the different plastics are the percentages reduction in environmental impact relative to reference case. In general, there is no significant difference between the reduction in environmental indicators for the different types of plastic.

Table 22: Summary of the percentage change in environmental impacts compared to the baseline, when using 30% recycled content and 30% recyclability for the basecase laptop computer (BC2)

Material	Climate change, total	Ozone depletion	Human toxicity, cancer	Human toxicity, non-cancer	Particulate matter	Ionising radiation, human health	Photochemical ozone formation, human health	Acidification
Units	*kg CO2 eq*	*kg CFC-11 eq*	*CTUh*	*CTUh*	*disease incidence*	*kBq U235 eq*	*kg NMVOC eq*	*mol H+ eq*
30% recycled plastic (R1) and 30% recyclability (R2)								
PMMA	18%	66%	30%	28%	36%	62%	35%	34%
PC	22%	n/a	26%	23%	24%	44%	29%	28%
Silicone	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TDI	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
PET	15%	n/a	20%	23%	18%	27%	26%	24%
ABS	27%	10%	29%	29%	25%	12%	25%	26%

Material	Eutrophication, terrestrial	Eutrophication, freshwater	Eutrophication, marine	Ecotoxicity, freshwater	Land use	Water use	Resource use, minerals and metals	Resource use, fossils
Units	*mol N eq*	*kg P eq*	*kg N eq*	*CTUe*	*pt*	*m3 water eq. of deprived water*	*kg Sb eq*	*MJ*
30% recycled plastic (R1) and 30% recyclability (R2)								
PMMA	33%	13%	33%	30%	21%	n/a	32%	36%
PC	28%	n/a	28%	29%	n/a	25%	n/a	30%
Silicone	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TDI	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
PET	26%	28%	26%	27%	21%	21%	28%	26%
ABS	27%	25%	27%	29%	21%	n/a	26%	28%
PMMA	33%	13%	33%	30%	21%	n/a	32%	36%

Table 23: Summary of the percentage change in environmental impacts compared to the baseline, when using 100% recycled content and 100% recyclability for the basecase laptop computer (BC2)

Material	Climate change, total	Ozone depletion	Human toxicity, cancer	Human toxicity, non-cancer	Particulate matter	Ionising radiation, human health	Photochemical ozone formation, human health	Acidification
Units	*kg CO2 eq*	*kg CFC-11 eq*	*CTUh*	*CTUh*	*disease incidence*	*kBq U235 eq*	*kg NMVOC eq*	*mol H+ eq*
100% recycled plastic (R1) and 100% recyclability (R2)								
PMMA	61%	219%	100%	92%	120%	208%	115%	115%
PC	72%	n/a	85%	78%	82%	148%	95%	92%
Silicone	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TDI	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
PET	50%	n/a	67%	75%	59%	91%	87%	81%
ABS	89%	32%	95%	97%	83%	41%	82%	87%

Material	Eutrophication, terrestrial	Eutrophication, freshwater	Eutrophication, marine	Ecotoxicity, freshwater	Land use	Water use	Resource use, minerals and metals	Resource use, fossils
Units	*mol N eq*	*kg P eq*	*kg N eq*	*CTUe*	*pt*	*m3 water eq. of deprived water*	*kg Sb eq*	*MJ*
100% recycled plastic (R1) and 100% recyclability (R2)								
PMMA	109%	45%	111%	100%	71%	n/a	106%	121%
PC	94%	n/a	95%	98%	n/a	82%	n/a	101%
Silicone	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
TDI	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
PET	88%	92%	88%	91%	70%	71%	94%	85%
ABS	89%	85%	89%	97%	72%	n/a	87%	93%

6.5. Design options for Critical Raw Materials

Critical Raw Materials (CRMs) and Strategic Raw Materials (SRMs) are found mainly in the waste PCBs and electronic components of personal computers. The economic value of these components includes some precious metals like gold and silver, as well as some critical raw materials such as copper and aluminium. Palladium is emerging as a CRM that is recoverable as part of the recovery of copper. There can also be rare earths in the magnets used in magnetic hard disk drives, although these hard drives are becoming less common in the market. Where the key parts of computers can be separated prior to shredding, these separated materials can be delivered to companies specialising in processing and recycling them.

Recyclers have stated that before setting recycled content requirements on CRMs, the economics of their recycling should be addressed. For CRMs, distinguishing between pre-consumer and post-consumer recycled material could not be feasible.

For the moment no recycled content requirements for CRMs and SRMs are proposed. For copper and aluminium such requirements are not necessary, these two CRMs are already recovered and recycled as much as economically justified.

For the moment no recyclability requirements for CRMs and SRMs are proposed. Recyclability of CRMs and SRMs from depends on collection rates (which are beyond the scope of this study), and to a lesser extent on the recycling rate of printed circuit boards. Recyclers state that the latter is already high.

Considering the lack of information on the types and quantities of CRMs and SRMs, setting information requirements could be relevant, however, considering the expected small quantities, and the considerable traceability effort for recyclers, it requires further evaluation.

7. Estimates of Magnitude of Impacts

7.1. Comparison of Materials vs. Energy in Use

Estimates of product lifetime and power consumption and operating hours in various energy consumption modes were adapted from an internal draft of the computers impact assessment. Using those estimates, the total electricity consumption over the lifetime of the product was estimated in order to compare the environmental footprint of the materials used in the product with the energy in use phase.

The values for lifetime, and the hours in operation and power consumed in on-mode, standby-mode and off-mode were input into ERT. The electricity mix selected in the ERT was 243-Electricity grid mix 1kV-60kV technology mix consumption mix, to consumer 1kV-60kV. The inputs for the two base case models are shown in the table below. These estimates may be revised in the future and are only being used in this study to provide a basis for comparison.

Table 24: Service life, power consumption and operating hours for laptop and desktop basecase computers

Modelling input estimate	Laptop computer (BC2)	Desktop computer (BC5)
Product (service) life in years	5.1 yrs	6.1 yrs
On-mode power consumption (watts)	30 W	65 W
On-mode number of hours per year	2000 hr	2000 hr
Standby-mode power consumption (watts)	0.87 W	1.66 W
Standby-mode number of hours per year	2000 hr	2000 hr
Off-mode power consumption (watts)	0.37 W	0.57 W
Off-mode number of hours per year	4760 hr	4760 hr

Given the above inputs, the ERT estimates the environmental impacts of the materials and end-of-life (including impacts and credits) and the environmental impacts of the energy consumed while in use, assuming an average electricity mix. The figures below present the results for the basecase (for plastic, 0% recycled content, 0% recyclability) scenario. The orange shaded portions of the environmental impact represent the impact from energy-in-use and the blue shaded portions represent the impact from the materials and end-of-life treatment. These impacts are over the whole lifetime of the computer, as defined from the estimates in the table above (5 years for a laptop and 6 years for a desktop). The relative share of the impacts vary substantially with the different environmental indicators.

Figure 13 shows that the environmental impacts for the laptop computer are roughly 50/50, when comparing materials and end-of-life treatment with energy-in-use. For some indicators, energy-in-use dominates, while for others, its materials and end-of-life treatment.

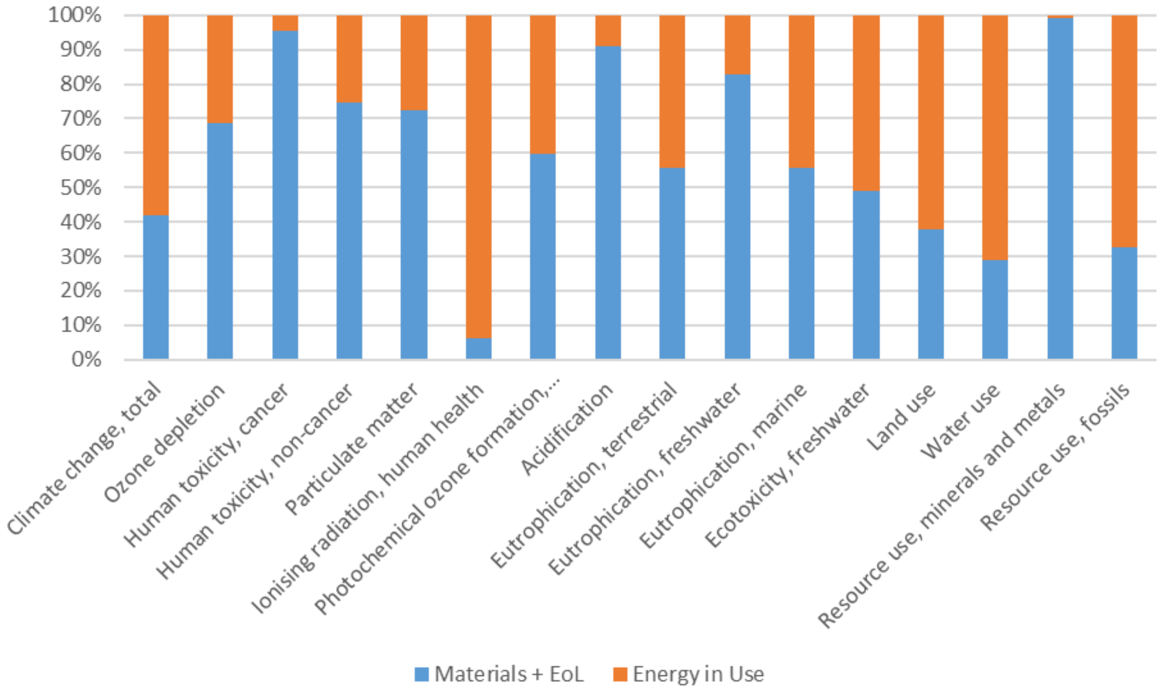


Figure 13: Environmental impacts comparison for materials and end-of-life and energy-in-use for the basecase laptop computer (BC2)

For the desktop computer, the same scenario was calculated and a very similar result was found. Some environmental impact indicators are dominated by the energy-in-use and others are more heavily impacted by the materials incorporated into the computer.

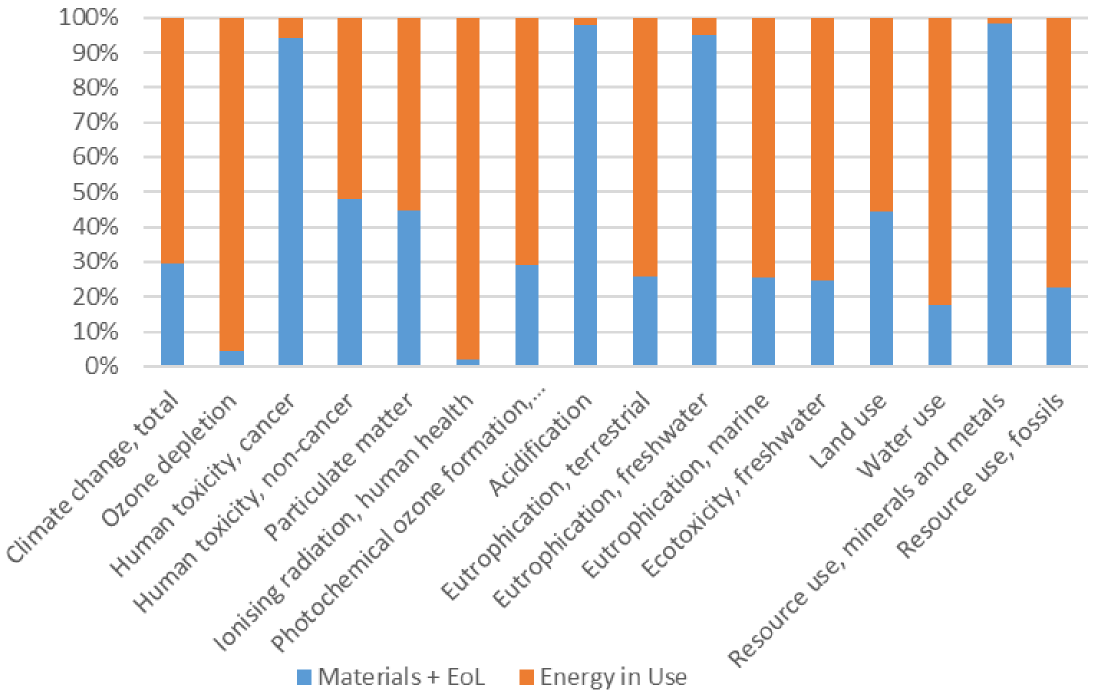


Figure 14: Environmental impacts comparison for materials and end-of-life and energy-in-use for the basecase desktop computer (BC5)

7.2. Savings Potential Compared to Sales & Stock in 2030

This section provides an estimate of relative order of environmental benefit for the measures considered in recycled plastic and recyclability of plastic for the sales and stock of laptops and desktop computers in 2030. These benefit calculations consider two combinations: 10% recycled plastic content with 10% recyclability at end of life, and 30% recycled plastic content with 30% recyclability at end of life. The benefits calculated for the representative base case model laptop and desktop computer are then multiplied by the projected sales and stock in 2030 to estimate the magnitude of the savings potential overall from these two measures. Adjustments can easily be made to these estimates. From the table of sales and stock, it is clear that these two formats (laptop and desktop) constitute the vast majority of the personal computer market (i.e., approximately 88% of the total PC market).

Table 25: Sales and Stock estimates in 2030 for laptop and desktop basecase computers

Type	**2030 Sales** *[units]*	**2030 Sales** *[percent]*	**2030 Stock** *[units]*	**2030 Stock** *[percent]*
Laptop Computer	70,666,000	68%	324,064,000	64%
Desktop Computer	20,969,000	20%	121,914,000	24%
Other types of Computer	11,642,849	11%	60,686,061	12%
Totals	103,277,849		506,664,061	

Given the above shipment and stock estimates, the ERT provides estimates the environmental impacts of the materials and end-of-life (including impacts and credits). Considering these estimates and only adjusting the two parameters – the recycled plastic content and the recyclability at end of life – per unit benefits were calculated for the base case laptop and desktop computers. While there are sixteen environmental indicators in the ERT, we have selected carbon dioxide emissions as our reference point because it is considered more easily comparable to other analyses and policy measures considered.

The table below presents these values, which are 0.13 kg of CO_2 savings for the 10%/10% scenario for laptops, and approximately 3 times larger at 0.40 kg/CO2 savings for the 30%/30% scenario. The desktop has more plastic, and therefore has more savings per unit, with 0.54 kg CO_2 savings for the 10%/10% scenario and 1.62 kg CO_2 savings for the 30%/30% scenario. Now, multiplying each of these individual (per unit) savings by the sales and stock in 2030, an estimate of the overall order of magnitude from these measures is quantified and shown in the table below.

Table 26: Sales and Stock estimates in 2030 for laptop and desktop basecase computers

Policy Scenario	**GHG Savings / unit** *[kg CO_2 eq]*	**2030 Sales** *[tonnes CO_2 eq]*	**2030 Stock** *[tonnes CO_2 eq]*
Laptop: 10% PCR plastic content & 10% recyclability at end of life	0.13	9,521	43,664
Laptop: 30% PCR plastic content & 30% recyclability at end of life	0.40	28,564	130,991
Desktop: 10% PCR plastic content & 10% recyclability at end of life	0.54	11,312	65,769
Desktop: 30% PCR plastic content & 30% recyclability at end of life	1.62	33,937	197,307

Combining laptop and desktop savings, approximately 20,000 metric tonnes of CO_2 would be saved for the 10%/10% scenario if all sales in 2030 incorporated those requirements. If (hypothetically) the entire stock of laptops and desktops switched overnight to incorporate this measure, the combined savings would be approximately 110,000 metric tonnes of CO_2. It is recognised, however, that the in reality the change in stock would happen gradually over time as the models are replaced, also taking into account the possibility of over-compliance (i.e., products designed to contain more recycled content than required).

The values for the 30% / 30% scenario are approximately triple those of the estimates for 10% / 10%, with approximately 60,000 metric tonnes of CO_2 savings for the 2030 sales and approximately 330,000 metric tonnes of CO_2 savings for the 2030 stock.