Nordic Council of Ministers

Ecodesign requirements for circularity of servers and data storage products

Contents

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Summary

This report is carried out by Viegand Maagøe A/S for the Nordic Working Group for Circular Economy (NCE), Nordic Council of Ministers. The project investigates circular aspects of servers and data storage products and provides proposals for policy options, which can be implemented within the Ecodesign Directive framework[1]. It also addresses other potential policy measures especially green public procurement criteria. The focus areas of the work are critical, environmentally relevant, and scarce materials.

Introduction (section 1)

The introduction describes the background and the focus areas of the report and shortly describes the most relevant policy context such as the ongoing revision process for the current ecodesign regulation for serves and data storage products and the ESPR regulation which will increase the focus on requirements beyond energy efficiency and intend to boost circularity of products.

Scoping and state of play (section 2)

Section 2 describes servers and data storage products and the relevant legislation with main focus on resource efficiency and especially on scarce and critical raw materials (CRMs) and other environmentally relevant materials. Other environmentally relevant materials in servers are primarily plastics.

The main elements of the products are shortly described as well as some important aspects with regard to the expected technical evolution for servers and data storage products. It is found that:

- A shift from HDDs (Hard Desk Drives) to SSDs (Solid State Drives) is ongoing, but a total replacement is not foreseen in the near future as HDDs and SSDs have different functionalities. HDDs provide high capacity at lower cost for "cold" data, whereas SSDs outperform "warm" data which needs to be accessed more rapidly and more frequently.
- Quantum computing is still a technology in its very early stages, but the technology is already being tested at large scales. If it overcomes its technical barriers, it has the potential to become a market disruptor.

1. Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products.

- Regarding on-premises servers or cloud bases solutions there has been a paradigm shift towards data virtualization and the utilization of Cloud Data Centres. Although there appears to be consensus that Data centres handle most of the data traffic, there seems to be less of a clear trend in regard to where the majority of servers can be found.

Section 2.3 describes the background for the European and Nordic focus on critical and scarce raw materials and addresses shortly why servers and data storage products are relevant in this context (this is further developed in section 4). Main findings are that the need for CRMs in Europe will increase significantly over the coming decades and that this will cause significant supply risks because the majority of the materials is supplied from countries outside the EU (especially from China). Another finding is that there are various reserves of CRMs in the EU and in the Nordic countries which are currently not utilized (mined).

Legislation (section 3)

This section briefly describes various legislation, voluntary measures and standards for servers and data storage products with a focus on European measures. The content is used as input and inspiration for development of policy measures in section 7.

The described measures and standards are among others:

- The current ecodesign regulation for servers and data storage products (EU/2019/424)
- The ecodesign and energy labelling regulations for smartphones and tablets as examples of regulations with extended material efficiency requirements
- The EU GPP criteria (Green Public Procurement criteria) for servers, data storage and network equipment.
- EU Code of Conduct on Data Centre Energy efficiency
- Data Centers (DE-UZ 228) - Blue Angel
- EU material efficiency standards (the so-called EN 4555X series of standards).
- Data sanitation/data deletion standards

Material Aspects (section 4)

This section identifies and analyses the specific technical aspects related to material efficiency and circular economy of servers and data storage products especially regarding scarce, environmentally relevant, and critical raw materials.

Based on literature and dialogue with stakeholders it is concluded:

- That servers and data storage products include various CRMs and precious metals, but that the amount especially for CRMs are small per product and component. In addition, the content varies from product to product and from component to component. For instance, the content of CRMs in PCBs varies considerably (due to size, grade, application, included components, manufacturer etc.). The products do only include small amounts of plastics (fans, cables etc.).
- The lifetime of servers varies, and the tendency is that the lifetime is shorter in large data centres than in server rooms. In general, the actual lifetime is shorter than the technical lifetime especially in large data centres.
- That there has been a slowdown in the increase in energy efficiency performance for servers and data storage products meaning that measures to prolong the lifetime is more relevant than previously.
- That there is already an established circular thinking system in datacentres, where the equipment is repaired and recycled, but there is a lack of efficiency due to different interests and approaches of stakeholders along the different life cycle stages. Very important aspects with regard to reuse are availability of firmware and software updates and secure data deletion.
- That servers are to some extent modular designed. It is possible to replace some larger parts/components when the servers are in operation, but that there is a lack of modularity and standardisation for the other components and parts of components (too many fixings/fasteners, inconsistent location across models and generations etc.).
- That availability of software and hardware updates is of high importance for the lifetime and reuse of servers and data storage products. As software is generally not supplied by the manufacturer with the product, ecodesign regulation on software induced obsolescence might not be possible to implement, but the issue could be addressed through other measures such as Green Public Procurement (GPP).
- Various standard with regard to data deletion exist and different appropriate deletion methods can be used depending on the data's sensitivity. But there is among operators (especially for the smaller server rooms and data centres) concerns about the data security, and this might hinder reuse of the products. Further information or education could help to create larger trust in secure data deletion and the appropriate methods to apply.
- That increased information on the content of CRMs in servers and data storage products could support the possibilities for increased recycling. This could be through extended product information requirements in a revised ecodesign regulation servers and data storage products or requirements for a digital product passport. Work on developing and preparing a standards-based Digital Product Passport (DPP) aligned with the requirements of the

Ecodesign for Sustainable Product Regulations (ESPR) is ongoing under the European CIRPASS project with focus on the electronics, batteries, and textile sectors (CIRPASS, n.d.).

- That possibilities for substitution of highly critical CRMs in the ICT sector (Information and communications technology sector) do exist, but that the majority of potential substitutes are currently in the research and development stage, and that market-ready solutions are scarce. However, the physical properties and behaviour of the various materials at atomic level is very particular and the potential for substitution or change of design is very limited/impossible for many components in the foreseeable future.
- That it is possible both to substitute plastic types and to reduce the use of plastics, but also that the amount of plastics in servers and data storage products are limited. As for CRMs physical properties of the materials are important and this reduce the possibilities for substitution and use of recycled plastic in servers and data storage products.
- That there is a very low recycling rate of CRMs from servers and data storage products and that the main barriers are lack of recycling facilities and market infrastructure for recycled CRMs.
- That the PCBs are both the component with the highest environmental impact and with the highest scrap price. PCBs have been identified as the most environmentally impactful components of DC equipment and the ones with the highest economic and environmental benefits if recycled by take-back schemes.

Environmental impacts (section 5)

This section shows that the highest environmental impacts for servers and data storage products are related to the life cycle stages material extraction (mining and extraction process) and the use phase due to intensive energy consumption. When we in this study are only dealing with impacts related to the materials used in the products the most important stage is the mining and extraction.

The main environmental impacts of mining activities include:

- Production of large quantities of extractive waste and tailings
- Risks from collapse of Extractive Waste Facilities
- Acid mine drainage (AMD)
- Metal deposition and toxicity
- Loss of Biodiversity and Habitat
- Other social impacts such as occupational health and safety violations that have effects on worker's lives, employment conditions including long hours, low wages and temporary contracts.

The importance of the impacts from mining and extracting activities reinforces the need for durability, repairability, and reuse requirements.

For the manufacturing process the impacts are to a high extent related to a huge amount of electricity consumed during the energy intensive production processes of semiconductor components but other impacts relate to a high consumption of water during the manufacturing process and pollution with metals rejected from the production plants.

There are no relevant impacts of the materials embedded in the products in the use phase.

Recycling processes produce environmental impacts as well, depending on the process used and where it is carried out. Impacts are among others related to energy consumption. A larger share of e-waste still ends up being exported illegally and is handled by informal recycling methods which have worse environmental impact than formal recycling processes. Informal recycling results in emission of toxic materials to the environment. Informal recycling is attractive from a cost perspective with the use of nonskilled manual labour, and a disregard of environmental or health hazards.

Policy options (section 6)

The previous sections have identified material aspects of servers and data storage products and addressed the most important impacts.

Section 7 of the report identifies the relevant policy options with the aim to reduce the use of CRMs and plastics in servers and data storage products, and increase reuse, recycling, and recovery. The policy options are structured according to the waste hierarchy.

Policy options for implementation within the ecodesign framework, for green public procurement and other policy options are identified.

The policy options for ecodesign are:

Type	Measure	Specification	Section
Avoid	**Ban the use of CRMs**	Ban the use of CRMs in all other parts than in electronic components for instance in the chassis (enclosure or cabinet)	4.3.1.2
		Ban the use of specific CRMs with high risk of depletion and supply. The specific CRMs would need to be further investigated.	4.3.1.2
	Restrict the number of CRMs	Require that only a limited number of CRMs can be used in specific products or components	4.3.1.2
	Ban the use of non-recyclable plastics	Require that the plastics used should be limited to ones with established high recyclability rates	4.3.2
	Ban the use of plastics	Ban the use of plastics in specific components (where alternatives are available)	4.3.2
Reduce	**Limit the use of virgin CRMs and plastics**	Information requirement to facilitate recycling (this could be information requirement regarding content of CRMs, disassembly requirements etc.)	4.5
		See policy option related to reuse.	6.2.3
Reuse	**Availability of spare parts**	Specific listed spare parts shall be available for at least 8–10 years[2]. Should include all main elements in the server and data storage products. Spare part should among others include data storage devices (HDDs, SSDs, etc.), Motherboard, PCBs, RAM, CPUs, GPU, chassis/racks, fans, PSUs, integrated switch, capacitors, batteries, RAID controllers, and network interface cards.	4.4.1
	Disassemblability	Fasteners shall be removable and the process for replacement shall be feasible with no tool, or with basic tools. The process for replacement shall be able to be carried out in a use environment and shall be possibly to be carried out by a generalist or expert (depending on the component). This should at least apply to the components in the spare part list.	4.4.3
	Standardize design between brands and generations	Require that some specific parts of servers are standardized (for instance racks, sockets of CPUs, and connectors. across brands and generations.	4.4.4
	Improve requirements on secure non-destructive data deletion	Require that a secure data sanitization functionality that deliberately, permanently, and irreversibly removes or destroy the data stored on a data storage device shall be made available for the deletion of data contained in all data storage devices of the product.	4.4.5

2. For smartphones the period for availability of spare parts is until at least 7 years after the date of end of placement on the market.

		Information requirement regarding the presence of the secure data sanitization functionality, its application and degree of security, and the supported data deletion standards.	4.4.5
		Require that the functionality for data sanitization can provide a certificate attesting that data are deleted from the data storage product with a high security level.	4.4.5
	Improve the requirements on firmware updates	Require that software and firmware updates including security updates and updates to correct firmware issues should be available free of charge for at least 8–10 years after the date of end of placement on the market of the product	4.4.6
		Require that software updates do not make existing hardware and products obsolescent	4.4.6
		Require that essential firmware and software licenses are supported at least for a period corresponding to the technical lifetime of the product (8 to 10 years) and that frequent and necessary updates are provided during the period.	4.4.6
	Prevent part pairing[3]	Prohibit the use of part pairing of serialised parts[4] (the appropriateness of this should be investigated further).	4.4.8
		In case spare parts to be replaced are serialised parts, require that manufacturers provide non-discriminatory access for professional repairers to any software tools, firmware or similar auxiliary means needed to ensure the full functionality of those spare parts and of the device in which such spare parts are installed during and after the replacement	4.4.8
Recycle	**Design for recycling**	Se requirement for Disassemblability above.	4.5.1
		Require that PCBs are produced in the same color, or in specific colors depending on their content	4.5.4
	Reduce the number of different plastics used.	Require that plastics should be of the types an established recycling infrastructure (ABS, PP, PA, PC, PC/ABS, HIPS, PE). If not possible the manufacturer should document, why other plastic types are necessary in the technical documentation.	4.5.2
		Prohibit the use of polymer blends and foams. If not possible the manufacturer should document, why these materials are necessary.	4.5.2

3. Parts-pairing is a software serial identification system ensuring that all the components in a device are matched to the device. If a component is replaced (with an identical one) by a third-party repairer, the system will identify that component as “other” and will not function appropriately.
4. ‘Serialised part’ means a part which has a unique code that is paired to an individual unit of a device and whose replacement by a spare part requires the pairing of that spare part to the device by means of a software code to ensure full functionality of the spare part and the device.

Information about content of CRMs in products and components	Require that manufacturer shall provide information about the content of critical raw materials in specific components (such as PCBs, HDDs and SSD, PSUs, CDUs and capacitors. Information should be supplied for all materials in the most recent EU list of critical raw materials when the product is placed on the market.	4.5.1
	Require that the above-mentioned information should be available in a QR placed close to name of the product and/or in the Digital Product Passport	4.4.7

Policy options for public procurement

The following policy measures are proposed for public procurement as supplement to the proposed ecodesign policy options:

- Include criteria regarding:
  - non-destructive and secure data deletion and provision of a certificate
  - reused products in procurement (for instance a minimum share of recycled components)
  - attempted reuse/reselling before recycling
- Require that:
  - CRMs come from mines with responsible mining (for instance IRMA's standard for responsible mining)
  - providers are classified as sustainable under the EU Taxonomy
  - suppliers are classified as sustainable under the EU Taxonomy
  - providers have not signed contracts requiring the destruction of servers, when taken out of service
  - IT consultants providing IT services has green skills
  - products bear and ecolabel (type 1 - third part certified)
  - some specific highly critical materials are not used in products or specific components
- Challenge the lengths of contracts and require that contracts take into account reuse and recycling
- Look into
  - The possibility of establishing a circular economy index to be used in public procurement.
  - Making a scoring/weighting system in the criteria to assist procurers

Other policy measures

In addition, the following other measures dealing with voluntary initiatives, harmonizations etc. are proposed:

- Creation of an EU Code of Conduct for Data Centre Circularity in line with the EU Code of Conduct for Energy Efficiency of data centres
- Harmonization and improvements on data deletion to prevent that standards recommend destructive data deletion and to creating of standards to ensure a high data security level

- Update of design brief to ensure that servers and data storage products manufactured outside EU (in Asia etc.) and imported EU are design to minimise the use of CRM.
- Due diligence requirements on economic operators who place on the market or put into service servers and data storage products in line with the ones in the new battery regulation.

1 Introduction

The Nordic Working Group for Circular Economy (NCE) under the Nordic Council of Ministers (NCM) wants to support the development of the European Union's product policy, more specifically the increased focus on environmental aspects and circular economy in the EU Ecodesign Directive.

The study focuses on possible regulation of scarce, environmentally relevant, and critical raw materials through information requirements, design for dismantlability and minimum share of recycled raw materials. It identifies current regulations, legislations, and standards and defines and recommends relevant policy options especially related to scarce, environmentally relevant, and critical raw materials.

The background of the study is the increased focus on designing sustainable products and circular economy in European product policies. Examples of this is the revision of the Ecodesign Directive, which will be transformed into a new Ecodesign for Sustainable Products Regulation (European Commission, 2022a), and the Circular Economy Action Plan (European Commission, 2022b). The Ecodesign and Energy Labelling Working Plan 2022–2024 (European Commission, 2022c), which was published in May 2022, also incorporates the possibilities of the existing EU ecodesign rules to strengthen the focus on the circularity aspects of ecodesign, in line with the Circular Economy Action Plan 2020.

The Ecodesign and Energy Labelling Working Plan 2022–2024 identifies three aspects to contribute to the circular economy, with a view of a future increased emphasis on circular economy, and potentially more product-specific requirements. These aspects are:

- Recycled content
- Durability, firmware, and software
- Scarce, environmentally relevant, and critical raw materials (CRMs).

The Ecodesign for Sustainable Products Regulation (ESPR)[5] will replace the current Ecodesign Directive. It will be applicable to a broader range of products and make it possible to further expand sustainability requirements for the regulated products.

5. On 4th December 2023 a provisional agreement was reached between the European Parliament and the Council on the Ecodesign for Sustainable Products Regulation. https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6257

Requirements under ESPR will go beyond energy efficiency and aim to boost circularity, covering, among others:

- Product durability, reusability, upgradability, and repairability
- Presence of chemical substances that inhibit reuse and recycling of materials
- Energy and resource efficiency
- Recycled content
- Carbon and environmental footprints
- Available product information, in particular a Digital Product Passport.
- Measures to end the wasteful and environmentally harmful practice of destroying unsold consumer products.

An ecodesign regulation for servers and data storage products (EU) 2019/424 (European Commission, 2019) was adopted in 2019 and the first requirements was applicable from 1. March 2020 including the material efficiency requirements and the information requirements regarding Critical Raw Materials (CRMs). The review clause (Article 8) of the current regulation prescribes that the Commission shall assess the regulation and present the results to the Consultation Forum by March 2022. This deadline has not been met, but a review study is on-going and is expected to be finalised ultimo 2023. With regard to circular economy the review study shall address in particular the appropriateness of updating the material efficiency requirements for servers and data storage products, including the information requirements on additional critical raw materials (tantalum, gallium, dysprosium and palladium), taking into account the needs of the recyclers.

The scope of the study is enterprise servers (rack servers and blade servers) and data storage products as defined in the current ecodesign regulation for servers and data storage products. Data centres where these products are applied are one of the main providers of IT e-waste due to their interrupted activity and the high rates of equipment replacement.

Methodology

The content of the study is based on input from stakeholders via a questionnaire, interviews, and a stakeholder meeting in combination with literature reviews. Comments from stakeholders are presented in text boxes in the report.

2 Scoping and state of play

The starting point for the work is the existing regulation on servers and data storage products, the ongoing review of this regulation and the increasing focus on resource efficiency in the European product policy.

The aim of this section is to describe servers and data storage products and the relevant legislation with main focus on resource efficiency and especially on scarce and critical raw materials (CRMs) and other environmental relevant materials. Other environmentally relevant materials in servers are primarily plastics. Plastics is chosen as a focus point, as it is, together with CRMs, the most problematic materials to recover from servers (WeLOOP, 2020).

The scope of the study is enterprise servers (rack servers and blade servers) and data storage products as defined in the current ecodesign regulation for servers and data storage products.

2.1 Servers and data storage products

Servers and data storage products consist of computer systems and associated components, mostly operated interconnectedly and typically housed in data centres. The report on "Reporting requirements of data centres for the European Energy Efficiency Directive" (Viegand Maagøe, 2023) estimates there in the EU are around 55.000 very small data centres (below 100 kW threshold[6]), and less than 800 professional (colocation and co-hosting) data centres.

Enterprise servers and storage products are commercial information and communication technology (ICT) sold in the business-to-business (B2B) market. Server and storage products provide individual functionalities and are two separate product categories even though they are both covered by the same ecodesign regulation. The provided IT services are not created by a single machine but through a combined (virtual) server and storage environment.

Most servers except for stand-alone products such as tower servers are mounted in standardised 19-inch rack cabinets (or chassis). The chassis encloses and makes it possible to mount the servers and main subassemblies.

This study focuses on enterprise servers and data storage products used in server rooms and data centres.

6. Threshold for the proposed reporting requirements for data centres

2.1.1 Servers

Enterprise servers can in broad terms be categorized as:

- **Rack servers**: are designed to be inserted and fixed directly in the 19-inch rack. The server rack usually fits multiple rack servers.

- **Blade servers:** are servers with a modular design, that fits into a blade enclosure (or cabinet/chassis), which holds multiple blade servers.

Rack servers integrate all functional elements of a server including the mainboard (populated with processor, memory, and other active and passive electronics), passive and active cooling devices, power supply unit, interfaces and connectors in a single enclosure (called cabinet or chassis). The individual servers need to be manually connected to the power distribution and network (cabling). The hardware and software configuration of rack servers are optimised for a certain application spectrum and performance.

Blade servers have many components removed to save space, minimize power consumption and other considerations. The blade server fits inside a blade enclosure, providing services (the so-called shared resources) including power supply, active cooling, storage capacity and network connections. Together, blades and the blade enclosure form a blade system. Different blade providers have differing principles regarding what to include in the blade itself, and in the blade system as a whole.

Blade servers have the highest processing power and can be 'hot-swapped' (easily removed from the chassis and replaced to avoid redundancy).

Enterprise server consists of the following main components (European Commission, 2015b; JRC, 2015):

- **Chassis/cabinet:** A housing made of metal and plastic material that encloses the electronic components and provides mounting features e.g. for the power supply unit, cooling elements, and other functional components.
- **Main board (also referred to as motherboard)**[7]**.** This is the main printed circuit board (PCB) that provides the computing and communication functionality, and which is populated with active components including the CPU (central processor unit) with attached RAM (random access memory) and chipset, storage media (typically HDDs and SDDs) and network devices as well as passive electronic components including resistors, capacitors, etc.

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7. The content of the main board varies from server to server, but this is a typical structure.

- **Other PCBs:** A number of other PCBs of different dimensions/mass and grades are included in servers. PCBs are located in chassis, HDDs, ODDs, mainboard, PSU, expansion card, memory cards (from JRC environmental footprint study table 19).
- **Cooling system:** The cooling of the active electronic components such as the CPU is typically achieved by a combination of passive and active technologies. In general, passive cooling includes a heat spreader directly attached to the top of the processor chip, a large heat sink or heat pipes that distribute the thermal energy away from the chip and towards the active cooling system which is most often a fan unit.
- **Storage devices and drives:** The storage system derives historically from hard disc drives (HDD) and includes nowadays 3.5-inch and 2.5-inch HDDs as well as 2.5-inch solid state drives (SSDs). Some servers feature other drives (CD-ROM/Blu-Ray) as well.
- **Input/Output (I/O) control and network connectors**: Servers are remotely accessible via Ethernet connection and therefore feature multiple network interfaces and links (connectors) on the backside.
- **Power supply unit (PSU):** The PSU is typically configured as a single unit or a multiple unit and comes in its own housing (metal cage). It typically receives alternating current (AC) from the main and transform it to direct current (DC) at the relevant voltage and provides the power for server.
- **Cables.** Various cables connections
- **CPU (Central Processing Unit)**. Handling all instructions and commands for all incoming and outgoing data. Is typically placed on the motherboard mentioned above.
- **GPU (graphic processing unit)**: Offers increased power and speed (compared to the CPU) for running computationally intensive tasks, such as video rendering, data analytics, and machine learning.

The composition of the servers and where the components are placed varies from product to product.

Looking at results of environmental assessments for servers it is important to observe the boundaries i.e. which components and auxiliary items are included in the Bill of Material (BoM).

2.1.2 Data storage products

A data storage product is a storage system that supplies data storage services to clients and devices attached directly to the device or through a network (to remote clients). A storage product composed of integrated storage controllers, storage media (typically HDDs and/or SSDs), embedded network elements, software, and other devices. The main components include housing elements, a disk platter, spindle and voice coil motors, read and write heads, active and passive electronic components including semiconductor devices, cooling elements and connectors.

Data storage equipment is operated free standing (pedestal) or in a cabinet (rack-mounted) and is most often installed in a server room or data centre.

The data storage system supplements the server's internal memory, by providing more capacity, redundancy, and flexible data management. The storage system hardware consists basically of a larger number of storage media (HDDs or SDDs), a controller that handles the input and output (IO) requests, and the necessary connectivity for data transmission. All these devices are mounted in a chassis together with power supply units, active cooling devices (fans) and management interfaces. The storage system is connected to the servers or clients by means of direct connections or network connections.

Data storage systems include following subsystems (from EU prep study):

- **Storage media and devices:** These include hard disk drives (HDDs), solid state devices (SSDs), tape cartridges, and optical disks providing non-volatile data.
- **Storage controller:** External or internal subassembly including a processor (sequencer) and other electronics which autonomously process a substantial portion of IO requests (input/output request) directed to storage devices.
- **Storage elements**: Product configuration (e.g. controller enclosure or disk enclosure) such as redundant array of independent disks (RAID) or a robotic tape library with a number of storage devices and integrated storage controller for handling I/O requests.
- **Connectivity and network elements**: Storage devices can be directly connected to a host or connected through a network. Connectivity and networks are based on various technologies (protocols) including Serial Advanced Technology Attachment (SATA), Serial Attached SCSI (SAS), Fibre Channel (FC), Infiniband (IB) or Ethernet (TCP/IP).
- **Connectors and cables**: The data transmission between servers and storage devices requires interface controllers (integrated or on separated cards), connectors and cables. The functionality, performance and form factors are important aspects.

HDDs are used in combination with SSDs for data storage [WeLOOP,2020]. As SSDs score better than HDDs in many performance indicators, the HDDs are gradually disappearing and being replaced by SSDs. Another core replacement reason next to performance is the decreasing price of SSDs. Nevertheless, HDDs still have a strong edge in terms of cost and capacity (JRC, 2023a). HDDs provide high capacity at lower cost for "cold" data, which is rarely accessed, whereas SSDs outperform "warm" data which needs to be accessed more rapidly and more frequently.

HDDs use the magnetism of materials on a rotating platter to store data. Permanent magnets (NdFeB) are used. HDDs contain REE such as Nd and Dy. Other metals and plastics are also used and there is a high concentration of aluminium (WeLOOP, 2020).

SSDs are based on semiconductor engineering materials. High purity silicon is the main material found in flash memories, made of floating-gate transistors. SSDs mainly contain PGMs and silicon metals. The most interesting property is the higher read and write speed compared to HDDs. The absence of mechanical parts in SSDs make the reading process faster, given that fragmentation of data does not affect the speed of the process. The heat and the noise produced are also much lower than those from HDDs, so the energy savings in cooling are also an advantage of this technology.

2.2 Technical evolution of servers and data storage products

2.2.1 A movement from HDD to SSD

In the current regulation, the information requirements relevant for CRMs focus on neodymium in HDDs

(Hard Disk Drives), and cobalt in batteries. In this regard, the replacement of HDDs by SSDs (Solid-State Drivers) and how this is affecting servers is a significant technology change.

Input from stakeholders

Question: ***What type of data storage products are used in data centres and is there a trend towards one or the other?***

Answer 1: "*We expect the % of SSD to continually increase in comparison to HDD."*

Answer 2: *"We can confirm that the development is going from HDD to SSD "*

Question: ***To your knowledge, can the replacement of HDDs by SSDs affect material efficiency and circularity of servers and storage, or more generally on ICT products?***

Answer 1: ***"****The CEDaCI project's criticality assessments show that criticality risk is lower in SDDs than HDDs per unit of storage (GB/TB etc)."*

Answer 2: "*Not to a great extent. According to analysis I have seen, there is strong overlap between SSDs and HDDs".*

The foresight study by JRC (2023a), finds that HDDs are gradually being replaced by SSDs. This observation was supported by the stakeholders interviewed for this project.

This replacement will influence the content of CRMs in servers and data storage products, especially as it will reduce the content of neodymium. SSDs do not contain magnets and thus no neodymium, but SSDs is constituted by flash memories containing high purity silicon metal among other CRMs found in PCBs. The weight of CRMs is lower in SSDs compared to HDDs, however, the number of different CRMs is higher. The CEDaCI project assesses that the criticality of SSDs is generally lower than HDDs. But as the heterogeneity is higher in SSDs it might be even more difficult to achieve circularity of the materials used in them as recycling streams will be smaller and the materials more mixed. The functionality of the two types of drives also differs, and so it is not considered prudent to push for a faster shift towards SSDs through regulation or to promote the replacement through other means. This is further elaborated in Section 021.

When switching from HDD to SDD it is, also important to be aware of a potentially increased climate impact from the production phase, as at least one product declaration from Samsung, cited in the 'Ecodesign preparatory study on enterprise servers and data equipment', estimates that the emissions of greenhouse gases is more than 6 times higher for the production of SSDs.

As for the batteries, these are typically small CR2032 lithium batteries for preserving the memory data, during power absence. This battery technology is expected to continue to be used in the near future.

2.2.2 Gallium based semiconductors

There are constant innovations and changes made in the tech industry. One of them is the increasing use of gallium nitride (GaN) semiconductors as an alternative to the typical silicon semiconductors used in PCBs (S. Glaser, 2023). As literature indicates that this type of semiconductor has the potential to yield higher energy efficiency than the typical silicon version, it might become an increasingly utilized technology, to meet continues energy efficiency targets. As gallium is also a CRM, this change in technology will switch rather than reduce the number of CRMs in servers and data storage products. If this technology becomes market dominant a large part of the silicon metal currently found in servers and data storage products, will be replaced by gallium. However, the weight of gallium needed in semiconductors is unknown.

Input from stakeholders

Question: Do you see quantum computers becoming an integral part of data centers in the future?

***Answer:** "Yes, it will replace other servers and become an integral part of DCs, but the timeframe is currently not clear."*

Question: *Do you know any technological evolution that can affect material efficiency and circularity of servers and storage, or more generally on ICT products?*

Answer: *"Possibly quantum computing but it is still very conceptual and there are no LCAs or CRM studies to date."*

2.2.3 Quantum computing

The company IBM Quantum has announced plans to open the first quantum data centre in Europe, which is scheduled to be operational in 2024 (IBM, 2023). IBM Quantum already operates a quantum data centre in New York, USA, (IBM, 2022), and the company Equinix have installed a quantum computer in their data centre in Tokyo (Equinix, 2023). The technology is still in its very early stages, but as the examples above show the technology is already being tested at large scales. If it overcomes its technical barriers, it has the potential to become a market disruptor. Although the broad use of quantum computers in the data centre industry might still be several years into the future, it would be prudent to take the market impact into consideration.

Although data is still poor the content of CRMs quantum devices is analysed in a Dutch study from 2021 (Gloria, 2021). It has assessed the contents of CRMs in different selected Quantum communication devices and the results are shown in the Figure 1. CRMs in electronics are not included in the figure, since no proper data could be retrieved on what kind of PCBs were used in the different devices.

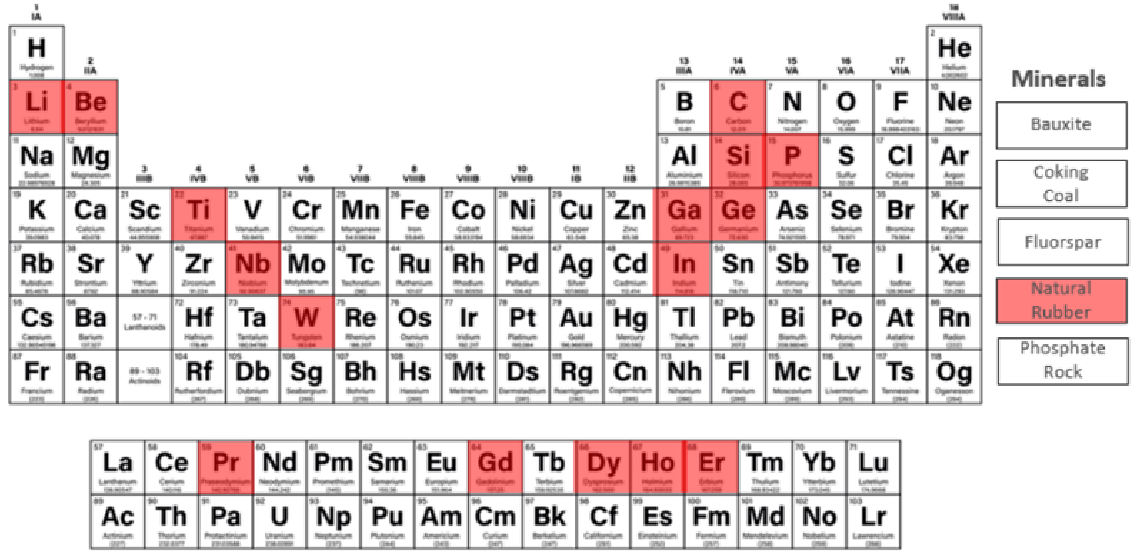

Figure 1. Critical Raw Materials contained in Quantum Technologies (PCBs not included).

2.2.4 On premises or cloud-based solutions

Historically, servers were set up at the same physical location where the service was needed – a model also known as a physical DC model (WeLOOP, 2020). However, there has been a paradigm shift towards data virtualization and the utilization of Cloud Data Centres, where data can be stored and accessed in and from different locations. This has given rise to massive-scale data centres owned and operated by the data storage providers. It was estimated in the ICT Impact study from 2020, that Cloud Data Centres represented 83% of the market in 2016 and was anticipated to handle 94% of the total global workload by 2021 (VHK and Viegand Maagøe, 2020). See the graph and table below.

Input from stakeholder

"Most in quantities are in the data centres. Normal servers are 50/50 between the two, but customized are most in DCs." – Industry organisation"

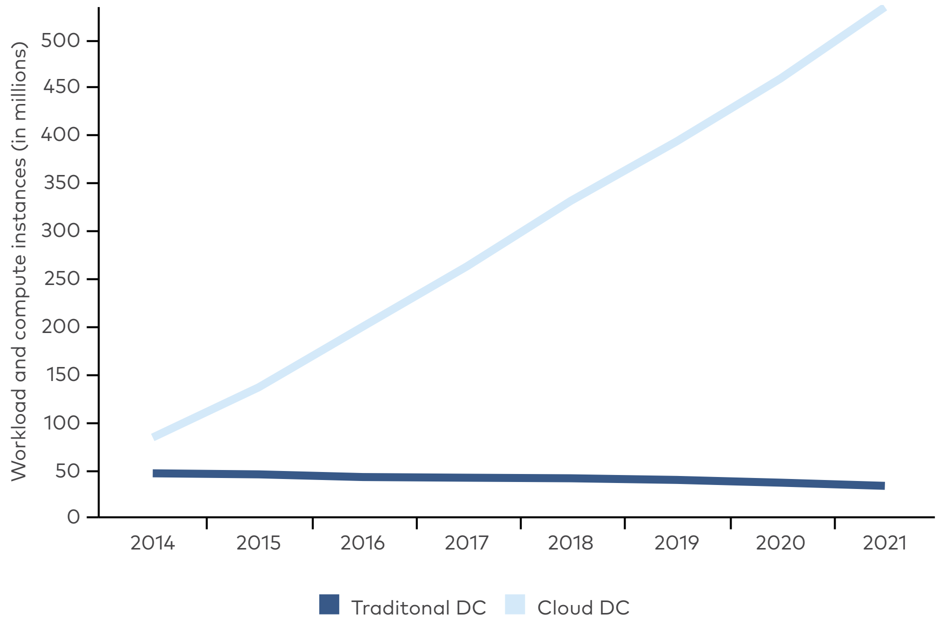

Figure 2. Expected global trend in internet traffic and data centre workloads 2014-2021. Based on data from (VHK and Viegand Maagøe, 2020)

Table 1. Share of total workload and compute instances between traditional data centers and cloud data centres. Source: (VHK and Viegand Maagøe, 2020)

	2014	2015	2016	2017	2018	2019	2020	2021
Traditional DC	36%	25%	17%	14%	11%	9%	7%	6%
Cloud DC	64%	75%	83%	86%	89%	91%	93%	94%

Speaking with stakeholders there seems to be less of a clear trend in regard to where the majority of servers can be found. It was argued by one stakeholder, that it has become much easier and cheaper to get highly energy efficient on-premises service solutions, which have a faster response time than cloud. Another argued that the GDPR had been a hindrance for many to shift to cloud, as the DC were often located outside EU, and not compliant with the regulation. Although there appears to be consensus that DC's handle most of the data traffic, it was estimated by one stakeholder that the share of market servers (not custom made) was distributed with a 50/50 share between cloud and on-premises solutions. This was not contested by any of the other stakeholders when presented with the information.

Input from stakeholders

"The trend is that more companies are moving part of their storage to their own premises away from the cloud. It is easier to get energy efficient solutions in server rooms today than what it used to. Having the servers on premise can give a higher respond time." – Industry organisation

"As long as there are no security issues, then people are shifting to cloud" – Procurer

"People are moving away from cloud and towards ownership." – Refurbisher

"GDPR has been an obstacle for more companies to transition to the cloud. Most cloud companies are not located in the EU, so they have not complied with the EU's GDPR regulations. However, this is supposed to have been resolved now." - Procurer

2.3 Critical raw materials

Servers and data storage products include various precious and critical raw materials. Raw materials are crucial to Europe's economy and to the economy of the Nordic countries. A secure and sustainable supply of raw materials is a prerequisite for a resilient economy and raw materials are essential for the green and digital transition which is of high priority in both the EU and in the Nordic countries.

The supply of many critical raw materials is highly concentrated. For example, China provides a very large share of EU's supply of rare earth elements (European Commission, 2023a) (100% of HREEs[8] and 85% of LREEs[9]) and 85% of the EU supply of Neodymium. Turkey provides 99% of the EU's supply of borate, and South Africa provides 71% of the EU's needs for platinum and an even higher share of the platinum group metals iridium, rhodium, and ruthenium. 63% of the world's cobalt, used in batteries, is extracted in the Democratic Republic of Congo, while 60% is refined in China (European Commission, 2023b). This concentration exposes the EU to significant supply risks. There are precedents of countries leveraging their strong position as suppliers of CRMs against buyer countries, for instance through export restrictions.

The EU has in December 2023 adopted a new regulation on strategic and critical raw materials (see more in section 4. The regulation includes in its Annex 1 a list of strategic raw materials as well as an updated list of critical raw materials.

8. HREEs: Dysprosium, erbium, europium, gadolinium, holmium, lutetium, terbium, thulium, ytterbium, yttrium
9. LREEs: Cerium, lanthanum, neodymium, praseodymium and samarium

Strategic materials are selected based on the relevance of a raw material for the green and digital transition and defence and space applications, taking into account:

- the amount of strategic technologies using a raw material as an input
- the amount of a raw material needed for manufacturing relevant strategic technologies
- the expected global demand for relevant strategic technologies.

Various of the materials are categorised as both strategic and critical materials.

2.3.1 List of critical raw materials

Every third year the EU publish a list of critical raw materials (CRMs). The list is based on an assessment covering a larger number of materials. The fourth list was published in 2020 (European Commission, 2020a) and the fifth list in 2023 (European Commission, 2023a).

The first assessment (2011) identified 14 critical raw materials (CRMs) out of the 41 nonenergy, non-agricultural candidate raw materials. In the 2014 exercise, 20 raw materials were identified as critical out of 54 candidates. In 2017, 27 CRMs were identified among 78 candidates in 2017. The 2020 list includes 30 raw materials identified as critical.

According to the Critical Raw Materials Alliance (n.d.), Critical Raw Materials (CRMs) are those raw materials, which are economically and strategically important for the European economy but have a high-risk associated with their supply. They are classified as 'critical' because:

- They have a significant economic importance for key sectors in the European economy, such as consumer electronics, environmental technologies, automotive, aerospace, defence, health and steel.
- They have a high supply risk due to the very high import dependence and high level of concentration of set critical raw materials in particular countries.
- There is a lack of (viable) substitutes, due to the unique and reliable properties of these materials for existing, as well as future applications; combined with low recycling rates.

The Commission committed to updating the list at least every 3 years to reflect production, market, and technological developments.

Fifth list of critical raw materials

The fifth technical assessment 2023 of critical raw materials screens 70 candidate raw materials comprising 67 individual materials and three materials groups: ten heavy rare earths elements (HREEs), five light rare earths elements (LREEs), and five platinum-group metals (PGMs), 87 individual raw materials in total (European Commission, 2023a).

Four new materials have been assessed: neon, krypton, xenon and roundwood. Titanium metal has been assessed in addition to titanium. Aluminium and bauxite have been merged for consistency reasons.

The proposal of the CRM Act Regulation contains the list of Strategic Raw Materials (SRMs) and the list of CRMs. The Regulation proposes to automatically add SRMs selected based on a new methodology (Annex 1 of the Regulation) on the CRMs list, defined by the established CRM methodology (Annex 2 of the Regulation). The CRM methodology was developed by the European Commission in cooperation with the Ad hoc Working Group on Defining Critical Raw Materials (AHWG) in 2017. The methodology is based on the two main criteria of Economic Importance (EI) and Supply Risk (SR). The thresholds remain at SR ≥ 1.0 and EI ≥ 2.8 rounded to one decimal. The method is described in Annex II of the proposed regulation (European Commission, 2023b).

Main results of the 2023 criticality assessment

Table 3 shows the 34 raw materials proposed for the CRM list 2023. New CRMs compared to the 2020 CRM list are shown in italics. The list includes both critical and strategic raw materials. Table 2 highlights the strategic materials in italics.

New CRMs on the list in 2023 are arsenic, feldspar, helium, manganese, copper and nickel. Copper and nickel do not meet the CRM thresholds but are included as Strategic Raw Materials. Materials that are no longer on the list are indium and natural rubber. For indium used in flat panels displays both supply risk and economic importance of have dropped below thresholds and for Natural rubber used in tyres the supply risk has decreased below the threshold mainly due to increased recycling. See Table 4 for comparison of the 2023 list with the one from 2020. The materials in red are new materials in the list in 2023 compared to the list in 2020. It is important to notice that with the adoption of the Critical Raw Materials Act in December 2023 two changes were made to the list. Aluminium/Bauxite is changed to Bauxite/Alumina/Aluminium (to include alumina the intermediate processing form of aluminium) and 'Graphite – battery grade' is added to the list.

Table 2. Critical raw materials in the 2023 CRM list. *Copper and nickel do not meet the CRM thresholds but are included as Strategic Raw Materials. PGM: Platinum Group Metals. Source: (European Commission, 2023a)

2023 Critical Raw Materials (new CRMs in italics)			
Aluminium/bauxite	Coking coal	lithium	phosphorus
Aantimony	*feldspar*	LREE	scandium
arsenic	fluorspar	magnesium	silicon metal
baryte	gallium	*manganese*	strontium
beryllium	germanium	natural graphite	tantalum
bismuth	hafnium	niobium	titanium metal
boron/borate	*helium*	PGM	tungsten
colbalt	HREE	phosphate rock	vanadium
		*copper**	*nickel**

Table 3. Critical raw material list 2023 with strategic raw materials in italics. *Copper and nickel do not meet the CRM thresholds but are included as Strategic Raw Materials. PGM: Platinum Group Metals. Source: (European Commission, 2023a)[10].

2023 Critical Raw Materials (Strategic Raw Materials in italics)			
Aluminium/bauxite	Coking coal	*lithium*	phosphorus
Aantimony	feldspar	LREE	scandium
arsenic	fluorspar	*magnesium*	*silicon metal*
baryte	*gallium*	*manganese*	strontium
beryllium	*germanium*	*natural graphite*	tantalum
bismuth	hafnium	niobium	*titanium metal*
boron/borate	helium	PGM	*tungsten*
colbalt	*HREE*	phosphate rock	vanadium
		*copper**	*nickel**

10. With the adoption of the Critical Raw Materials Act in December 2023 two changes have been made to the list. Aluminium/Bauxite is changed to Bauxite/Alumina/Aluminium (to include alumina the intermediate processing form of aluminium) and 'Graphite – battery grade' is added to the list.

Table 4. Comparison of the 2020 CRM list with the 2023 list. Source: (European Commission, 2023a). See also footnote 9.

2023 Critical Raw Materials (Strategic Raw Materials in italics)			
Aluminium/bauxite	gallium	phosphate rock	vanadium
Aantimony	germanium	phosphorus	arsenic
baryte	hafnium	PGM	feldspar
beryllium	HREE	scandium	helium
bismuth	lithium	silicon metal	maganese
borate	LREE	strontium	copper
colbalt	magnesium	tantalum	nickel
coking coal	natural graphite	titanium metal	~~indium~~
fluorspar	niobium	tungsten	~~natural rubber~~

Legend:
Black: CRMs in 2023 and 2020
Red: CRMs in 2023, non-CRMs in 2020
~~Strike:~~ Non-CRMs in 2023 that were critical in 2020

The three materials groups on the list contain:

- **HREE**: dysprosium, erbium, europium, gadolinium, holmium, lutetium, terbium, thulium, ytterbium, yttrium
- **LREE**: cerium, lanthanum, neodymium, praseodymium and samarium
- **PGM**: iridium, palladium, platinum, rhodium, ruthenium

2.3.2 Conflict materials

Two of the materials on the EU list of critical raw materials are also appointed as conflict materials in the EU Conflict Minerals Regulation[11]. The four materials mentioned in the Conflict Materials Regulation are tin, tantalum (strategic raw material), tungsten (critical raw material) and gold[12]. All the four conflict materials are used in server and data storage products.

11. REGULATION (EU) 2017/821 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 May 2017 laying down supply chain due diligence obligations for Union importers of tin, tantalum and tungsten, their ores, and gold originating from conflict-affected and high-risk areas https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2017:130:FULL
12. https://policy.trade.ec.europa.eu/development-and-sustainability/conflict-minerals-regulation_en

The conflict materials come from politically unstable areas, where the minerals trade can be used to finance armed groups, fuel forced labour and other human rights abuses, and support corruption and money laundering. The Conflict Minerals Regulation aims to help stem the trade of four minerals which as mentioned sometimes finance armed conflict or are mined using forced labour.

2.3.3 Use of critical Raw materials

The EU foresight study (JRC, 2023a) investigates the use and supply chain structure and future demand for the main raw materials of 15 selected key technologies across the five strategic sectors (renewable energy, electromobility, energy intensive industry, digital, and aerospace/defence great importance for the green transition and digital development. The analysis includes data servers and storage products in the sector digital.

The study shows that various strategic and critical raw materials are used in the selected technologies including for servers and data storage products.

Strategic raw materials found in servers and data storage: Gallium, Magnesium, REE (magnets)[13] Boron, PGM (platinum-group metals), Bismuth, Germanium, Silicon Metal, Manganese, Nickel, and Copper

Critical raw materials found in servers and data storage: HREE (rest)[14], Phosphorus, Scandium, Antimony, Beryllium, Arsenic, Hafnium, Baryte, Aluminium, and Helium.

The highest supply risk is found for Gallium, Magnesium, REE (magnets), Boron and HREE (rest).

According to the study cobalt is not used in servers and data storage products. But other sources indicate that cobalt is included in the batteries.

2.3.4 Supply of critical raw materials

CRMs are supplied to the EU from all over the world. Figure 3 gives an overview of the biggest suppliers to the EU of specific raw materials. As can be seen, China is a major supplier of many CRMs to the EU, and many other countries are the primary supplier of specific raw materials such as South Africa, Chile, Brazil, DR Congo, Turkey, Guinea and Kazakhstan. For some CRMs EU countries contribute significantly to the EU supply e.g. hafnium from France, strontium from Spain and nickel from Finland.

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13. REE (magnets): REE used in permanent magnets such as neodymium and dysprosium
14. Without the RRE in the magnets

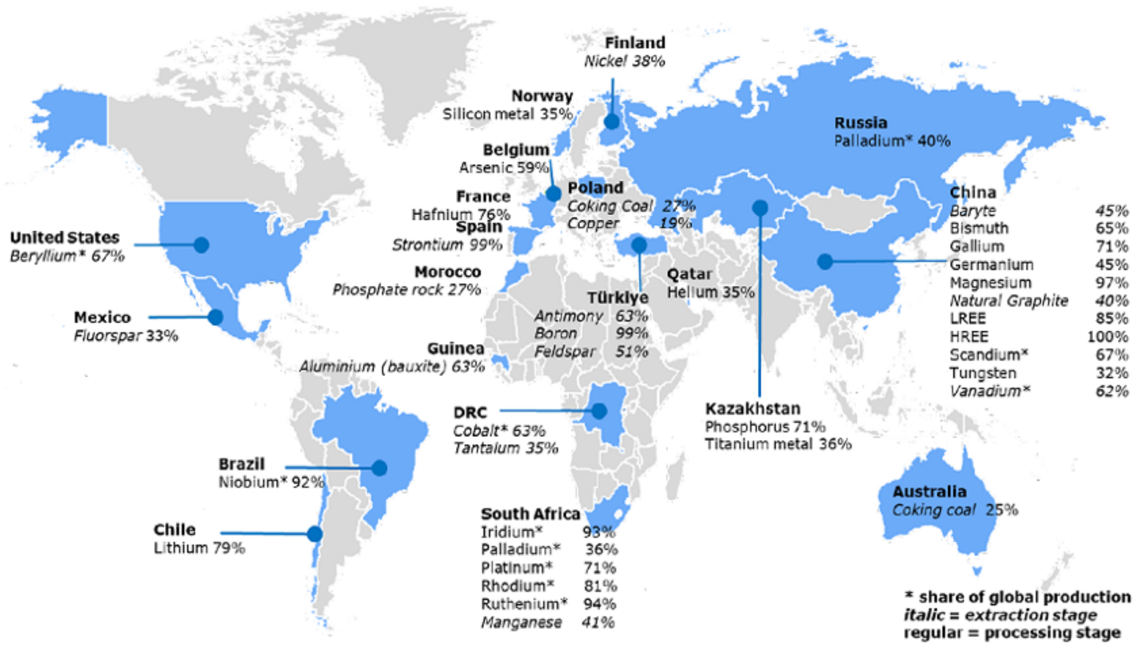

Figure 3. The biggest suppliers of CRM to the EU (European Commission, 2023a).

There are several differences on the map compared to the situation in the previous assessment (European Commission, 2022a): Belgium appears as the major EU supplier of arsenic (59%); major production of germanium in Finland ceased in 2015; Finnish production of nickel doubled and supplies 38% of the EU consumption; Germany ceased gallium production in 2016 and China became major supplier to the EU with 71%; Qatar appears as the main supplier of helium (35%); South Africa is our main supplier of manganese with 41%. It also appears that the Nordic countries are the main suppliers of CRMs to the EU on a few CRMs, i.e. silicon metal and nickel. For these materials Finland's share is 38% of the EU supply of nickel and Norway's share is 35% for silicon metal.

However, other CRMs such as copper, cobalt, phosphate, and platinum are also extracted in the Nordic countries, but only in small amounts compared to the global supply.

Figure 4 shows the European countries share of the global extraction and processing of CRMs. As the figure shows, the EU only account for a small share of the global CRM extraction, with the exception being the extraction of strontium in Spain.

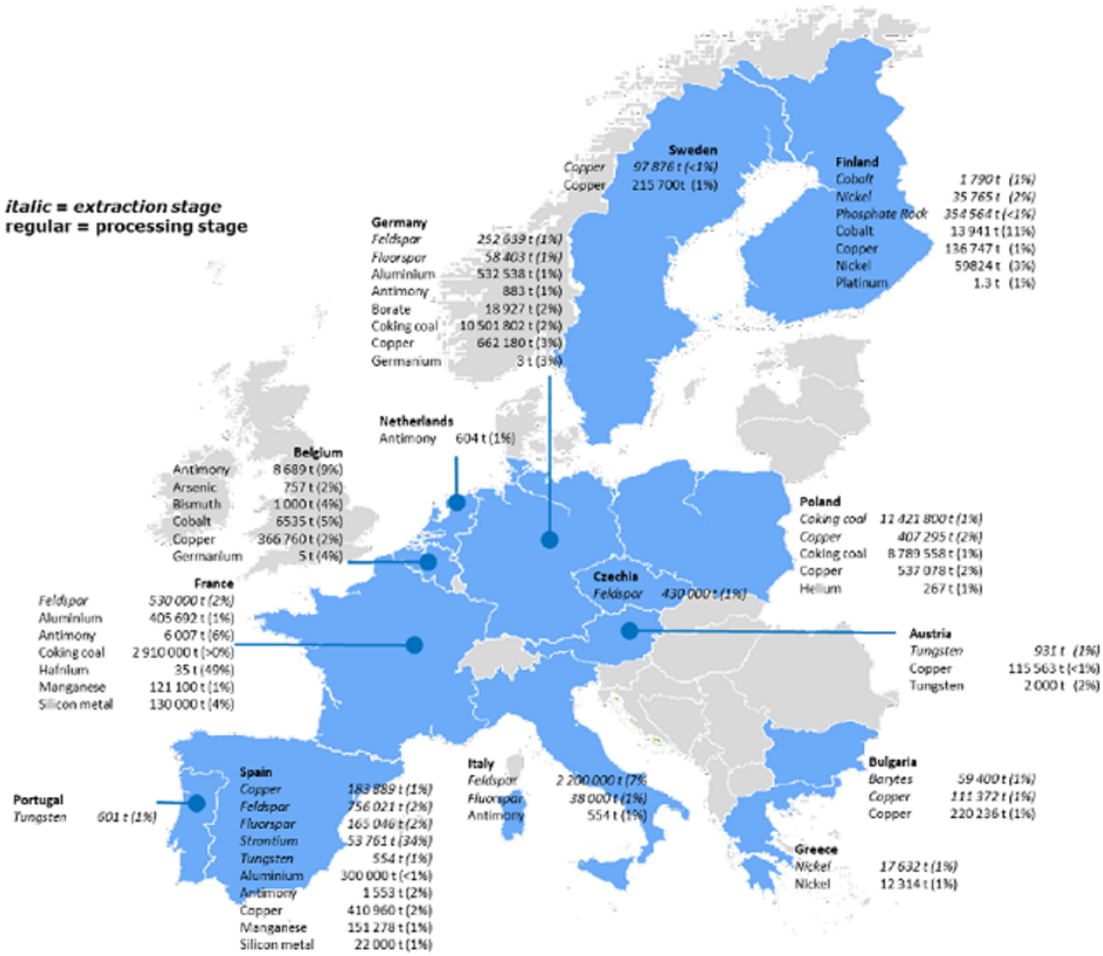

Figure 4. EU producers of CRMs with a global share of over 0.5%. Share of **global supply** in brackets. (2016–2020) (European Commission, 2023a).

2.3.5 Reserves of CRMs in the EU and Nordic countries

There are various reserves of CRMs in the EU and in the Nordic countries which are currently not utilized (mined). Specifically, Finland, Iceland, Norway, Sweden and Greenland, feature some of the most extensive active mining industries, mining and mineral processing technology developers, and untapped mineral and metal resources in Europe today (Eilu, et al., 2021).

It is increasingly recognized that mining countries now aspire to higher environmental, social and governance standards for exploitation and production of metals and minerals on a global scale. Here, the Nordic countries have several advantages due to a combination of a longstanding and technologically highly developed mining and mineral processing industry combined with strict environmental and health regulations. Expanding production in the Nordic countries would contribute to making Europe more resilient to supply risk and help to secure more responsible sourcing of the raw materials that are necessary for a green energy transition. This should preferably also include the development of new processing and manufacturing capacity for CRMs, such as the REEs, to ensure complete European supply chains and, thus, minimize supply risk issues.

Figure 5 shows an overview of all major known critical metal and mineral deposits, and their most prospective areas (in pink) in the Nordic countries. The mapping includes all critical raw materials on the EU 2020 list of critical raw materials. Recently the EU has published a new 2023 list with some new critical materials which are not included in the mapping. The new materials are arsenic, feldspar, helium, manganese, copper, and nickel. Regarding the new materials Finland in a large supplier of nickel. The figure shows that there are various unexploited deposits of critical raw materials in the Nordic countries. Iceland is not shown in. Overall, only sparse occurrences of CRMs are known in Iceland, but do include baryte, fluorspar and titanium, and also minor non-CRM albeit green energy relevant copper mineralization.

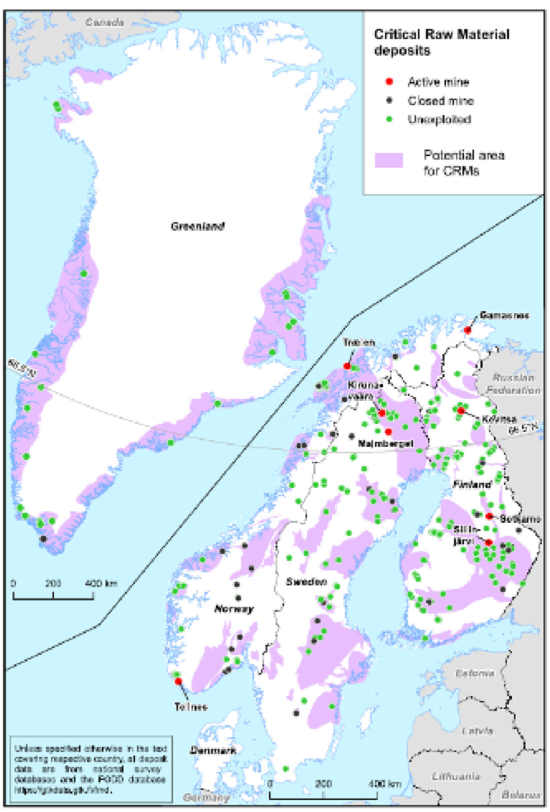

Figure 6. Map of all major known critical metal and mineral deposits, and their most prospective areas (in pink) in the Nordic countries (2020 list of CRMs). Mines in active operation (red dots) are named. Note that production at Kiruna and Malmberget is currently of iron ore only (Eilu, et al., 2021).

2.3.6 Future needs for CRMs

The 2023 foresight study also assesses the EU's materials needs and vulnerabilities now and in the future for the 15 key technologies.

It estimates that the need for CRMs in Europe will increase significantly over the coming decades. Table 5 shows the projected increase in CRMs in 2030 and 2050 compared to 2020.

Table 5. Projected demand of selected CRM in 2030 and 2050 compared to 2020 (JRC, 2023a).

CRM	2030	2050
Lithium	x 12	x 21
Graphite	x 14	x 26
Cobalt	x 6	x 5
Nickel	x 10	x 16
Dysprosium	x 6	x 7
Terbium	x 4	x 5
Neodymium	x 5	x 6
Praseodymium	x 4	x 4
Platinum	x 30	x 200
Silicon metal	x 2	x 1
Copper	x 6	x 10
Aluminium	x 4	x 6

It can be observed that the demand for almost all the select CRMs is projected to increase significantly. Especially, the use of Platinum is expected to increase dramatically (x 30 in 2030 and x 200 in 2050). Platinum is one of the materials in the PGM group[15] of materials and is used in servers. This will make the EU increasingly dependent on their suppliers of CRMs to fulfil the demand of its industries, such as the sectors working with electronics (including servers and data storage) and renewable energy.

15. PGM group: iridium, palladium, platinum, rhodium, ruthenium.

Emerging technologies such as ferroelectric RAM would require up to 40 kilotons of platinum, which is about 600 times the currently yearly demand of the EU. With regards of tantalum, its main application is in special capacitators, characterised by high capacitance, small size and high performance. Thin layers of tantalum are also used in integrated circuits. Tantalum's use in electronic applications will also increase dramatically, and it could overtake the current use of this material of all applications factored together. On the other hand, other CRMs such as gallium, dysprosium, palladium are expected to stagnate, according to some sources mentioned in the foresight study. However, the authors highlight that these scenarios are based on conservative and technology-constant approach of digitalisation, and other sources suggest a much larger increase in material consumption.

2.3.7 Secondary raw material input

A higher share of End-of-Life recycling of critical raw materials could help reduce the supply risk. The 2023 EU CRM study reports end-of life recycling input rates (EOL-RIR) for CRMs as shown in Figure 6 (European Commission, 2023a).

The End-of-Life Recycling Input Rate (EOL-RIR) is the percentage of overall demand that can be satisfied through secondary raw materials (resulting ratio of recycling from old scrap to European demanding the manufacturing stage).

The data on EOL-RIR shows that there for some materials is no input from recycled material in the manufacturing process which indicates that there might be a large unexploited source of CRMs in the products we throw out, which if fully utilized could supply a large part of the EU's demand for certain CRMs.

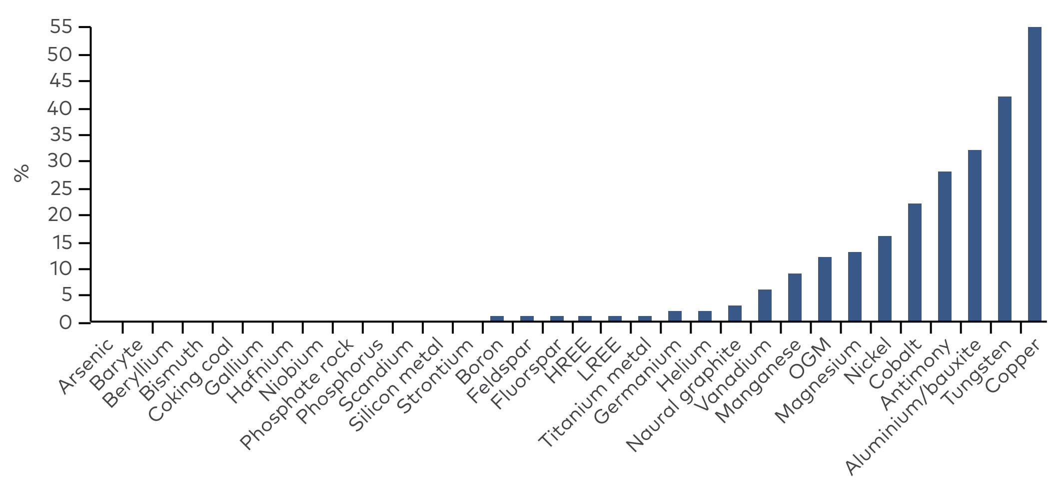

Figure 6. End of life recycling input rate (EOL-RIR). Source: (European Commission, 2023a)

2.4 Plastics

Plastics are widely used in energy related products and also in servers and data storage products, where it is often found in e.g., the chassis, fans and cables. Plastics is indicated by literature to make up between 1–7% of the total server weight, see Section 4.1.4 and 4.5.2.

Plastic is an extraordinarily versatile material. When subjected to heat, it becomes highly malleable, allowing for the creation of a vast array of shapes and forms. By introducing various additives, plastic can be tailored to possess a wide range of properties, making it suitable for even the most demanding applications. However, this inherent adaptability, which proves invaluable during its use in products and various applications, transforms into a significant challenge when it reaches the hands of recyclers upon disposal.

The issue arises from the fact that different types of plastics do not blend well together. To obtain a high-quality secondary plastic stream, an effective separation process is essential. This separation can be particularly challenging when plastics are part of a composite with other materials. Additionally, the presence of various additives in plastics, such as dyes, fillers, and flame retardants, further complicates the recycling process.

Recycling the material also needs to be economically viable, and for this to happen several factors must align. There needs to be a substantial waste stream of plastic material, the plastic must be recyclable into a sufficiently high-quality product, and there must be a market demand for the recycled material.

In this section, we address the current state of plastics recycling in the European Union, highlighting the need for improvements in recycling practices, especially concerning servers and data storage products. Later in the report, we will explore the types of plastics commonly found in servers and propose strategies to enhance their recyclability.

2.4.1 Current state of plastics recycling and policy in the EU

To sketch out the playing field, we should first look at what the legislative focus on plastic has been over the last years. In December 2015, the Commission adopted the first Circular Economy Action Plan (CEAP), in which plastics were identified as a focus area (European Commission, 2015a). In 2018 this resulted in the creation of 'A European Strategy for Plastics in a Circular Economy', which set out key commitments for action at EU level (European Commission, 2018a). In March 2020 The European Commission adopted the new Circular Economy Action Plan (CEAP), which is an initiative under the European Green Deal, Europe's new agenda for sustainable growth (European Commission, 2020b).

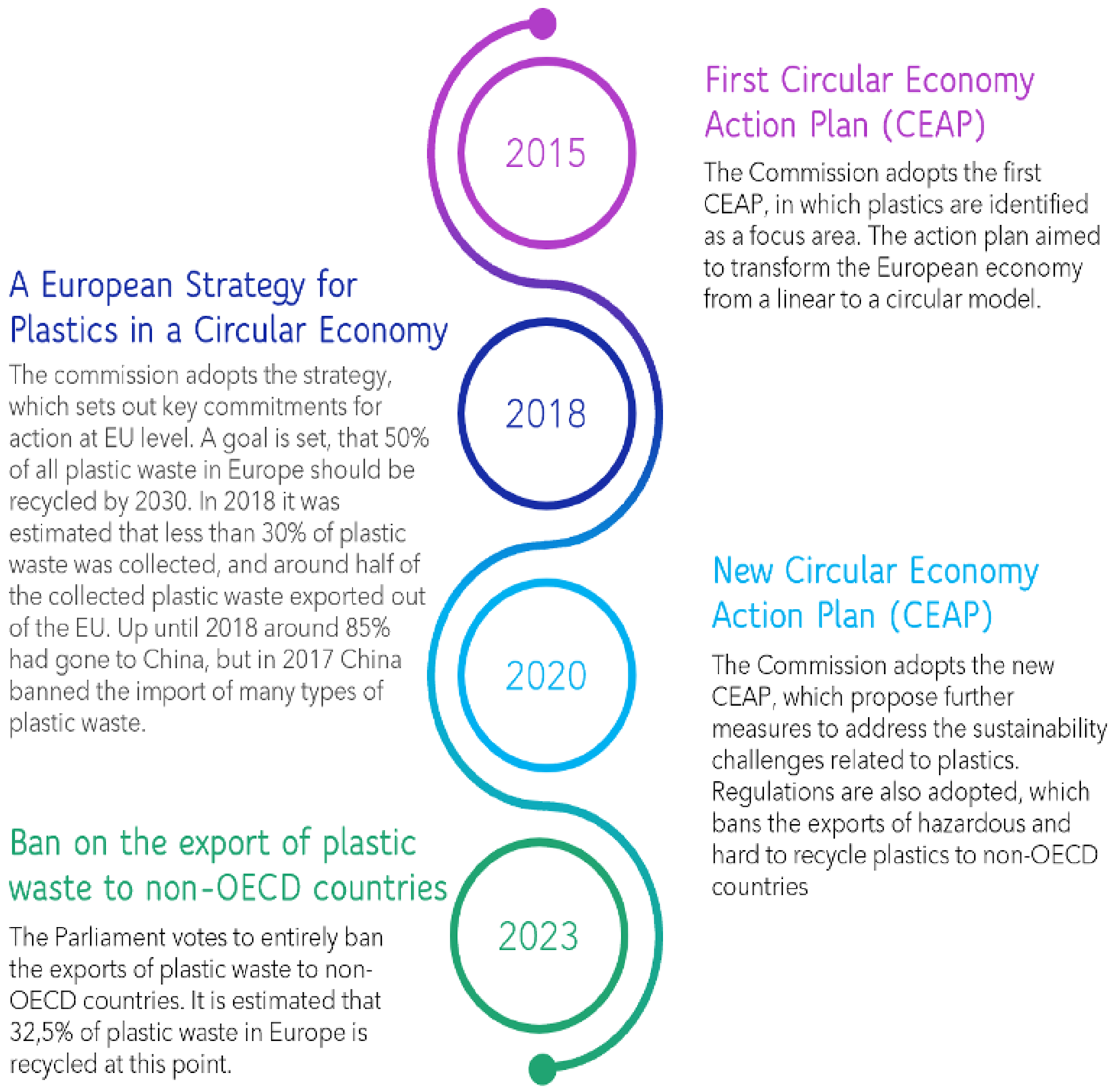

Figure 7. Selected EU legislation on plastics. Own creation.

In a communication from the European Commission in 2018 on 'A European Strategy for Plastics in a Circular Economy', a strategic vision for Europe's new plastics economy was sketched out (European Commission, 2018a). The vision states that by 2030 more than half of all plastics waste generated in Europe should be recycled. In 2018 the available data showed that less than 30% of plastic waste in Europe was collected for recycling, and that around half of it was sent outside of Europe for treatment. This export of, often low quality, plastic waste has been the topic of much debate and has generated significant attention over environmental, economic, and ethical concerns. Before 2018 close to 85% of the exported plastic waste had furthermore gone to China, where its subsequent fate is unknown.

However, in 2017 China banned the import of many types of plastic waste fractions which fostered an abrupt shift in the European plastic waste management strategy. In 2020 the EU adopted regulations banning the exports of hazardous and hard to recycle plastics to non-OECD countries (European Parliament, 2020), and in January 2023 the EU Parliament voted to entirely ban the exports of plastic waste to non-OECD countries (EU Monitor, 2023).

Currently the estimated recycling rate of plastics in the EU is estimated at 32,5% based on 2018 numbers (European Parliament, 2023a). Around half of all plastic waste collected in the EU is still exported to be treated outside the EU.

The current political focus and discourse on plastic waste exports reflects a growing awareness of the need to manage plastic waste more responsibly and sustainably, both at the national and international levels. However, it puts pressure on the European recycling infrastructure, which consequently will have to manage a larger amount of plastic waste than it currently does. Hopefully it will create incentives to invest, expand, regulate, and redesign.

2.4.2 The impact of plastic consumption, waste, and recycling

About 6% of global oil consumption is used to produce plastics; by 2050, this share could reach 20% (European Parliament, 2023b). This is due to an expected doubling of plastics consumption in the coming 20 years (European Commission, 2020b), coupled with a general reduction in the use of oil for fuel and energy purposes.

The European plastic use makes up around 14% of the global use (Statista, 2023), and electronics accounts for around 6% of the European plastics demand (Plastics Europe, 2022). Servers and data storage devices makes up an unknown portion of the electronics plastics demand. The Information and communication technology (ICT) sector is, however, growing rapidly and two experts in the field, Deborah Andrews and Beth Whitehead, have projected the data centre industry to increase fivefold towards 2030, compared to 2018 (Andrews & Whitehead, 2019).

ICT products are becoming more technologically advanced, incorporating intricate plastic elements and plastics fused with other materials, as well as containing hazardous components that create obstacles for recovery within current recycling systems (European Commission, 2018a). The products also contain many different types of polymers, which can be difficult for the recyclers to identify, and the products can be hard and time consuming to dismantle.

In the communication from the EC it is stated, in relation to the recycling of plastics from electronics, together with the automotive and construction industry, that:

> ***"There is little incentive to take into account recycling or reuse aspects when designing plastics for applications in [...] electronics given that the plastic waste fraction is small and there are no EU wide targets for recycling and recovery." –(European Commission, 2018a)***

It further states, that the EU targets on plastics recycling can be met with only a minimum amount of recycling of plastics from the electronics, automotive and construction industry (European Commission, 2018a). This together with the small waste fractions, and the lack of specific reuse and recycling targets, creates little incentive to account for end-of-life aspects in the design phase. Thus, design for reuse and recycling has generally not been a priority for the EEE industry. It is important to create this incentive so that the end-of-life aspects can be prioritised in the design phase on par with the technical, economic, and marketing aspects.

Conversely, increased regulation on environmentally hazardous substances in plastics has enhanced the opportunity for recycling, as many harmful substances have been, and continues to be, phased out (European Commission, 2018a). Although, hazardous substances within WEEE are still considered to be a major obstacle to recycling. When it comes to reuse of plastic parts from WEEE, the lack of standardisation in part types is brought forth as the main obstacle for large scale reuse. As there is a limited number of players on the data centre server market, and the end users of the products is often businesses, there might be an opportunity to create standardisation on plastic types and additives used, which would create larger and cleaner waste streams, with the possibility of establishing closed loop recycling.

3 Legislation, voluntary initiatives, and standards

There are various standards and EU legislation relevant for servers and data storage products. This section will describe the ones that are considered most relevant for elaboration of material efficiency requirements within the EU ecodesign framework.

The addressed legislation, voluntary measures and standards are:

Legislation:

- The ecodesign framework Directive and the Ecodesign for Sustainable Products Regulation (ESPR)
- Critical Raw Materials ACT (CRMA)
- The current ecodesign regulation for servers and data storage products
- Energy Efficiency Directive (EED)
- The ecodesign and energy labelling regulations for smartphones and tablets as examples of regulations with extended material efficiency requirements
- Product specific legislation: Batteries.

Voluntary measures:

- The EU GPP criteria (Green Public Procurement criteria) for servers, data storage and network equipment
- Taxonomy (Mandatory for some companies)
- EU Code of Conduct on Data Centre Energy efficiency
- Data Centers (DE-UZ 228) – Blue Angel
- Climate Neutral Data Centre Pact.

Standards

- EU material efficiency standards
- EN standards in the EN 303 800 series
- ITU standards especially relevant for servers and data storage products
- Data sanitation standards
- Development of standards to support 2019/424 (Mandates)
- Development of standards regarding Plastics recycling, and recycled plastics. Plastic (M/584).

There are various other EU legislations which are relevant for the material efficiency of servers and data storage products including among others the WEEE Directive[16], and the RoHS Directive[17] but they are not described in detail in this report.

3.1 Legislation

3.1.1 The Ecodesign Directive and the Ecodesign for Sustainable Product Regulation (ESPR)

The EU Ecodesign Directive[18] is the framework for setting of ecodesign requirements for energy related products such as servers and data storage products.

The Directive can be used for adoption of both energy efficiency requirements and requirements with regard to resource efficiency and circularity of products. While regulations adopted within the ecodesign framework in the beginning mainly focused on energy efficiency, the most recent regulations implement various detailed rules with regard to material efficiency.

The EU Commission are revising the Ecodesign Directive and published in March 2022 the proposal for a new Ecodesign for Sustainable Products Regulation (ESPR) [19] and in the beginning of December 2023 a provisional agreement on the Regulation was reached between European Parliament and the Council[20]. The next steps are the formal adoption of the new regulation by the European Parliament and the Council, and publication in the Official Journal. The Regulation will enter into force on the 20th day following its publication.

The ESPR extends the ecodesign framework in two ways: first, to cover the broadest possible range of products; and second, to broaden the scope of the requirements with which products are to comply.

The framework will allow for the setting of a wide range of requirements, including on:

- product durability, reusability, upgradability and reparability
- presence of substances that inhibit circularity

16. Directive 2012/19/EU of July 2012 on waste electrical and electronic equipment (WEEE) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02012L0019-20180704
17. Directive 2011/65/EU of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:02011L0065-20160715
18. Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32009L0125
19. Proposal for a Regulation of the European Parliament and of the Council establishing a framework for setting ecodesign requirements for sustainable products https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52022PC0142.

    A link to the final adopted act was not available at the time of publishing this report.
20. Provisional agreement between European Parliament and the Council on ESPR: https://ec.europa.eu/commission/presscorner/detail/en/ip_23_6257

- energy and resource efficiency
- recycled content
- remanufacturing and recycling
- carbon and environmental footprints
- information requirements, including a Digital Product Passport.

The "Digital Product Passport" will provide information about products' environmental sustainability. This information will be easily accessible by scanning a data carrier and it will include attributes such as the durability and reparability, the recycled content, or the availability of spare parts of a product. It should help consumers and businesses make informed choices when purchasing products, make it easier to repair or recycle products, and facilitate tracking substances of concern along the supply chain. It should also improve transparency about products' life cycle impacts on the environment and help public authorities to better perform checks and controls.

Labelling can be introduced as well. The proposal also contains measures to end the destruction of unsold consumer goods, as well as expand green public procurement and provide incentives for sustainable products.

For groups of products that share sufficient common characteristics, the framework will also allow for setting horizontal requirements.

3.1.2 Critical Raw Materials Act

The EU adopted in December 2023 the Critical Raw Materials Act (final act not yet available per January 2024). The aim of the act is to ensure that the EU have access to a secure and sustainable supply of CRMs and enable the Europe to meet its 2030 climate and digital objectives[21]. The act among others reduces the permitting times for domestic mining and recycling projects.

The act has the following general objectives:

- to strengthen the different stages of the European critical raw materials value chain
- to diversify the EU's imports of critical raw materials to reduce strategic dependencies
- to improve the EU capacity to monitor and mitigate current and future risks of disruptions to the supply of critical raw materials
- to ensure the free movement of critical raw materials on the single market while ensuring a high level of environmental protection, by improving their circularity and sustainability.

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21. Proposal for a Regulation of the European Parliament and of the Council establishing a framework for ensuring a secure and sustainable supply of critical raw materials https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52023PC0160. Final act not yest av

To achieve the general objective mentioned above the Regulation aims to:

a. strengthen the different stages of the strategic raw materials value chain with a view to ensure that, by 2030, Union capacities for each strategic raw material have significantly increased so that, overall, Union capacity approaches reaches the following benchmarks:
    i. Union extraction capacity is able to extract the ores, minerals or concentrates needed to produce at least 10% of the Union's annual consumption of strategic raw materials, to the extent that the Union’s reserves allow for this
    ii. Union processing capacity, including for all intermediate processing steps, is able to produce at least 40% of the Union's annual consumption of strategic raw materials
    iii. Union recycling capacity, including for all intermediate recycling steps, is able to produce at least 25%[22] of the Union's annual consumption of strategic raw materials. Additionally, the Union should be able to recycle significantly increasing amounts of each strategic raw material in waste.
b. diversify the Union's imports of strategic raw materials with a view to ensure that, by 2030, the Union's annual consumption of each strategic raw material at any relevant stage of processing can rely on imports from several third countries, none of which provide more than 65% of the Union's annual consumption
c. improve the Union's ability to monitor and mitigate the supply risk related to critical raw materials
d. ensure the free movement of critical raw materials and products containing critical raw materials placed on the Union market while ensuring a high level of environmental protection, by improving their circularity and sustainability.

More specific the regulation:

- sets out lists of strategic critical raw materials, to be reviewed at least *every three years*[23]. The lists and the methods to be used appear from Annex I (strategic raw materials) and Annex II (critical raw materials) of the Regulation.
- sets out a framework to strengthen the EU’s strategic raw materials value chain by selecting and implementing Strategic Projects, that will be eligible for streamlined permitting processes and facilitated access to financing opportunities, which will be also improved by better coordination (Chapter III of regulation)

22. This is changed in the final act (from 15% in the proposal)
23. This is changed in the final act (from four in the proposal)

- develops a mechanism for coordinated monitoring of critical raw materials supply chains and provides measures to mitigate supply risks. It sets out a framework for systematically monitoring critical raw materials supply risks at different stages of the value chains. It also sets out a framework for risk mitigation by coordinating strategic stocks for strategic raw materials, by requiring large importers and manufacturers to regularly audit their supply chains and facilitating the joint purchases of strategic raw materials (Chapter IV of Regulation).
- contains provisions for developing the circularity of critical raw materials markets and lowering the environmental footprint of critical raw materials (Chapter V of Regulation). This includes:
    - setting rules for Member States to adopt and implement measures on circularity, in particular with regard to waste streams with high critical raw materials recovery potential
    - setting rules for Member States and extractive waste operators to assess the potential to recover critical raw materials from extractive waste sites.
    - requiring of information on the type and composition of permanent magnets incorporated in products as well as on their recycled CRM content.
    - provides, following a dedicated assessment, for the introduction of minimum recycled content thresholds
    - setting out rules for the recognition by the Commission of certification schemes related to the sustainability of critical raw materials.
    - provisions regarding the declaration of the environmental footprint or critical raw materials placed on the EU market
    - rules on free movement, conformity and market surveillance related to products incorporating permanent magnets and CRMs for which the environmental footprint has to be declared.
- provides a framework for cooperation on Strategic Partnerships with third countries related to raw materials and to achieve greater synergies between Strategic Partnerships and Member States' cooperation with relevant third countries (Chapter VI of the Regulation).
- sets up a European Critical Raw Materials Board, composed of high-level representatives from the Member States and the Commission, which will chair the Board. The Board will provide advice to the Commission and assist with coordination, cooperation and information exchange to support the implementation of this Regulation. (Chapter VII of the Regulation).

In addition, the regulation includes various articles on penalties, monitoring progress and on carrying out an evaluation of the Regulation. It also establishes a common reporting for Member States related to different measures and contains an article ensuring that confidential information collected under this Regulation is handled in a consistent manner.

The regulation does also contain measures on recyclability of permanent magnets in several product groups, although for some reasons the list of product groups covered, does not include servers.

3.1.3 Ecodesign regulation for servers and data storage products

The ecodesign regulation for servers and data storage products (EU) 2019/424[24] was adopted in 2019 and the first requirements was applicable from 1st March 2020 including the material efficiency requirements and the information requirements regarding CRMs. No energy labelling regulation is adopted for servers and data storage products.

The material efficiency requirements in the ecodesign regulation deal with disassembly for repair and reuse of components, secure data deletion, availability of firmware and security updates, information requirement regarding content of cobalt in batteries and neodymium in HDDs (hard desk drives) and instruction on disassembly operations.

The requirement on the extraction of key-components is expected to foster the reparability and upgradability of servers and data storage products; nevertheless, the information on disassembly operations can be useful for other categories of stakeholders, such as the recyclers. The requirements are further described below.

The various information requirements apply from the time a product model is placed on the market until at least eight years after the placing on the market of the last product of a certain product model:

Disassemble for repair and reuse

Manufacturers shall ensure that joining, fastening, or sealing techniques do not prevent the disassembly for repair or reuse purposes of the following components, when present:

- data storage devices (including HDDs and SSDs)
- memory
- processor (CPU[25])
- motherboard (main circuit board of the server)[26]

24. Commission Regulation (EU) 2019/424 laying down ecodesign requirements for servers and data storage products https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0424
25. A typical CPU is a physical package to be installed on the server motherboard via a socket or direct solder attachment. The CPU package may include one or more processor cores.
26. For the of the regulation, the motherboard includes connectors for attaching additional boards and typically includes the following components: processor, memory, BIOS (Basic Input/output system), and expansion slots.

- expansion card/graphic card
- PSU (power supply)
- chassis
- batteries.

Secure data deletion

A functionality for secure data deletion shall be made available for the deletion of data contained in all data storage devices of the product.

Availability of firmware and security updates

The latest available version of the firmware shall be made available from two years after the placing on the market of the first product of a certain product model for a minimum period of eight years after

the placing on the market of the last product of a certain product model, free of charge or at a fair, transparent, and non-discriminatory cost.

The latest available security update to the firmware shall be made available from the time a product model is placed on the market until at least eight years after the placing on the market of the last product of a certain product model, free of charge.

Information regarding security updates

The following information shall be available in the instruction manuals for installers and end-users (when present with the product), and on the free-access websites of manufacturers.

- information on the secure data deletion functionality, including instructions on how to use the functionality, the techniques used and the supported secure data deletion standard(s)

Information regarding content of CRMs

The following information shall be available free of charge to third parties dealing with maintenance, repair, reuse, recycling and upgrading of servers (including brokers, spare parts repairers, spare parts providers, recyclers and third-party maintenance) upon registration by the interested third party on a website:

- indicative weight range (less than 5 g, between 5 g and 25 g, above 25 g) at component level, of the following critical raw materials:
    - Cobalt in the batteries
    - Neodymium in the HDDs

Instructions on disassembly operations

The following information shall be available free of charge to third parties dealing with maintenance, repair, reuse, recycling and upgrading of servers (including brokers, spare parts repairers, spare parts providers, recyclers, and third-party maintenance) upon registration by the interested third party on a website:

- instructions on the disassembly operations for the components mentioned, including, for each necessary operation and component:
    - the type of operation
    - the type and number of fastening technique(s) to be unlocked
    - the tool(s) required.

The regulation also includes information requirements related to the tested functionality of the products under declared operation condition classes (temperature and humidity) which indirectly addresses the durability:

- Information to be provided by manufacturers: declared operating condition class; it shall also be indicated that 'This product has been tested to verify that it will function within the boundaries (such as temperature and humidity) of the declared operating condition class'.

Review clause

The review clause (Article 8) of the current regulation prescribes that the Commission shall assess the regulation and present the results to the Consultation Forum by March 2022. This deadline has not been met but a review study was initiated in the beginning of 2023 (ICF, n.d.)[27].

With regard to circular economy the review study shall address in particular the appropriateness of updating the material efficiency requirements for servers and data storage products, including the information requirements on additional critical raw materials (tantalum, gallium, dysprosium and palladium), taking into account the needs of the recyclers (European Commission, 2019).

3.1.4 Energy Efficiency Directive (EED)

The recently published revised EED[28] sets reporting obligations on data centres with an ICT power demand above 500 kW, as follows:

a. the name of the data centre, the name of the owner and operators of the data centre, the date on which the data centre started its operations and the municipality where the data centre is based

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27. Link to the homepage of the review study: https://eco-servers-review.eu/
28. Directive (EU) 2023/1791 of the European Parliament and of the Council on energy efficiency https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023L1791

b. the floor area of the data centre, the installed power, the annual incoming and outgoing data traffic, and the amount of data stored and processed within the data centre
c. the performance, during the last full calendar year, of the data centre in accordance with key performance indicators about, inter alia, energy consumption, power utilization, temperature set points, waste heat utilization, water usage and use of renewable energy, using as a basis, where applicable, the CEN/CENELEC EN 50600-4 'Information technology – Data centre facilities and infrastructures', until the entry into force of the delegated act adopted pursuant to Article 33(3).

An EU-level database will collect and publish data, which is relevant for the energy performance and water footprint of data centres with a significant energy consumption.

The reporting obligations are applicable from 15 May 2024 and every year thereafter. The EED also encourages that the contracting authorities make use of the core set of EU GPP criteria for data centres, server rooms, and cloud services. The obligations in the EDD are mainly dealing with energy performance of data centres.

In addition, Member States shall encourage owners and operators of data centres in their territory with a power demand of the installed IT equal to or greater than 1 MW to consider the best practices referred to in the most recent version of the European Code of Conduct on Data Centre Energy Efficiency.

Furthermore, contracting authorities and contracting entities that purchase data centres, server rooms and cloud services shall regarding **energy efficiency** of the product or service, make their best efforts to purchase only products and services that respect at least the technical specifications set at 'core' level in the EU GPP criteria for data centres, server rooms and cloud services.

3.1.5 Ecodesign regulations for mobile phones, cordless phones, and tablets

The ecodesign regulations for mobile phones, cordless phones and tablets (in the following smartphones and tablets)[29] is some of the most recent adopted ecodesign regulation and is the regulation with the most extensive circular economy requirements so far. Below is a summary of the ecodesign requirements for smartphones in ecodesign regulation (EU) 2023/1670. The requirements for tablets are very similar to those for smartphones, and they include examples of ambitious requirements related to material efficiency.

29. Commission Regulation (EU) 2023/1670 laying down ecodesign requirements for smartphones, mobile phones other than smartphones, cordless phones and slate tablets. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1670

The resource efficiency requirements in the ecodesign regulation include, among others:

- requirement for the availability of spare parts and access to repair and maintenance information
- spare parts shall be available for seven years after the date of end of placement on the market
- information on prices of spare parts (not seen in other regulations so far)
- detailed requirements regarding disassembly regarding fastener types (fasteners shall be removable, reusable or resupplied – for batteries resupplied or reusable),
- required tools, working environment and skills) and for preparation for reuse
- requirements for replacement of serial parts (not seen before in ecodesign regulations)
- detailed and new types of requirements regarding design for reliability (including requirements regarding drop resistance, scratch resistance, protection from dust and water ingress, reliability of buttons and switches, battery endurance, battery management, and operating system updates
- marking of plastic components
- recyclability requirements (access to dismantling information, including the sequence of dismantling steps, tools or technologies needed to access the targeted components).
- requirement for information in technical documentation and on free-access website of the manufacturer including:
- compatibility with removable memory cards, if applicable
- information regarding content (indicative weight range) of critical raw materials and environmentally relevant materials
- recyclability rate
- the percentage of recycled content for the product or a part thereof, where available.

Information to be made available in instructions and in user manuals on a free-access website of the manufacturer:

- how to access, via the device, information about the battery management system
- instructions for optimal battery maintenance
- where the package does not include a charger, the following information "For environmental reasons this package does not include a charger. This device can be powered with most USB power adapters and a cable with USB Type-C plug."

Information to be shown on the display of the smartphone:

- that data encryption is enabled by default in the course of configuring a new device, including an explanation that this facilitates data erasure through factory reset
- If wireless charging is selected, a message notifying the user that wireless charging will likely increase the energy consumed the charging of the battery.

Some of the requirements are very product-specific, but a number of them are of a more general/horizontal nature and could also be applied to other products with similar characteristics. Some of these are described below. For more details, please refer to regulation 2023/1670.

Disassembly requirements

The regulation includes very detailed requirements regarding disassembly, as summarized below:

From 20 June 2025 manufacturers, importers, or authorized representatives shall ensure that the process for replacement of available parts meets the following criteria:

For spare parts available to professional repairers and for the display assembly:

- fasteners shall be removable, reusable or resupplied
- the process for replacement shall be feasible in at least one of the following ways:
    - with no tool, with a tool or a set of tools that is supplied with the product or spare part, or with basic tools
    - with commercially available tools.
- the process for replacement shall, as a minimum, be able to be carried out in a workshop environment
- the process for replacement shall, as a minimum, be able to be carried out by a generalist.

For spare parts available to professional repairers and end-users, *with the exception of the battery or batteries:*

Manufacturers, importers, or authorized representatives shall ensure that the process for replacement of parts meets the following criteria:

- fasteners shall be removable, reusable or resupplied
- the process for replacement shall be feasible with no tool, with a tool or a set of tools that is supplied with the product or spare part, or with basic tools
- the process for replacement shall be able to be carried out in a use environment
- the process for replacement shall be able to be carried out by a layman.

For batteries:

Manufacturers, importers, or authorized representatives shall ensure that the process for battery replacement meets the following criteria:

- fasteners shall be resupplied or reusable
- the process for replacement shall be feasible with no tool, with a tool or a set of tools that is supplied with the product or spare part, or with basic tools
- the process for replacement shall be able to be carried out in a use environment
- the process for replacement shall be able to be carried out by a layman.

or, as an alternative to the above points, ensure that the process for battery replacement meets the following criteria:

- fasteners shall be removable, reusable or resupplied
- the process for replacement shall be feasible in at least one of the following ways:
    - with no tool, with a tool or a set of tools that is supplied with the product or spare part, or with basic tools
    - with commercially available tools.
- the process for replacement shall, as a minimum, be able to be carried out in a workshop environment
- the process for replacement shall, as a minimum, be able to be carried out by a generalist
- the battery endurance in cycles achieves a minimum of 500 full charge cycles, and after 500 full charge cycles the battery must, in addition have, in a fully charged state, a remaining capacity of at least 83% of the rated capacity
- the battery endurance in cycles achieves a minimum of 1000 full charge cycles, and after 1000 full charge cycles the battery must, in addition have, in a fully charged state, a remaining capacity of at least 80% of the rated capacity
- the device is at least dust tight and protected against immersion in water up to one meter depth for a minimum of 30 minutes.

Requirements for preparation for re-use

Manufacturers, importers, or authorized representatives shall ensure that devices:

- encrypt by default, using a random encryption key, the user data stored in the internal storage of the device

- include a software function that resets the device to its factory settings and securely erases by default the encryption key and generates a new one
- record the following data from the battery management system in the system settings or another location accessible to end-users:
    - Date of manufacture of the battery
    - Date of first use of the battery after the set-up of the device by the first user
    - Number of full charge/discharge cycles (reference: rated capacity)
    - Measured State of Health (remaining full charge capacity relative to the rated capacity in %).

Requirements for serialised parts

From 20 June 2025 or from one month after the date of placement on the market, whichever is later, manufacturers, importers or authorized representatives shall, at least until 7 years after the date of end of placement on the market:

a. In case the parts to be replaced by spare parts referred to in point 1(a) are serialised parts, provide non-discriminatory access for professional repairers to any software tools, firmware or similar auxiliary means needed to ensure the full functionality of those spare parts and of the device in which such spare parts are installed during and after the replacement
b. In case the parts to be replaced by spare parts referred to in point 1(c) are serialized parts, provide non-discriminatory access for professional repairers and end-users to any software tools, firmware or similar auxiliary means needed to ensure the full functionality of those spare parts and of the device in which such spare parts are installed during and after the replacement
c. Provide, on a free access website of the manufacturer, importer or authorized representative, a description of the procedure for the notification and authorization of the intended replacement of serialized parts by the owner of the device referred to in point (d); the procedure shall allow for remotely providing the notification and authorization
d. Before providing access to the software tools, firmware or similar auxiliary means referred to in points (a) and (b), the manufacturer, importer or authorized representative may only require to have received a notification and authorization of the intended part replacement by the owner of the device. Such notification and authorization may also be provided by a professional repairer with the explicit written consent of the owner
e. Manufacturers, importers or authorized representatives shall provide access to the software tools, firmware or similar auxiliary means referred to in points (a) and (b) within 3 working days after having received the request and, where applicable, the notification and authorization referred to in point (d)

f. The access to the software tools, firmware or similar auxiliary means referred to in point (a) may, as regards professional repairers, be limited to professional repairers registered in accordance with points 2(a) and (b).

Design for reliability

The reliability requirements include the following issues (for further description see Annex II, B, 1.2 of the regulation):

- Drop resistance
- Scratch resistance
- Protection from dust and water ingress (using the IP codes)
- Battery endurance in cycles
- Battery management
- Operating system updates.

The requirements regarding battery endurance, battery management and operating system updates are considered of particular relevance for other products containing batteries and operative systems.

Marking of plastic components

Plastic components heavier than 50 g shall be marked by specifying the type of polymer with the appropriate standard symbols or abbreviated terms set between the punctuation marks '>' and '<' as specified in available standards. The marking shall be legible. Plastic components shall be exempt from marking requirements provided the following conditions are fulfilled:

- the marking is not possible because of the shape or size
- the marking would impact on the performance or functionality of the plastic components
- marking is technically not possible because of the moulding method.

For the following plastic components, no marking shall be required:

- packaging, tape, labels and stretch wraps
- wiring, cables and connectors, rubber parts and any other component where not enough appropriate surface area is available for the marking to be of a legible size
- PCB assemblies, PMMA boards, optical components, electrostatic discharge components, electromagnetic interference components, speakers
- transparent parts where the marking would obstruct the function of the part in question.

The proposed requirement for marking plastic is in line with the current requirements for electronic displays.

Information requirements

The proposed information requirements include some new elements compared to current regulations. These are as follows:

Information about CRM content

Manufacturers, importers, or authorised representatives shall provide in the technical documentation and make publicly available on free access websites the following information:

- indicative weight range of the following CRMs and environmentally relevant materials:
    - Cobalt in the battery (weight range: less than 2 g, between 2 g and 10 g, above 10 g)
    - Tantalum in capacitors (weight range: less than 0,01 g, between 0,01 g and 0,1 g, above 0,1 g)
    - Neodymium in loudspeakers, vibration motors, and other magnets (weight range: less than 0,05 g, between 0,05 g and 0,2 g, above 0,2 g)
    - Gold in all components (weight range: less than 0,02 g, between 0,02 g and 0,05 g, above 0,05 g).

Information regarding recyclability rate, percentage of recycled content and battery endurance

Manufacturers, importers, or authorised representatives shall provide, in the technical documentation and on publicly available, free-access websites, the following information:

- the indicative value of the recyclability rate R_{cyc}
- the indicative percentage of recycled content for the product or a part thereof, where available; if not available, the recycled content should be indicated as “not known” or “not available”
- minimum battery endurance in a number of cycles.

Ingress protection

Manufacturers, importers, or authorised representatives shall provide, in the technical documentation and on publicly available, free-access websites, the following information:

- ingress protection rating.

Information regarding batteries

User instructions in the form of a user manual, on a free-access website of the manufacturer, importer or authorised representative, shall include information regarding:

- how to access, via the device, information about the battery management system on:
    - date of manufacture of the battery
    - date of first use of the battery after the set-up of the device by the first user
    - number of full charge/discharge cycles (reference: rated capacity)
    - measured State of Health (remaining full charge capacity relative to the rated capacity in %).
- instructions for battery maintenance, including the following:
    - impacts on battery lifetime related to exposure of the device to elevated temperatures, suboptimal charging patterns, fast charging and other known adverse factors
    - effects of switching off radio connections, such as Wi-Fi, Bluetooth etc. on device power consumption
    - information about whether the device supports other features which extend battery lifetime, such as smart charging, and about how these features are activated or under which conditions they work best.

Common chargers support

Where the package does not include a charger, the user instructions shall include the following information: "For environmental reasons this package does not include a charger. This device can be powered with most USB power adapters and a cable with USB Type-C plug."

This requirement is relevant for all products placed on the marked with an external power supply.

3.1.6 Energy labelling of smartphones and tablets (regulation (EU) 2023/1669) [30]

For smartphones and slate tablets, an energy labelling regulation including circular economy aspects was published in August 2023. The layout and content of the energy label are shown in Figure 8. It is the first EU energy label including a reparability class on a scale from A to G based on a Repairability Index.

30. Commission Delegated Regulation (EU) 2023/1669 with regard to the energy labelling of smartphones and slate tablets. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1669

The reparability class of a smartphone or a slate tablet shall be determined on the basis of the repairability index. The most reparable being class A and the least reparable being class E, on a scale from A–E.

Table 6. Repairability classes of smartphones and slate tablets

Reparability Class	Reparability Index (R)
A (most raparble)	R ≥ 4,00
B	4,00 > R ≥ 3,35
C	3,35 > R ≥ 2,55
D	2,55 > R ≥ 1,75
E (least reparable)	1,75 > R ≥ 1,00

The Repairability Index is calculated from six scoring parameters as follows:

R = (SDD*0,25) + (SF*0,15) + (ST*0,15) + (SSP*0,15) + (SSU*0,15) + (SRI*0,15)

where:

- SDD is the 'Disassembly Depth' score.
- SF is the 'Fasteners (type)' score.
- ST is the 'Tools (type)' score.
- SSP is the 'Spare Parts' score.
- SSU is the 'Software Updates (duration)' score.
- SRI is the 'Repair Information' score.

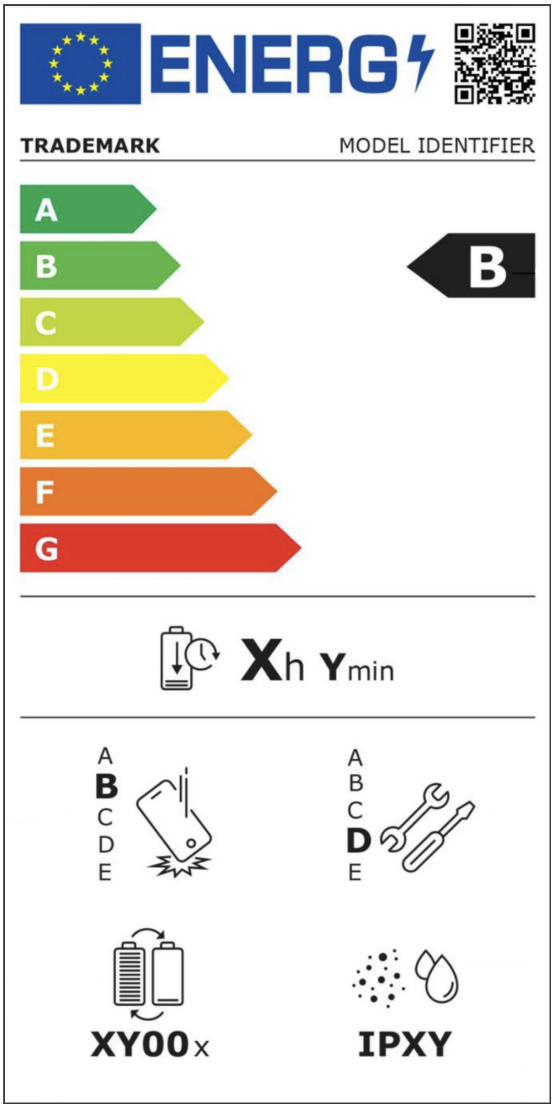

Figure 9. Layout of energy label for smartphones and slate tablets

The parameter that counts the most in the reparability index the score is the disassembly depth (DD). It shall be calculated based on the number of steps required to remove a part from a product, without damaging that product. Points ranging from 1 to 5 (the more steps the lower score). The points are assigned as follows:

DDi ≤ 2 steps = 5 pts

5 steps ≥ DDi > 2 steps = 4 pts

10 steps ≥ DDi > 5 steps = 3 pts

15 steps ≥ DDi > 10 steps = 2 pts

DDi > 15 steps = 1 pt.

For the calculation of disassembly steps, the following rules shall apply:

- the disassembly depth count is completed when the target part is separated and individually accessible
- where multiple tools need to be used simultaneously, the use of each tool counts as a separate operation. Operations related to cleaning, removing traces or heating are counted as steps
- where remote notification or authorisation of serial numbers is necessary for the full functionality of the spare part and the device, these actions are counted as additional disassembly steps.

For **fasteners**, 5 points are assigned to reusable fasteners, 3 points to resupplied fasteners and 1 point to removable fasteners.

For tools, points ranging 1 to 5 are assigned as follows:

- no tools = 5 pts
- basic tools = 4pts
- a set of tools that is supplied (or offered to be supplied at no additional cost) with the spare part = 3 pts
- a set of tools that is supplied (or offered to be supplied at no additional cost) with the product = 2 pts
- commercially available tools =1pt.

Points from 1 to 5 to are also assigned for spare part availability (more points if spare parts are also available to end-users), software updates (duration) and repair information.

The calculation methods needed for the establishment of label parameters are described in the proposed regulation. In addition, a tool for the calculation of the reparability index is provided in the regulation (see the section on transitional methods).

The parameters on the label could also be relevant for other product groups, especially other electronic products. Some could probably be applied horizontally but others would need product-specific adaptation.

Transitional methods are outlined in the proposed regulation in Annex IVa. The standard EN 45554:2020 is used as reference test method for fasteners (type) score (S_F) and Tools (type) score (S_T)

Product information sheet

The proposed regulation also requires that the supplier shall upload to the product database (EPREL) the information set out in the Product Information Sheet.

The user manual or other literature provided with the product shall clearly indicate the link to the model in the product database as a human-readable Uniform Resource Locator (URL), as a QR code or by providing the product registration number.

The Product Information Sheet shall include a variety of information, including the individual scores of the parameters used for the calculation of the repair score, maximum pre-tax price for various spare parts, list of spare parts available to professional repairers and to end-users respectively, number of falls without defects, battery endurance in cycles, ingress protection rating and screen scratch resistance.

3.1.7 Product specific legislation: Batteries

The Batteries Regulation (Regulation (EU) 2023/1542)[31] is the first piece of European legislation taking a full life-cycle approach and an example of product-specific legislation mentioned previously. It is not related to Ecodesign Directive however it acknowledges the potential need to regulate some batteries in products such as mobile phones under ecodesign measures.

Starting from 2025, the Regulation will gradually introduce declaration requirements, performance classes and maximum limits on the carbon footprint of electric vehicles, light means of transport (such as e-bikes and scooters) and rechargeable industrial batteries.

The Batteries Regulation sets requirements on the content of harmful substances in batteries, which will be regularly reviewed. In addition, targets for recycling efficiency, material recovery and recycled content will be introduced gradually from 2025 onwards. All collected waste batteries will have to be recycled and high levels of recovery will have to be achieved, in particular of critical raw materials such as cobalt, lithium and nickel. This will guarantee that valuable materials are recovered at the end of the useful life of the battery and brought back in the economy by adopting stricter targets for recycling efficiency and material recovery over time.

Starting in 2027, consumers will be able to remove and replace the portable batteries in their electronic products at any time of the life cycle. This will extend the life of these products before their final disposal, will encourage re-use, and will contribute to the reduction of post-consumer waste.

31. Regulation (EU) 2023/1542 of 12 July 2023 concerning batteries and waste batteries, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023R1542

Key data will be provided on a label, where a QR code will provide access to a digital passport with detailed information on each battery that will help consumers and especially professionals along the value chain in their efforts to make the circular economy a reality for batteries.

Under the new law's due diligence obligations, companies must identify, prevent and address social and environmental risks linked to the sourcing, processing and trading of raw materials such as lithium, cobalt, nickel and natural graphite contained in their batteries.

3.2 Voluntary initiatives

3.2.1 EU GPP for data centres, server rooms, and cloud services

The EU has set voluntary green public procurement criteria (GPP criteria) for data centres, server rooms and cloud services which includes criteria for servers and data storage because these are main elements in data centres and server rooms (European Commission, 2020c).

The EU GPP criteria addresses various issues related to energy and material efficiency. The requirements regarding material efficiency are:

- Control of hazardous substances (Restricted Substance Controls RSCs) in servers, data storage and network equipment. The RSCs must apply, as a minimum, to the REACH candidate list of substances and Restricted substances and exemptions in the Restriction of Hazardous Substances Directive (criteria SC2).
- Design for repair and upgrading of servers and data storage (criteria TS 3)
- End-of-life management of servers, data storage and network equipment (criteria TS4)

The requirements on design for repair and upgrading are:

The tenderer must provide clear instructions to enable a non-destructive repair or replacement of the following components:

- data storage devices,
- memory
- processor (CPU)
- motherboard
- expansion cards/graphic cards
- power supply unit (PSU)
- fans
- batteries.

As a minimum, the instructions should include for each necessary repair operation and component:

1. the type of operation
2. the type and number of fastening technique(s) to be unlocked
3. the tool(s) required.

The instructions must be made available to authorised third parties, including brokers, spare parts repairers, spare parts providers, recyclers, and maintenance providers via registration on the manufacturer's webpage. These instructions must be made available for a minimum of 8 years after the server product is placed on the market.

The above are to a large extent in line with the current ecodesign requirement for servers and data storage products, meaning that they are mandatory for products placed on or put into service in the EU.

The requirements on end-of-life management are:

Tenderers must provide a service for:

- The re-use and recycling of the whole product and/or
- The selective treatment of components in accordance with Annex VII of the WEEE Directive[32] for equipment that has reached the end of its service life
- The recycling of components in order to recover Critical Raw Materials.

The service must comprise the following activities:

- Collection
- Confidential handling and secure data erasure (unless carried out in-house)
- Functional testing, servicing, repair and upgrading to prepare products for re-use
- The remarketing of products for re-use
- Dismantling for component re-use, recycling and/or disposal.

In providing the service, the tender must report on the proportion of equipment prepared or remarketed for re-use and the proportion of equipment prepared for recycling.

Preparation for re-use, recycling and disposal operations must be carried out in full compliance with the requirements in Article 8 and Annexes VII and VIII of the (recast) WEEE Directive 2012/19/EU and with reference to the list of components for selective treatment. See Figure 9.

32. The components requiring selective treatment in accordance with Annex VII of the WEEE Directive are mercury containing components and batteries.

Components requiring selective treatment in accordance with Annex VII of the WEEE Directive:

- mercury containing components
- batteries
- printed circuit boards greater than 10
- plastic containing brominated flame retardants, chlorofluorocarbons (CFC), hydrochlorofluorocarbons (HCFC) or hydrofluorocarbons (HFC), hydrocarbons (HC)
- external electric cables
- polychlorinated biphenyls (PCB) containing capacitors
- components containing refractory ceramic fibres
- electrolyte capacitors containing substances of concern
- equipment containing gases that are ozone depleting or have global warming potential (GWP) above 15
- ozone-depleting gases must be treated in accordance with Regulation (EC) No 1005/2009

Figure 9. Components requiring selective treatment according to WEEE.

Tenderers must also provide evidence of all the actions performed in order to improve the recycling of the Critical Raw Materials cobalt (in batteries) and of neodymium (in HDDs), in line with the available information on Cobalt and Neodymium content, as foreseen in Annex II.3.3.a to the Ecodesign Regulation (EU) 2019/424[33].

Verification:

The tenderer must provide details of the arrangements for collection, data security, preparation for re-use, remarketing for re-use and recycling/disposal. This must include, during the contract, valid proof of

compliance of the WEEE handling facilities to be used and the separation and handling of specific components that may contain Critical Raw Materials.

Operation condition range

In addition, the GPP document includes a criterion regarding operating condition range (temperature and humidity) which could be of importance for the lifetime/ durability of servers and data storage equipment (criteria TS2).

Tenderers must also provide evidence of all the actions performed in order to improve the recycling of the Critical Raw Materials cobalt (in batteries) and of neodymium (in HDDs), in line with the available

information on Cobalt and Neodymium content, as foreseen in Annex II.3.3.a to the Ecodesign Regulation (EU) 2019/424[34].

33. This regulation was adopted in 2019 and the mentioned requirements have applied since 1 March 2020.
34. This regulation was adopted in 2019 and the mentioned requirements have applied since 1 March 2020.

Verification:

The tenderer must provide details of the arrangements for collection, data security, preparation for re-use, remarketing for re-use and recycling/disposal. This must include, during the contract, valid proof of

compliance of the WEEE handling facilities to be used and the separation and handling of specific components that may contain Critical Raw Materials.

3.2.1.1 Application of the GPP criteria

Experience of the Danish Agency for Digital Government

In 2022 the Danish Agency for Digital Government published an analysis of green public procurement of datacentres, server rooms and cloud services[35]. The analysis showed that:

- Few public authorities set green requirements in tenders for data storage and processing, and the requirements that are set are very uneven, qualitative, and difficult to measure.
- Many public authorities would like to include green requirements but are worried about making too strict requirements and thereby risk limiting the field of suppliers.

On this background the Agency for Digital Government in a partnership with central, regional, or local authorities, has initiated a pilot testing of the application of the EU's Green Public Procurement Criteria for data centers, server rooms and cloud service. The results should serve as a basis for decision-making for further implementation of green public procurement requirements for these products/ services.

The preliminary experiences and observations of the pilot testing are that[36]:

- The GPP criteria are applicable in public tenders, e.g., because the criteria are linked to the subject of the contract and are based on objective criteria and standards, and the majority of the criteria are market compliant.
- The EU GPP criteria documents[37] are difficult to access for both buyers and suppliers and there is currently a low maturity in terms of understanding and applying the underlying standards (how to calculate and document).
- As a result of the ongoing testing and upcoming identical EU reporting requirements according to the revised Energy Efficiency Directive (see section 3.1.4) and the Taxonomy Regulation, a gradual maturation in the market is already visible and it is therefore expected that in 2024 the suppliers will be able to apply the criteria correctly.

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35. Grønne datacentre, Danish Agency for Digital Government, 2022 (only available in Danish). https://digst.dk/media/26780/digitaliseringsstyrelsens-afrapportering-for-initiativ-om-groenne-datacentre.pdf
36. Based on communication with Frederik Nøhr Brünner, Danish Agency for Digital Government.
37. Criteria document and Technical report: https://circabc.europa.eu/ui/group/44278090-3fae-4515-bcc2-44fd57c1d0d1/library/9c925f22-deb3-427c-8a79-384c18c9792b?p=1&n=10&sort=name_ASC

The Agency for Digital Government concludes that the GPP's is an important tool as it reduces complexity for both the purchasing authority and the supplier and thereby reduces both resource consumptions and burdens. In addition, the GPP creates an increased transparency as the criteria and methods for documentation and verification are based on well-established standards also referred to in other relevant EU legislation for instance EED, and Taxonomy Regulation. Apart from reducing supplier's burdens, the use of identical standards and green requirements across GPP and other EU reporting requirements, also increases the supplier's visibility and thereby supports investments in reducing the supplier's products and services climate impact.

Experience of SKI

SKI (a centralized procurement body in Denmark) has in-depth experience with the use of GPP criteria for data centers, server rooms, and cloud services in several tenders (both framework agreements and dynamic purchasing systems). Their experience with the market and public procurers is that GPP is:

- Unclear/inadequate structure makes it very difficult to navigate through the criteria and identify the criteria relevant to the specific procurement.
- Confusing because the primary division/structure by Selection Criteria, Technical Specification, Award Criteria and Contract Performance Clauses is not helpful for a procurer, who needs to get a quick overview of relevant procurement criteria for their specific procurement as well as an overview of which requirements are related in content and possibly interrelated. Adding to this, the target audience experience an often unnecessarily complex language, with heavy use of technical terms and legal jargon, which deters use of the criteria.
- There is a lack of guidance around the individual criteria, which describes in a pedagogical way (for lay people) the object, purpose, substance and issues of attention of each criteria.

Whilst SKI agrees that the GPP is solid and relevant, the reality is that they are not used due – at least partly – to the above-mentioned obstacles.

In addition, SKI have identified the following questions to be critical for public procurers when they're in the process of selecting green criteria – questions that the GPP criteria do not answer:

1. Which green criteria can the market meet currently?
2. How much more expensive is it to use a specific green criteria?
3. Which of the criteria makes the biggest green impact?

In order to support public procurers in answering these essential questions, SKI has developed a new model for green criteria related to datacenters, which has been implemented in their 02.22 IT-services (a dynamic purchasing system). The model resembles an intersection (basic criteria, green light, yellow light and red light) as follows:

- Basic criteria (All suppliers can meet the criteria; not more expensive; supports the green agenda)
- Green (Most suppliers can meet the criteria; may be a little more expensive; supports the green agenda)
- Yellow (Few suppliers can meet the criteria; expected to be more expensive; supports the green agenda even more)
- Red (Very few suppliers can meet the criteria, costs may be significant; supports the green agenda a lot).

The tendering authority can freely choose which criteria they wish to use in their specific tender. In addition, SKI will once a year enter a dialogue with the suppliers on the system and the market to discover which criteria can be tightened whilst still following the methodology of the intersection -guidance. Criteria can thereby switch from, for example, red to yellow, yellow to green and so forth. Furthermore, in another tender from SKI (50.03 Server storage), SKI has used the GPP criteria as inspiration material for their award criteria of the framework agreement. Bidders were required to offer their "green services" in accordance with the GPP criteria's focus areas. Ultimately this enables public procurers and IT-staff to gain in-depth support and guidance with regard to sustainability and the management of their server and storage solutions.

3.2.2 EU Code of Conduct on Data Centre Energy efficiency

The EU Code of Conduct (CoC) started in 2008 and is operated by the Joint Research Centre (JRC), part of the European Commission[38]. Organisations can apply to join the CoC as participants (owners and operators of data centres) or as endorsers (committing to support the Code and participants through the development of products, information, services, education, or other programs) (JRC 2021b).

Participants sign a registration form, through which they commit to conduct an initial energy audit to identify the major energy saving opportunities, prepare and submit an action plan and implement this plan according to the agreed timetable. Energy consumption must be monitored regularly to see overtime progress in the energy efficiency indicator related to the data centre. All Participants are required to follow the best practice guidelines (Acton et al 2021) which are updated annually, and to report annually. They have an obligation to continuously monitor energy

38. https://e3p.jrc.ec.europa.eu/communities/data-centres-code-conduct

consumption and adopt energy management in order to look for continuous improvement in energy efficiency. One of the key objectives of the CoC is that each participant benchmarks their efficiency over time, using the CoC metrics in order to produce evidence of continuous improvement in efficiency.

In addition, every year data centres that have adopted innovative technologies to improve their energy efficiency and have demonstrated outstanding improvements are given the Code of Conduct Data Centre Award. The criteria for the winners are the reduced need for mechanical cooling of the data centre for most of the time and raised indoor temperature. These are among the most important measures to improve efficiency and reduce energy consumption.

Energy efficiency targets expressed as PUE are complemented by general commitments to monitor power and energy consumption, adopt good management practices, increasing IT utilisation, switching off components not needed, and reducing energy consumption where possible.

The EU Code of Conduct does not include recommendations related to material content of the IT equipment used in the data centres. But section 3.2 General Policies include some general recommendations regarding energy efficiency and overall environmental impacts. Examples are:

- Consider the embodied environmental impact of installed devices
- Life Cycle Assessment
- Environmental Management
- Training and Development

3.2.3 Taxonomy Regulation[39] and delegated act[40]

The EU taxonomy is a classification system, establishing a list of environmentally sustainable economic activities. It is aimed at helping the EU scale up sustainable investment and implement the European green deal. The EU taxonomy would provide companies, investors and policymakers with appropriate definitions for which economic activities can be considered environmentally sustainable. In this way, it would contribute to create security for investors, protect private investors from greenwashing, help companies to become more climate-friendly, mitigate market fragmentation and help shift investments where they are most needed.

The EU Taxonomy Climate Delegated Act defines which economic activities most contribute to meeting the EU's environmental objectives. It includes the activity storage, manipulation, management, movement, control, display, switching, interchange, transmission or processing of data through data centres, including edge computing, providing it complies with the EU Code of Conduct on Data Centre Energy efficiency.

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39. EU Taxonomy Regulation (2020/852/EU) https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32020R0852
40. COMMISSION DELEGATED REGULATION (EU) 2021/2139 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32021R2139

The delegated act includes technical screening criteria for 'do no significant harm' for the economic activity "Data processing, hosting and related activities". These criteria should ensure that the economic activity has no significant negative environmental impact. Relevant technical criteria for servers and data storage products are:

- The activity has implemented all relevant practices listed as 'expected practices' in the most recent version of the European Code of Conduct on Data Centre Energy Efficiency, or in CEN-CENELEC document CLC TR50600-99-1 'Data centre facilities and infrastructures - Part 99-1: Recommended practices for energy management'. The implementation of those practices should be verified by an independent third-party and audited at least every three years.
- The equipment used meets the requirements laid down in Directive 2009/125/EC for servers and data storage products. Currently this means the requirements in the ecodesign regulation for servers and data storage products (EU) 2019/424.
- The equipment used does not contain the restricted substances listed in Annex II to Directive 2011/65/EU of the European Parliament and of the Council, except where the concentration values by weight in homogeneous materials do not exceed the maximum values listed in that Annex (the RoHS Directive).
- A waste management plan is in place and ensures maximal recycling at end of life of electrical and electronic equipment, including through contractual agreements with recycling partners, reflection in financial projections or official project documentation.
- At its end of life, the equipment undergoes preparation for reuse, recovery or recycling operations, or proper treatment, including the removal of all fluids and a selective treatment in accordance with Annex VII to Directive 2012/19/EU of the European Parliament and of the Council (the WEEE Directive).

Whether the EU Taxonomy is mandatory for companies depends on different circumstances and obligations for different economic actors. However, companies of any size can use the EU Taxonomy on a voluntary basis to show investors and stakeholders in general whether they are carrying out or planning sustainable activities.

3.2.4 Data Centers (DE-UZ 228) – Blue Angel

The German Ministry of Environment and the German Federal Environment Agency have developed voluntary ecolabels for energy-efficient data centres: the environmental labels "Energy Efficient Data Center Operation" (DE-UZ-161) and "Climate Friendly Colocation Data Centers" (DE-UZ 214). These two sets of criteria have been consolidated into "Data Centers" (DE-UZ 228)[41], which covers existing operator models but also those operators who manage their information technology at a colocation data centre that has been awarded the Blue Angel.

In order to be awarded the Blue Angel, operators of data centres and information technology must comply with minimum requirements, and this must be verified by an independent auditor (mandated by the German Environment Agency). The environmental label for "Data Centers" may be awarded to those data centres that comply with criteria, which also includes a requirement on reuse management:

Reuse Management

In order to satisfy the guidelines for the avoidance of waste (see German Circular Economy Act (Kreislaufwirtschaftsgesetz § 6 waste hierarchy), the ecolabel aims to promote the reuse of information technology (servers and storage devices) after the end of their service life in the data centre. Information technology that leaves the data centre may not be scrapped or destroyed. The applicant must present a secure process for the deletion of data and a contractual agreement with a refurbishing company (maintenance and refurbishment). The servers may be donated free of charge to charitable organisations or also sold for a fee to professional refurbishing companies (e.g. the manufacturer).

Exemption: Data media that contain confidential information ("classified documents") according to the General Administrative Provision for the Material Protection of Classified Information 25/34 DE-UZ 228 Edition January 2023 (accessible at: GMBl. 2018 no. 44–47, p. 826) or other sensitive data for which there is no secure and non-destructive deletion process available that meets the requirements of the Federal Office for Information Security (BSI) are exempt from this requirement.

3.2.5 Climate Neutral Data Centre Pact

Cloud Infrastructure Service Providers in Europe (CISPE) and the European Data Centre Alliance (EUDCA) have created a governance coalition known as the Climate Neutral Data Centre Pact. Signatories to the Pact may be trade associations representing data centre operators or

41. Blue Angel Data Centres (DE-UZ 228). Basic Award Criteria. Edition January 2023. Version 1. https://produktinfo.blauer-engel.de/uploads/criteriafile/en/DE-UZ%20228-202301-en-criteria-V1.pdf

companies[42] that own or operate data centres within the European Union. Beginning January 1, 2021, representatives from the data centre trade associations and companies that have signed the initiative, and the European Commission will meet twice annually to review the status of this initiative. By no later than July 1, 2023, signatories will certify adherence.

Climate Neutral Data Centre Pact (2021) states the requirements are:

- Energy efficiency, using PUE as a metric
- Matching electricity use by purchasing clean energy (clean energy)
- Setting and meeting ambitious targets for water usage effectiveness
- Increasing the quantity of server materials repaired or reused and creating a target percentage for repair and reuse (circular economy)
- Exploring possibilities to interconnect with district heating systems and other users of heat.

3.3 Standards

3.3.1 EU material efficiency standards

To support the implementation of material efficiency requirements within the framework of the EU Ecodesign Directive, various standards have been developed under the standardisation mandate M/543 from the European Commission especially targeting material efficiency aspects under the Ecodesign Directive. These are the EN 45552 to EN 45558 standards (the so-called EN 4555X series of standards).

In addition, a technical report CLC/TR 45550:2020 "Definitions related to material efficiency" was developed. The developed standards are shown in Table 7.

The standards include very detailed information regarding definitions, criteria, and assessment methods. For more information, please refer to the standards.

42. https://www.climateneutraldatacentre.net/

Table 7. Material efficiency standards for energy-related products

Reference	Topic
EN 45550:2020	Definitions related to material efficiency (technical report)
EN 45552:2020	General method for the assessment of the durability of energy-related products
EN 45553:2020	General method for the assessment of the ability to remanufacture energy-related products
EN 45554:2020	General methods for the assessment of the ability to repair, reuse and upgrade energy-related products
EN 45555:2019	General methods for assessing the recyclability and recoverability of energy-related products
EN 45556:2019	General method for assessing the proportion of reused components in energy-related products
EN 45557:2020	General method for assessing the proportion of recycled material content in energy-related products
EN 45558:2019	General method to declare the use of critical raw materials in energy-related products
EN 45559:2019	Methods for providing information relating to material efficiency aspects of energy-related product

The material efficiency standards developed under M/543, are horizontal standards which cannot be directly applied to energy-related products or product groups. The standards provide general methodologies to assess different material efficiency aspects of energy-related products. The horizontal documents need to be adapted in order to be applicable for specific products/product groups.

Short descriptions of the standards are given below. The standards include very detailed information regarding definitions, criteria, and assessment methods, so the text below presents only very brief overviews. For more information, please refer to the standards.

CLC/TR 45550:2020: Definitions related to material efficiency (technical report)

Includes definitions of parameters and methods relevant for assessing durability, upgradability and ability to repair, reuse and re-manufacture of products". The technical report constitutes a collection of common terms used in deliverables prepared in accordance with M/543.

As such, the definitions in the report provide a single definition of key terms used in the material efficiency standards further described below.

Application

This standard is considered of high importance to ensure the consistent use of terminology in the EN 4555X series standards and in regulations based on these.

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

This standard deals with parameters and methods for the assessment of reliability and durability of ErP (Energy-Related Products). It includes relevant terms and definitions and explains the key concepts to be considered.

Durability (of part or product): Ability to function as required, under defined conditions of use, maintenance and repair **until a limiting state is reached.** A limiting state can be changed to a functional state by maintenance and repair. Durability can be expressed in time (hours or years), number of operation cycles etc.

Examples of existing specific durability requirements are:

- the operational time for motors (expressed in hours) in the ecodesign regulation for vacuum cleaners.
- the minimum lifetime for hose (still useable after 40000 oscillations under strain) in the ecodesign regulation for vacuum cleaners.

Reliability: Probability that a product functions as required under given conditions, including maintenance, for a given duration without limiting events. Limiting events are for instance failure, wear-out failure, or deviation of any analogue signal. **To assess reliability, the time at which a certain percentage of products has reached a limiting state is used.**

An example of reliability requirements is the lamp survival factor for light sources:

- The lamp survival factor is the fraction of the total number of light sources that continue to operate at a given time under defined conditions and switching frequency (i.e. at least 9 light sources of the test sample of 10 units of the model must be operational after completing the test described in Annex V of the ecodesign regulation for light sources and control gears (EU) 2019/2020.

Application

Both durability and reliability requirements are very product-specific and closely connected to certain parameters of the product. Therefore, it will be necessary to develop/use product-specific requirements or test methods for certain relevant quality or performance parameters of the product. For instance, the proposed ecodesign regulation for mobile phones, cordless phones and tablets[43] does not refer to EN 45552:2020 with respect to the reliability requirements in the proposed regulation. In the Annex 3a including the transitional measurement methods, other standards specifically dealing with the parameters for which reliability requirements are set are mentioned (standard for measurement of free fall test etc.).

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

Provides a general method for assessing the ability of an energy-related product to be remanufactured (refurbishment is not part of this standard). Remanufacturing is identified as an industrial process where at least one change is made to the product influencing its safety, performance, purpose or type of the product. The standard identifies seven process steps which are important to the remanufacturing process and identifies and provides general methods for evaluation of product characteristics which are linked to the possibilities for remanufacturing of the product.

The identified product characteristics (called attributes in the standard) are:

Ability to be identified as a product relevant for remanufacturing.

Ability to locate access points and fasteners covers aspects that can help locating key elements in relation to the disassembling and assembling of the product, such as access points, fasteners, diagrams showing locations etc.

Accessibility of parts dealing with how easy it is for operators to get access to the parts of the product, which need to be disassembled, or to be repaired, replaced, or upgraded.

Ability to be disassembled or assembled describes the ability of the product to be separated into its parts and of the parts to be assembled. Criteria are, among others, the number of operators needed and number of tools, and (different) fasteners to be used.

Wear and damage resistant during the remanufacturing process steps describes the ability of the product or its parts to withstand all the treatment that is needed during the remanufacturing processes without been damaged, for instance that materials and fasteners are strong, and that materials and markings can withstand cleaning agents.

43. See proposed ecodesign regulation for mobile phones (including smartphones), cordless phones and tablets here: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12797-Designing-mobile-phones-and-tablets-to-be-sustainable-ecodesign_en. Be aware that the link does not show the final regulation.

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

Provides a generic method to assess the ability of products, or parts thereof to be:

- reused (product or its parts have reached the end of their first life and are used again for the same purpose)
- repaired (process of returning a faulty product to a condition where it can fulfil its intended use)
- upgraded (process of enhancing the functionality, performance, capacity, or aesthetics of the product)

The following four steps should be carried out in order to define any product-specific assessment method:

- Determination of the priority parts to be included in the assessment, where a priority part is determined by its likelihood to need replacement or upgrading, its suitability for reuse or the functionality of the part.
- Identification of criteria and appropriate categories relevant for the assessment of all priority parts
- Assignment of a ranking/classification score to each category of relevant criteria for different priority parts and
- Specification of a calculation method to aggregate the results from the three previous steps for each priority part.

The identification of priority parts should take into account the analysis of EN 45552, where a list of failure parts is identified as part of the analysis. Where relevant, the list of priority parts shall be ranked in terms of enabling repair, reuse, or upgrade.

The below-listed criteria should be assessed to decide which of them are relevant for the product group in question. The list is non-exhaustive.

Product-related criteria:

- Disassembly depth
- Fasteners and connectors
- Tools
- Working environment
- Skill level.

Support-related criteria:

- Diagnostic support and interface
- Availability of spare part for repair/update
- Types and availability of information
- Return models for repair/upgrade
- Availability of parts for upgrade
- Spare parts availability by duration of availability,
- Availability of data deletion/transfer and to restore to factory setting
- Availability of software and firmware support including updates.

A number of methods for the assessments are described in Annex A to the standard. The methods include: example of scoring system for disassembly depth; classifications of fastener types, tools, working environment and skill level; classification by diagnostic support and interfaces; various classifications regarding spare part availability and availability of information; classification of return options and data management and password and factory reset. Additionally, a method for aggregation of criteria scores are represented.

Application

Parts of this standard have been used in the proposed ecodesign and energy labelling regulations for mobile phones, cordless phones, and tablets regarding disassembly requirements (requirements for fasteners, tools, working environment and skills). This shows that (at least) part of the standard is applicable for setting more detailed repair and disassembly requirements.

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

Provides general principles for assessing the recyclability and recoverability of energy-related products. It elaborates on the product characteristics relevant for recyclability and recoverability of the product itself rather than the recycling or recovery processes.

The assessment of the recyclability/recoverability shall be based on the assumptions that the entire product undergoes the treatment in a selected reference end-of-life treatment scenario and that no preparing for reuse takes place. The scenario shall take into account the availability and efficiency of state-of the-art recycling and recovery processes to determine the recyclability/recoverability rate of an ErP.

The ability of the product to be recycled and recovered depends upon the following factors:

- the design characteristics of the product such as its structure, material composition, size, and mass
- the techniques, combination or sequence of techniques used to recycle or recover a given waste stream.

Marking of certain parts, which are separated during the recovery process, can facilitate selected recycling and recovery processes. Easy removal of certain parts does not necessarily increase recoverability if those parts are not removed in the reference end-of-life treatment scenario considered.

Critical Raw Materials (CRMs) generally have a negligible effect on the mass-based recyclability rate of the product, but may contribute towards reducing supply, economic and environmental risks and impacts. Therefore, the recyclability of CRMs shall be determined in accordance with a product-specific assessment.

When establishing assessment criteria for CRMs, the following aspects shall be considered:

- The potential presence of CRMs
- Distribution and concentration of CRMs across different parts
- Ability to access and remove parts containing CRMs
- Matters affecting possibilities to recycle CRMs.

The recyclability of CRMs may be assessed by the recyclability formula in the standard for those parts containing CRMs. A reference end-of-life treatment scenario and associated data for recycling and recovery factors of CRMs, must be defined.

The standard includes formulas for the calculation of the recyclability rate (R_{cyc}), and the recoverability rate, R_{cov}, of an ErP expressed in mass percent.

The calculation of the recyclability/recoverability rates for the entire product requires the determination of the recyclability/recoverability factors of all parts/ materials of the product. However, the recyclability and recoverability rates can also be calculated only for specific parts/materials. The recyclability and recoverability rate for an individual material or for a part of interest, can be calculated as the ratio of the material that can be recycled/recovered, divided by the total mass of that material contained in the product or part.

Application

This standard is used as reference test method for calculation of the R_{cyc} in the proposed regulation for mobile phones, cordless phones, The end-of-life scenario to be applied is described in the regulation. See Annex IIIa regarding Transitional Methods. This shows that the standard is applicable if a relevant end-of life scenario is established for the product and its components/materials.

Due to the large uncertainties regarding data and the actual end-of-life scenario it seems more relevant to focus on specific parts/materials of interest than on entire products.

EN 45556:2019: General method for assessing the proportion of reused components in energy-related products

Provides general methods for assessing the proportion of reused components in an ErP. It deals with the assessment of the proportion of reused components on a generic level and it is intended to be used by technical committees when producing product-specific, or product group standards. Aspects like performance, validation, verification and suitability of reused components are not in the scope of the standard.

The calculation of the proportion of reused components can be applied at product level, by assessing each product on its own, or it can be based on a mass balance or number balance over a period of time. i.e.:

- Proportion of reused components calculated based on the mass of the reused components and the total weight of the product (in percentage)
- Proportion of reused component in the product by number calculated based on the number of reused components and the total number of components in the product (in percentage)
- As above but for mass and numbers for a defined period of time.

Formulas for the above calculation are included in the standard.

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

Describes a general method for assessing the proportion of recycled material in an energy-related product. It is applicable as the framework to be used for defining the assessment of recycled material content in specific product groups.

Recycled material is defined as material which either is pre-consumer material or post-consumer material. It has the same meaning as secondary material.

Pre-consumer material is material diverted from the waste generated during a manufacturing process excluding reutilization of materials such as rework, regrind or scrap generated in a process and being reincorporated in the same process that generated it.

Post-consumer material is material recovered from waste generated by households or by commercial, industrial and institutional facilities in their role as end-users of a finished product. This includes returns of products, or parts thereof, from the distribution of finished products for end-users.

Recycled material content is expressed as the average ratio of recycled materials used to the total production output of energy-related products over a specific period. The assessment of recycled material content requires:

- a description of the scope of the assessment
- a description of the material composition of a single product
- a management system to trace the type of material inputs, for both primary and recycled materials
- performance of a mass balance calculation, linking recycled material content of parts/products to total materials used in parts/products produced.

The standard describes how to determine the recycled material content of an ErP or its parts, as well as how to determine the recycled material content of a material, as manufacturers can sometimes be ErP manufacturers, part manufacturers and/or material manufacturers.

It is possible to perform the assessment of the ErP or parts thereof for

- all materials
- a type of material, e.g. plastic, metal, glass
- individual material, e.g. polypropylene, aluminum, float glass.

The scope of the assessment shall define whether the recycled material content assessment is done on the pre-consumer material or the post-consumer material or both.

More details of the assessment and calculation methods are included in the standard. The standard does also provide guidance for specific materials such as plastic, metals, and glass.

The verification of recycled material content relies on documented proof for traceability provided by the relevant operator in the CoC (chain of custody). The traceability system shall be able to track recycled materials from the moment they are identified as recycled materials to their final application. As a minimum, traceability information for the recycled materials is needed to calculate the recycled materials content.

Application

This standard is used as a reference test method in the proposed regulation for mobile phones, cordless phones and tablets, where it is required that manufacturers should provide information about the percentage of recycled content for the product or a part thereof (where available). See Annex IIIa regarding Transitional Methods. In the proposed regulation.

The standard seems to be more applicable to components or specific materials (for instance plastic) than for the entire product.

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

Proposes a standardized format for reporting use of Critical Raw Materials (CRMs). The main intention of EN 45558 is 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 does not provide any specific method or tool to collect CRM data. Process chemicals, emissions during product manufacturing and packaging are not in the scope of this standard.

The following definitions of critical raw materials (CRMs) are provided:

- **Critical Raw Material:** materials included in the Commission's list of Critical Raw Materials (European Commission, 2017a) and future updates to this.
- **Regulated CRM:** critical raw material for which a specific regulatory requirement has been set. Regulation could for instance be implemented via measures under the Ecodesign Directive.
- **Non-regulated CRM:** critical raw material for which no specific regulatory requirements have been set.

EN 45558 refers to the standard on material declaration EN IEC 62474, which is developed to facilitate the collection and declaration of information on the use of substances in products and product parts. It contains:

- a standardized list of declarable substances with standardized names to avoid misspelling (declarable substances list, DSL)
- a standardized format for declaration to ensure that declarations from different suppliers can easily be understood and exchanged.

The flexibility of the EN IEC 62474 declaration format enables the supply chain to effectively associate the CRM to both the product and to a specific part of that product.

Despite being developed for electrical and electronic equipment, EN IEC 62474 can be adapted to any type of industry as long as the substance list and the data exchange format follow the requirements stipulated in IEC 62474.

EN 45558 describes how to assess and declare the use of CRMs for both regulated and non-regulated CRMs. For regulated CRMs, a material declaration must be provided, and it should follow the specification in the applicable legislation. Typical requirements are:

- reporting of the name of the substance or substance group
- reporting the amount of the substance or substance group
- reporting the location of the substance in the product, if relevant
- exemptions, if applicable.

For non-regulated CRMs, it is voluntary to provide a material declaration. However, companies may still need to collect data on a CRM even if it is not regulated. In this case EN IEC 62474 can also be used. But as non-regulated CRMs are not automatically included in the Declarable Substance List, the manufacturers will need to create their own substance list. Examples of relevant information to be collected and assessed for non-regulated CRMs are:

- business information
- product information (e.g. product ID, name, category, weight)
- name of the substance or substance group
- amount of the substance or substance group
- Location(s) of the substance in the product
- Threshold for the reporting of the substance or substance group

Application

This standard is used as reference test method in the proposed regulation for mobile phones, cordless phones, and tablets. It was mentioned that EN 45558:2019 should be applied to gold following the same approach as for CRMs (even though gold is not on the CRM list). See Annex IIIa regarding Transitional Methods in the proposed regulation. This indicates that the standard can be applicable to broader group of materials than just CRMs.

EN 45559:2019: Methods for providing information relating to material efficiency aspects of energy-related products

Provides a general method for the communication of material efficiency aspects of energy-related products (ErP). It is intended to be used when developing a communication strategy in horizontal, generic, product-specific, or product-group publications. While the other standards in the EN 45552 45558 series provide methods to assess material efficiency aspects, this standard focuses on the communication of the various aspect-related information.

It describes a systematic approach for dealing with information linked to material efficiency requirements for ErPs within the framework of Ecodesign Directive. This includes, among others, identification of information to be mentioned (aspect-related content), target groups for the information, data sensitivity, and the means of communication and media to be used.

Application

This standard is of general nature and applicable to all ErPs.

Application of material efficiency standard[44]

CLC/TC 59X has considered whether some of the standards could be more directly applicable for household and similar electronic appliances in the scope of the Ecodesign Directive and has concluded *that EN 45558 regarding declaration of the use of critical raw material are directly applicable*.

Use of the standards EN 45554:2020 (method for assessment of the ability to repair, reuse and upgrade of energy related products) and EN 45555:2019 (method for assessment of recyclability and recoverability of energy-related products) have been analysed in the context of the draft regulation on mobile phones, cordless phones and tablets (Schischke, et al., 2022). These standards explicitly mention that they are not intended to be directly applicable to individual product groups but require a further product group specific specification. The overall conclusion of the analyses is that the standards allow for setting both specific (i.e., threshold) requirements and generic (e.g., scoring) requirements.

The analyses conclude that, regarding EN 45554:2020, there is a tendency to pick specific elements from the standard and translate them into a specific requirement, for instance with regard to the type of fasteners, and requirements related to working environment and skills.

Regarding EN 45555:2019, relevant uncertainties related to the calibration of the reference end-of-life scenario were identified. And it is furthermore found that data points on exact material composition of products are very limited and frequently refer to end-of-life analysis. But still the standard is included in the proposed regulation for smartphones and slate tablets as a transitional test method.

44. ETSI EN 303 808 v1.1.1 (2023-01) Applicability of EN 45552 to EN 45559 methods for assessment of material efficiency aspects of ICT network infrastructure goods in the context of circular economy. https://www.etsi.org/deliver/etsi_en/303800_303899/303808/01.01.01_60/en_303808v010101p.pdf

ETSI has assessed whether the material efficiency standards EN 45552 to EN 45559 are directly applicable to ICT network infrastructure goods (ETSI, 2022).taking into account the specificities of ICT network infrastructure goods which include complex products designed for long operating lifetime, high availability and professional operation and maintenance processes in a business-to-business environment. It is concluded that the standard EN 45552 – EN 45555 is not directly applicable while EN 45556 – EN 45559 could be applied more directly – but may need smaller additions as outlined in clause 5 of the draft standard. The results are shown in Table 8.

With regard to **EN 45558 General method to declare the use of critical raw materials** it is conclude that:

Declaration of the use of critical raw materials is not specific for ICT network infrastructure goods compared to other EEE. Although different CRMs may be in focus for different ICT network infrastructure goods, as EN 45558 focuses only on declaration, it is not likely to need product-specific standardization.

Table 8. Summary of applicability of EN 45552 to EN 45559 standards to ICT network infrastructure goods (Source: ETSI EN 303 808 v1.1.1, 2023-01).

Refe-rence	Title	Direct applicability	Product or product group specific standards necessary
En 45552	General method for the assessment of the durability		X
EN 45553	General method for the assessment of the ability to remanufacture		X
En 45554	General method for the assessment of the ability to repair, reuse, upgrade		X
En 45555	General methods for assessing the recyclability and recoverability		X
En 45556	General method for assessing the proportion of reused components	X	
En 45557	General method for assessing the proportion of recycled content	X	
En 45558	General method to declare the use of critical raw materials	X	
En 45559	Method for providing information relating to material efficiency aspects	X	

3.2.2 ETSI standards

ETSI is one the European standardisations organisations. The ETSI Technical Committee (TC) for Environmental Engineering (EE) develops standards for reducing the eco-environmental impact of Information and Communications Technologies (ICT) equipment.

This includes the following issues:

- the Life Cycle Assessment (LCA) of ICT goods, networks and services
- methods to assess the energy efficiency of wireless access networks and equipment, core networks and wireline access equipment including Efficiency metrics/KPI definition for equipment and network
- network standby mode for household and office equipment
- circular economy standard for ICT solutions
- Power feeding solutions based on higher DC voltage to reduce losses on the distribution cabling and innovative efficient storage solution.

ETSI has investigated current approaches, concepts and metrics of Circular Economy (CE) and Resource Efficiency (RE) and their applicability for the ICT infrastructure goods. The document ETSI TR 103 476[45] includes:

a. introduction to CE and RE,
b. description of CE as used in the ICT industry,
c. description of existing CE and RE metrics and examples of their use,
d. proposes next steps in CE and RE standardization.

ETSI is under Mandate M/573 working on standards to support the current ecodesign requirements for servers and data storage products regarding energy and resource efficiency.

Work items relevant for resource efficiency are:

- EN 303 800-2 DEN/EE-EEPS47-2: "Environmental Engineering (EE); Assessment of material efficiency of ICT network infrastructure goods (circular economy); Part 2: server and data storage product **secure data deletion functionality**".
- ETSI EN 303 800-3 DEN/EE-EEPS47-3: "Environmental Engineering (EE); Assessment of material efficiency of ICT network infrastructure goods (circular economy); Part 3: server and data storage product **availability of firmware and of security updates to firmware**".

45. https://www.etsi.org/deliver/etsi_tr/103400_103499/103476/01.01.02_60/tr_103476v010102p.pdf

- ETSI EN 303 800-5 DEN/EE-EEPS47-5: "Environmental Engineering (EE); Assessment of material efficiency of ICT network infrastructure goods (circular economy); Part 5: server and data storage product **disassembly and disassembly instruction**".

Adoption of the standards is expected in the second half of 2024[46],[47].

3.3.3 ITU standards especially relevant for servers and data storage products

International Telecommunication Union (ITU) aims to standardise practices regarding IT equipment. Several standards consider the circular economy and e-waste to achieve long-term sustainability ambitions.

ITU-T L.1xxx standards are focused on power supply series, e-waste management and recycling of rare metals in ICT products, which could be also adopted in DCI:

- Recommendation ITU-T L.1100 (2012): Procedure for recycling rare metals in information and communication technology goods," (ITU, 2012). The standard provides information on the recycling procedures of rare metals in information and communication technology (ICT) goods. It also defines a communication format for providing recycling information of rare metals contained in ICT goods.
- Recommendation ITU-T L.1021 (2018): Extended producer responsibility – Guidelines for sustainable e-waste management (ITU, 2018a). The standard describes the extended producer responsibility (EPR). It expands on the different existing forms of EPR globally, not only in theoretical terms, but also with a practical view on their feasibility, challenges and prerequisites. It presents the definition of the EPR system, in addition to the roles and responsibilities of the different stakeholders and the different types of EPR, as well as how and why they could be used in certain contexts and not in others.
- Recommendation ITU-T L.1022: "Circular Economy: Definitions and concepts for material efficiency for Information and Communication Technology".

3.3.4 Data sanitation standards

Storage devices must go through data deletion, referred to as "data sanitisation", before being reused. In general, sanitisation is defined as the process of eliminating sensitive information from a document or other medium (i.e. digital media such as HDDs and SSDs.).

Existing standards about data sanitation and deletion of hardware are gathered in Table 9.

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46. Work Item Plan M/573 https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=52941&curItemNr=1&totalNrItems=2&optDisplay=10&qSORT=HIGHVERSION&qETSI_ALL=TRUE&SearchPage=TRUE&qETSI_NUMBER=103476&qINCLUDE_SUB_TB=True&qINCLUDE_MOVED_ON=&qSTOP_FLG=&qKEYWORD_BOOLEAN=&qCLUSTER_BOOLEAN=&qFREQUENCIES_BOOLEAN=&qSTOPPING_OUTDATED=&butSimple=Search&includeNonActiveTB=FALSE&includeSubProjectCode=&qREPORT_TYPE=SUMMARY
47. https://portal.etsi.org/webapp/WorkProgram/Report_WorkItem.asp?WKI_ID=58897

Table 9. Existing standards about data sanitation and deletion of hardware. List taken from Blancco[48]

Standard Name	# of Passes	Description
Air Force System Security Instruction 5020	2	Originally defined by the United States Air Force, this 2-pass overwrite is completed by verifying the write.
Aperiodic random overwrite/Random	1	This process overwrites data with a random, instead of static, pattern. Each sector of the drive will contain different data. This process is completed by verifying the write.
Blancco SSD Erasure	Proprietary	Blancco's multi-phase, proprietary SSD erasure approach utilizes all supported SSD security protocols. This innovative method includes multiple random overwrites, firmware level erasure, freeze lock removal and full verification.
Bruce Schneier's Algorithm	7	This 7-step process, presented by security technologist Bruce Schneier, overwrites using 1s, 0s and a stream of random characters.
BSI-2011-VS	4	This 4-pass system is the original BSI standard defined by the German Federal Office of Information Security.
BSI-GS	1	Defined by the German Federal Office for Information Security, this process begins by removing hidden drives (HPA/ DCO if existing) and overwriting with aperiodic random data. The next step triggers a firmware-based command dependent on the type of drive. The last step is to verify the write.
BSI-GSE	2	The BSI-GSE adds one extra step to the BSI-GS. After the first overwrite, an additional overwrite with aperiodic random data is added before moving on to the last two steps.
CESG CPA – Higher Level	3	The UK government's National Technical Authority for Information Assurance standard is a 3-pass process with a verification after each step.
Cryptographic Erasure (Crypto Erase)	N/A	This method uses the native command to call a cryptographic erasure, which erases the encryption key. While the encrypted data remains on the storage device itself, it is effectively impossible to decrypt, rendering the data unrecoverable. Because this method uses the native commands as defined by the manufacturer, it is only available if supported by the drive being erased.
DoD 5220.22-M	3	Published by the U.S. Department of Défense (DoD) in the National Industrial Security Program Operating Manual (also known as DoD document #5220.22-M), it specified a process of overwriting hard disk drives (HDDs) with patterns of ones and zeros. The process required three secure overwriting passes and verification at the end of the final pass. More on this standard is available at our blog, "Everything You Need to Know About the DoD 5220.22-M Disk Wiping Standard & Its Applications Today".

48. Data Wiping & Erasure Standards for Business - Blancco

DoD 5220.22-M ECE	7	This method is an extended (7-pass) version of the DoD 5220.22-M. It runs the DoD 5220.22-M twice, with an extra pass (DoD 5220.22-M (C) Standard) sandwiched in between.
Extended Firmware Based Erasure	3	This Blancco-defined standard adds an overwrite as the first step and then follows the standard Firmware Based Erasure, making this a 3-step process.
Firmware Based Erasure	2	This Blancco-defined standard is a 2-step process triggers a firmware command that is dependent on the drive type. The last step of the process is to verify the write.
HMG Infosec Standard 5, Higher Standard	3	Used by the British Government, this 3-pass overwrite adds one additional write. Like the baseline standard, this process is completed by verifying the write.
HMG Infosec Standard 5, Lower Standard	1	Used by the British Government, this 1-pass overwrite consists of writing a zero pattern. This process is completed by verifying the write.
IEEE 2883-2022 Clear	0-2	Developed by the IEEE Standards Association, IEEE Clear requires the removal/erasure of certain areas (such as hidden areas, depopulated storage elements, or cache zones, if existing). The data is then sanitized (via a firmware-based command or overwritten) and verified. To learn more, see our article, "New IEEE Data Erasure Standard Fills Technology Gap"
IEEE 2883-2022 Purge	0-2	Developed by the IEEE Standards Association, IEEE Purge requires the removal/erasure of certain areas (such as hidden areas, depopulated storage elements, or cache zones, if existing). The data is then sanitized (via a firmware-based command) and verified. To learn more, see our article, "New IEEE Data Erasure Standard Fills Technology Gap"
National Computer Security Center (NCSC-TG-025)	3	Defined by the US National Security Agency, this 3-pass system includes a verification after each pass of 0s, 1s and a random character.
Navy Staff Office Publication (NAVSO P-5239-26)	3	Published by the US Navy, this 3-pass system uses a specified character (and its complement) and a random character. The process is completed by verifying the write.
NIST 800-88 Clear	0-2	The National Institute of Standards and Technology Clear requires the removal of hidden areas (HPA/DCO, if existing). The data is then overwritten and verified.
NIST 800-88 Purge	0-2	This method requires the removal of hidden areas (HPA/DCO, if existing). A firmware-based command is triggered depending on the type of drive, and the last step is the verify the write. Our NIST Guide gives more detail.

3.3.5 Plastics

In August 2022, the European Commission notified to CEN and CENELEC the new Standardization Request on plastics recycling and recycled plastics, in support of the European Strategy for Plastics in a Circular Economy (M/584) **(CEN & CENELEC, 2023).**

The Standardization Request mandates CEN and CENELEC to revise eleven European Standards and develop around 45 new deliverables. Topics covered by the request include quality grades for sorted plastic waste, characterisation of recyclates, and design-for-recycling guidelines for a wide range of products used in different applications – such as packaging, construction, electronic and electrical equipment, road vehicles, and agriculture.

The work will involve seven CEN Technical Committees and two CENELEC Technical Committees. CEN/TC 249 'Plastics' will be revising and developing most deliverables, including a standard on quality grades for sorted plastics wastes (HDPE, LDPE, PP, PET, PVC, PS, EPS) and a standard on quality assessment of plastic recyclates for use in products (rHDPE, rLDPE, rPP, rPET, rPVC, rPS, rEPS, rABS).

4 Material aspects of servers and data storage products (Technical analysis)

This section identifies and analyses the specific technical aspects related to material efficiency and circular economy of servers and data storage products especially regarding scarce, environmentally relevant, and critical raw materials. It covers the specific items listed in the revision clause (Article 8) of Regulation 2019/424 related to circular economy and material efficiency and additional items also related to circular economy and material efficiency, which can provide input for revision of the requirement in the ecodesign regulation on servers and data storage products.

As mentioned previously this report especially deals with servers and data storage products in scope of the current ecodesign regulation. Servers and storage products provide individual functionalities and are two separate product categories even though they are both covered by the same ecodesign regulation. The provided IT services are often not created by a single machine but through a combined server and storage environment.

Materials consumption of servers and data storage products and the main components of the products are further described in the following.

4.1 Materials in servers and data storage products

Servers and data storage equipment require a variety of raw materials including various critical and strategic materials included in the EU's list of critical raw materials from 2023.

Main materials in servers and data storage products are metals, plastics and electronic components such as printed circuit boards (PCBs) and intergraded circuits (ICs). The electronic components are where the majority of CRMs are found.

From an environmental point of view the content of CRMs and plastics was found to be of especially high concern, as it is indicated from literature that their recycling rates are limited. The recycling rates for iron and precious metals are in general high and this is also the case for servers and data storage products.

Various studies have analysed the content of materials in servers and data storage products. The results are varying slightly depending on the boundaries and the examples of products analysed, but the overall picture is very must the same.

Important sources for content of materials (including CRMs) in servers and data storage products are:

- Environmental Footprint and Material Efficiency Support for product policy (JRC, 2015)
- Critical raw materials for strategic technologies and sectors in the EU - a foresight study (JRC, 2020)
- Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study (JRC, 2023a)
- The EU Ecodesign preparatory study for enterprise servers and storage equipment (European Commission, 2015b)
- A situational analysis of a circular economy in the data centre industry (WeLOOP, 2020)
- The ongoing EU preparatory study for servers and data storage products

An overview of the results from the studies is shown in the following.

4.1.1 Environmental Footprint and Material Efficiency Support for product policy

The JRC study has estimated the CRM content in PCB used in enterprise serves using a bottom-up approach, where they have dismantled several enterprise servers and harvested the different PCBs contained (JRC, 2015).

The mass of PCBs ranged from 19 to 1667 grams, whereas the dimensions ranged from 18 to 1680 cm^2. A more detailed analysis was carried out to list the type, mass, and dimension of components (mainly packages and capacitors), and the number of layers of the boards. The content of CRM and other metals was then estimated based on the material declarations of the manufacturers. Due to data availability limitations, most of the efforts were concentrated on integrated circuits, capacitors, transistors and coils. The amount of CRMs in the various components, including PCBs are summarized in Table 10 below.

The study concludes that the largest amount of CRMs in servers are located in HDDs, batteries, PCBs and connectors and that there is a large variability in the content of CRM, especially in PCBs.

The disassembly process did also provide useful information regarding the difficulties in reaching the valuable parts.

Table 10. Summary of the amount of CRMs in various server components (JRC, 2015).

Part	Material	Content	Amount per server (g)
Batteries	Cobalt	Co	9,0620
	Lithium	Li	1,1371
HDD	Dysprosium	Dy	3,604
	Neodymium	Nd	14,416
	Praseodymium	Pr	3,604
	Terbium	Tb	0,748
PCBs	Magnesium	Mg	0,004
	Neodymium	Nd	0,2135
	Palladium	Pd	0,3971
	Silicon	Si	6,6544
Connectors	Antimony	Sb	4,4361
	Beryllium	Be	0,0348
	Chromium	Cr	8,5648
	Cobalt	Co	0,2039
	Palladium	Pd	0,0002
	Silicon	Si	4,5726

a) Lithium was excluded from the CRM list in 2014.
b) Data sources used to estimate the content of CRM are included in table A4 in the annex of the JRC (2015) report.
c) Silicon in servers is contained in electronic grade (9N) in the die of packages. d) In most cases silicon is contained in stainless steel alloys

The JRC environmental footprint study also gives an overall estimate of CRMs in rack servers. See Table 11. The table shows that the CRMs contained in greatest amounts are neodymium in the magnets of HDDs, followed by silicon in the integrated circuits, and cobalt in batteries. Chromium was also found to be present in levels close to that of cobalt. The current ecodesign requirements deal with two of these i.e., neodymium and cobalt. These materials are still on the EU's list of critical raw materials in 2023.

Table 11. Estimated amount of critical raw materials in enterprise servers (rack server). (JRC, 2015).

Material	Symbol	Amount per server (g)
Antimony	Sb	4,4361
Beryllium	Be	0,0348
Chromium	Cr	8,5648
Cobalt	Co	9,2659
Lithium	Li	1,1372
Magnesium	Mg	0,004
Palladium	Pd	0,3973
Silicon	Si	11,2271
Dysprosium	Dy	3,604
Neodymium	Nd	14,6295
Praseodymium	Pr	3,604
Terbium	Tb	0,748

4.1.2 Critical raw materials for strategic technologies and sectors in the EU – a foresight study

According to the JRC (2020), digitalization will bring a huge increase in data needs and will have a big impact on technologies for data storage, including the additional demand of materials for memories production storage and related production materials. It estimates that the storage of the expected 2025 global datasphere would require up to 80 kilotons of neodymium, about 120 times the current yearly EU demand of this material. Using instead emerging technologies such as ferroelectric RAM would require up to 40 kilotons of platinum, which is about 600 times the currently yearly demand of the EU.

4.1.3 Supply chain analysis and material demand forecast in strategic technologies and sectors in the EU – A foresight study

According to the EU foresight study 2023 servers and data storage products include 16 critical raw materials listed in the CRM 2023 list. But the study does not include information regarding the amount of the CRM in the products and components.

According to the foresight study the materials are used for:

- Structural materials such as aluminium but also chromium, manganese and nickel, relevant alloying components of steels, are widely used in the chassis and other elements (e.g. fans, hard disk drives, power supply units). Nickel-alloys are commonly used in PCB (printed circuit board) pad finishes, mainboard (motherboard) and expansion cards. Aluminium and copper are important thermal interface materials in heat sinks, while copper is additionally used in cables, coils and for cladding double-sided and multilayer PCB boards. Barium (as $BaTiO_3$) is employed in conventional capacitors in a populated PCB. Bismuth and tin, used in different purities and alloys (e.g. with indium), are components of low-melting point solders, where also silver-based inks and films are applied to create electrical pathways. Antimony is mainly used as the trioxide for flame-proofing compounds in PCB manufacturing where glass fibre/epoxy laminates (FR-4) is the structural substrate.
- Silicon metal is the prevalent material for semiconductor wafers. It is consumed as silicon oxide (CMOS) with aluminium or copper-nickel alloy (incl. hafnium, scandium) and SiC (silicon carbide). Other key materials required to produce semiconductors, include arsenic, in epitaxial wafer for high-frequency and radiofrequency technology, beryllium, a p-type dopant in III-V compound semiconductors, hafnium, used in advanced metal-oxide-semiconductor devices, antimony as a dopant in n-type silicon wafers, scandium nitride (ScN) as a binary III-V indirect bandgap semiconductor, gallium and germanium. Germanium is also used as $GeCl_4$ and $SiCl_4$ for the production of optical fibre.
- Dysprosium, neodymium and praseodymium are components of NdFeB alloys used in HDD permanent magnets while terbium is additionally used in semiconductors and SSDs (solid state drives).
- A variety of PGMs are used for different applications: palladium in capacitor manufacturing and connectors; platinum in semiconductor devices; high purity ruthenium powder in the magnetic layers of HDD platters and resistors. Gold is used in connectors, PCB pad finishes and ICs (integrated circuits) (e.g. memory chip connector pins). CuBe alloys are well known for their superior stress relaxation resistance and fatigue strength and are used

in connectors. Hafnium (IV) oxide is used in optical coatings, and as a high-κ dielectric in DRAM capacitors.

- Disk platters are either based on aluminium alloys or glass and the cables for power supply and communication rely on copper or glass fibre.
- Thermal interface materials (TIM) are used in almost all components of a data centre including the server boards, switches, and power supplies. Ceramic-filled silicones are the most prevalent.

4.1.4 The EU Ecodesign preparatory study for enterprise servers and storage equipment

According to the review study by the European Commission (2015b), the main material in the composition of servers is metal, particularly from the chassis (cabinet/housing) which represent 44% of the total weight. Electronic components, PCBs and intergraded circuits (ICs) also constitute a paramount share of the composition and is where CRMs are primarily found. Plastics are also present in many forms, and with a large amount found in the chassis (housing) and in fans. Based on the data in Table 11 it can be estimated that around 7% of the assessed server consist of plastics. The identified plastics in servers are made up of 15 different polymers, both technical and bulk plastics.

The EU preparatory study includes the material content for three base cases (typical product configurations) of equipment i.e. a rack server (Table 12), as well as a blade server, a data storage product consisting of 0,5 controllers, two-disc array enclosures, and an average storage mix. The content of the latter four is not listed in this report. The table does not go into detail with the content of CRM in the different components, but it shows the content of PCBs and other electronic components which are known to include CRMs.

Table 12. Bill of materials of an average rack server. Based on (European Commission, 2015b).

Material	Weight (g)
Metal body	12265
Plastics	630
Aluminium	2076
Copper	827
Electronic components	1240
Steel	538
Iron based	55
Plastic (PBT-GF30)	206
Plastics (PCABSFR40)	21
Plastics (undefined)	200
Low alloyed steel	337
PCB	981
High Density Polyethylene	316
Acrylonitrile-butadiene	12
Polycarbonat (PC)	7
Solder	33
Gold	0,4
IC	40
Low-alloyed steel	1027
Chromium steel	66
Brass	49
Zinc	103
Polyvinylchloride (PVC)	237
Paper	50
Controller board	1667
Polyurethane (PUR)	2
Synthetic rubber	35

The EU preparatory study 2015 establishes the bill of materials for 3 base cases based on information from the JRC environmental footprint study. The content of CRMs in the base cases are shown below in Table 13.

Table 13. Estimated weight (in g) of diverse critical raw materials contained in the PCBs and HDDs of the Base Cases (BC-1: Rack server, BC-2: Blade server system, BC 3: Data storage equipment. Taken from (European Commission, 2015b).

Material	BC-1 (g)	BC-2 (g)	BC-3 (g)
Dysprosium	0,24	0,96	2
Neodymium	4,18	16,7	34,83
Praseodymium	0,58	2,32	4,84
Palladium	0,93	2,06	2,41
Platinum	0,09	0,2	0,24
Antimony	0,02	0,34	0,4
Silicon	11,01	24,4	28,53
Gallium	0,05	0,11	0,13
Germanium	0,06	0,14	0,16
Cobalt	0,05	0,1	0,12

It can be seen from the table above that the number of CRMs in servers and data storage products are limited. The largest amounts are found for Neodymium and Silicon.

The base cases 1 and 2 are not comparable because BC-1 is one rack server and BC-2 is a blade system with 8 blades (more capacity than one rack server).

The preparatory study also includes details of CRMs in components based on the JRC footprint study. These details will be presented below.

4.1.5 A situational analysis of a circular economy in the data centre industry

Another study done by the 'European Interreg' funded project 'CEDaCI' have applied a reverse engineering approach to try and determine the material content of servers (WeLOOP, 2020).

The study concludes that CRMs are mainly found in batteries, drives (HDD and SSD), PCBs and connectors. Neodymium (Nd) has the highest mass and is used in magnets in HDDs, followed by cobalt from batteries and silicon metal from the integrated circuits in PCBs. As the exact amounts of each CRM identified in the study is non-disclosed property of the CEDaCI project, Table 14 only shows the material categories identified and in which component they exist.

The report confirms the findings of the JRC study, that Neodymium is the CRM found in the highest concentration (0,05% in servers).

Table 14. CRM in data servers (WeLOOP, 2020).

Component	CRM name	CRM symbol
Lithium-Ion Batteries	Cobalt	Co
HDD	Dysprosium	Dy
	Neodymium	Nd
SDD	Silicon	Si
	(CRM found in PCB)	-
PCB	Palladium	Pd
	Platinum	Pt
	Antimony	Sb
	Silicon	Si
	Gallium	Ga
	Germanium	Ge
	Tantalum	Ta
	Cobalt	Co
Connectors	Antimony	Sb
	Beryllium	Be
	Cobalt	Co
	Palladium	Pd
	Silicon metal	Si metal

The study highlights that secure supply chain for CRMs must be ensured given the increasing number and volume of DCs in Europe and the high economic and social importance they represent.

Servers, storage equipment, network equipment and batteries are the components that are replaced most frequently. Information about the materials composition of these components is not easily available to end-of-life managers. It is known that these components include CRMs which are essential to their operation, but not their concentration and the location of them. The report is experiencing a shift to hyper-scale data centres and different technologies of storage equipment (from HDDs to SSDs), so the material composition is also changing. The design of some equipment is changing too and more 'stripped down' equipment with fewer components and embodied materials is being introduced to hyper-scale DCs via the Open Compute Project.

4.1.6 The ongoing EU study for review of regulation 2019/424

No new information regarding material content in the ongoing review study **(ICF, n.d.)**. The presented data in the draft task 4 report is from the EU preparatory study from 2015.

4.1.7 Input from stakeholders to this study.

Regarding content of raw materials, input is received from one stakeholder with relation to the CEDaCI project. The input is shown below.

Table 15. Input from stakeholder regarding material content in various components.

Component	Raw materials
Data storage devices	Al, Co, Dy, In, Mg, Nd, Pr, Si, Sr, Ti, W
Memory	Al, Co, Dy, Mg, Nd, Pr, Sb, Si, Sr, Ti
Processor (CPU)	Al, Co, Dy, Mg, Sb, Si, Sr, Ti
Motherboard	Al, Co, Dy, Mg, Sb, Si, Sr, Ti
PSU	Al, Co, Dy, Mg, Sb, Si, Sr, Ti
Chassis	Cr
Batteries	Li, Ni, Co, Cu, Al

4.1.8 Summary of the data on CRM content

As Table 16 shows, Cobalt, Dysprosium, Neodymium, Palladium, Silicon, Antimony, Platinum, Gallium and Germanium are the CRMs that all literature sources agree upon is present in the servers and data storage products. There are 22 different CRMs identified through literature and stakeholders as being present in servers and data storage devices.

Table 16. List of CRMs found in servers and data storage products based on the assessed literature. Sources: (JRC, 2015), (European Commission, 2015b) & (WeLOOP, 2020)

CRM		JRC	Prep. study	CEDaCI	Stakeholder
Cobalt	Co	X	X	X	X
Lithium	Li	X			X
Dysprosium	Dy	X	X	X	X
Neodymium	Nd	X	X	X	X
Praseodymium	Pr	X	X		X
Terbium	Tb	X			
Magnesium	Mg	X			X
Palladium	Pd	X	X	X	
Silicon	Si	X	X	X	X
Antimony	Sb	X	X	X	X
Beryllium	Be	X		X	
Chromium	Cr	X			X
Ruthenium	Ru	X*			
Platinum	Pt	X*	X	X	
Gallium	Ga	X**	X	X	
Germanium	Ge	X**	X	X	
Tantalum	Ta	X*		X	
Titanium	Ti				X

Strontium	Sr		X
Tungsten	W		X
Gadolinium	Gd	X**	
Bismuth	Bi	X**	
Hafnium	Hf	X**	

*These are added in the JRC study from 2020 (JRC, 2020).
**These are listed in a JRC study from 2023 (JRC, 2023b)

The table below shows where the assessed literature has found CRMs and what has been found. Similar to what can be seen from Table 16 there is some discrepancy between what the different sources find. JRC finds that there are 7 CRMs in the HDDs whereas CEDaCI only identifies 2. The two sources agree that there is Dysprosium and Neodymium in the HDDs. Both also agree on the presence of Silicon metal in the SSDs, but JRC also lists Tantalum, and CEDaCI points out that the SSD consists of PCBs, and thus all the CRMs found in PCBs are also found in SSDs. The content of the PCBs varies a lot between sources, whereas connectors are relatively consistent.

Table 17. Overview of where the literature locates CRMs in servers and data storage products. Greyed areas are ones where the source does not give information on that compartment. Sources: (JRC, 2015), (European Commission, 2015b) & (WeLOOP, 2020)

Compartment	CRM		JRC 2015	CEDaCI	Stakeholders
Batteries	Cobalt	Co	X	X	X
	Lithium	Li	X	X	X
HDD	Dysprosium	Dy	X	X	-
	Neodymium	Nd	X	X	-
	Praseodymium	Pr	X	-	-
	Terbium	Tb	X	-	-
	Chromium	Cr	X*	-	-
	Platinum	Pt	X*	-	-
	Ruthenium	Ru	X*	-	-
	Gadolinium	Gd	X**	-	

SSD	Silicon metal	Si	X*	X	-
	Tantalum	Ta	X*	-	-
	CRMs in PCB		-	X	X
PCB	Magnesium	Mg	X	-	X
	Neodymium	Nd	X	-	X
	Palladium	Pd	X	X	-
	Silicon	Si	X	X	X
	Platinum	Pt	X**	X	-
	Antimony	Sb	X**	X	X
	Gallium	Ga	X**	X	-
	Germanium	Ge	X**	X	-
	Tantalum	Ta	-	X	-
	Cobalt	Co	-	X	X
	Strontium	Sr	-	-	X
	Dysprosium	Dy	X**	-	X
	Titanium	Ti	-	-	X
	Tungsten	W	-	-	X
	Bismuth	Bi	X**	-	-
	Hafnium	Hf	X**		
	Terbium	Tb	X**		
Connector	Antimony	Sb	X	X	-
	Beryllium	Be	X	X	-
	Chromium	Cr	X	-	-
	Cobalt	Co	X	X	-
	Palladium	Pd	X	X	-
	Silicon	Si	X	X	-

*These are added in a JRC study from 2020 (JRC, 2020).
**These are listed in a JRC study from 2023 (JRC, 2023b)

4.1.9 Summary on material content

Based on the above it can be concluded that servers and data storage products include various CRMs and precious metals, but that the amount especially for CRMs are small per product and component. In addition, the content varies from product to product and from component to component. For instance, the content of CRMs in PCBs varies considerably (due to size, grade, application, included components, manufacturer etc.). However, the four CRMs indicated to be present at highest concentrations are neodymium (HDDs), silicon metal (PCBs/SSDs), cobalt (batteries) and chromium (connectors).

In addition, availability of data is poor, and the analyses is partly carried out on older products (from scrap). It is therefore also important to consider how the content of CRMs will develop in the future due to technical changes of the products etc. and the possibilities to influence the use of CRMs via legislation (for instance via the ecodesign framework) and voluntary means (for instance public procurement or ecolabelling).

4.2 Lifetime of servers and data storage products

The 'Ecodesign Preparatory Study on Enterprise Servers and Data Equipment' (European Commission, 2015b) lists the average economic and technical lifetime of different types of equipment, based on the estimates of DIGITALEUROPE, see Table 18. The figure shows that there is a large discrepancy between how long the equipment is in a condition where it is seen as useful to the owner (economic lifetime) and how long the equipment can technically continue to function (technical lifetime). The equipment is typically replaced when it meets the end of its economic lifetime.

Table 18 Average economic and technical lifetimes of different equipment, according to DIGITALEUROPE

Equipment type	Average economic lifetime (in years)	Average technical lifetime (in years)
Tower, rack, multi-node or blade server	3 for lease 3–5 for primary user up to 5–7 for secondary user	7–10
Mainframe servers	7–15	20
Data storage devices (hard disk drives, solid-state drives, hybrid drives) and systems	5–7	7–10
Server and storage related network equipment (switches and routers)	5–7	15–20

The report states that the market research firm IDC makes similar estimates for volume and midrange servers (3–5 years life cycle) and that IDC recommended 4-year server refresh cycle to business managers to achieve increased processing power/performance, increased reliability, and reduced costs. The IDC also estimates that a 5-year-old server has an increased failure rate of 85% compared to a 3-year-old server, and that the downtime is 21% higher.

Input from stakeholders

"-Company name- has previously changed the servers each year due to improved computing power in newer equipment " – Academic

One stakeholder stated that some large data centres replace their servers yearly due to the energy efficiency improvements of newer generations. Another stakeholder further mentioned that some large data centres are obligated by the manufacturers to destroy the servers when they are taken out of service. This was stated to be due to the low price that the data centres can buy the servers at, and the manufacturers not wanting high quantities of relatively new servers to enter the market, potentially affecting their sales. These two statements indicate that there might exist a market failure which should be addressed.

Reasons for early replacement include energy efficiency improvement in latest products, operating system conversions, new (compute) capacity or capability, and service contracts. For example, technologies such as virtualisation and those arising from software defined hardware structures (e.g. Software Defined Data Centres, Software Defined Infrastructure, Software Defined Networking, etc.) will reconfigure or accelerate retirement of older systems.

The factors that influence the economic and technical lifetime is described in many ways in the literature. The two most important distinctions are between 'absolute obsolescence' and 'relative obsolescence' (JRC, 2023b). These are defined as follows:

- **Absolute obsolescence**: refers to the physical wear down of the product when a product is broken and cannot be repaired. Absolute obsolescence refers to the failure of a product to function and is mainly influenced by the product nature determined by design. In this case, the actual lifetime equals the designed lifetime.

- **Relative obsolescence:** depends on the users' evaluation of a product in comparison to new products when a product is physically still functioning but considered obsolete by the user. Relative obsolescence refers to the disuse of a functional product. In this case, the actual lifetime is less than the designed lifetime. This is a joint result of the product's nature and consumer's decision. This decision can be highly influenced by marketing, sometimes also referred to as marketing induced obsolescence. It includes further different types of obsolescence as described below.

There are different types, or sub-categories, relating to absolute and relative obsolescence concepts, which further details the underlying driver of the obsolescence. These are listed and described in the table below.

Table 19. List and description of the different types of obsolescence (JRC, 2023b).

Overall category	Obsolescence issue	Description
Absolute obsolescence	Technical	When the product no longer functions due to lack of performance of material or components.
	Functional/ incompatibility	*When the product no longer works properly due to lack of interoperability of software and/or hardware.*
Relative obsolescence	Psychological	Also called style, cosmetic or aesthetic obsolescence. When a product is replaced because the desire for a new item is strong although the old one is still functional.
	Economic	When the old product is replaced as the cost of repair or upgrading is high compared to replacement
	Technological	When the old item is replaced as a new product offering better quality, functionality or effectiveness is available
	Ecological	When a new product has a less harmful impact on the environment than the existing one

In the case of servers and storage products, both technological evolution and the adoption of energy efficiency measures can induce an increase of replacement of products, reducing their lifetime.

When considering measures to increase expected lifetime, it is also necessary to consider the balance point between replacement with new more efficient technology saving resources vs increasing resource consumption due to the embedded energy and related environmental impact for new products.

Input from stakeholders

"There are a lot of myths about performance there is very little if any difference between new and 1-2-3-year-old servers. Upgrade of some components can improve performance to meet users' needs and purchase of new servers is not always necessary." – Academic

"There has been a historical limitation at 14 nanometre lithography, but recent advancements have gotten the CPUs down to 7 nanometres and even 4 nanometres" – Academic

4.2.1 Server refreshing

One study by the IEEE has looked into the energy performance of remanufactured or refurbished servers compared to that of new servers, and also when it is economically wise to refresh the servers (IEEE, 2022). Refreshing the servers refers to the action of replacing the installed servers with newer or upgraded servers. The study finds that servers have to be older than 4,5 years before it makes economic sense to refresh to the newest generation of servers. This, the authors argue, is due to a slowdown in Moors law. Moors law being an observation, that the number of transistors on a microchip doubles every two years. One stakeholder informed, however, that there were new advancements in the size of CPUs (number of transistors on the microchips), affecting the energy consumption of the active use of the server. He also cautioned that increasing core count inside the CPU could raise idle power, which is counterproductive when servers are often underutilized.

Going back to the study, it takes as an example the improvement in energy efficiency between the generations. The energy efficiency improvement between an average on-premises generation 1 and generation 2 server was estimated at 42%, whereas the same improvement between a generation 5 and generation 6 server was estimated at 8%.

Figure 10 shows the evolution in energy performance for average on-premises non-virtualized servers' generations 1 to 6.

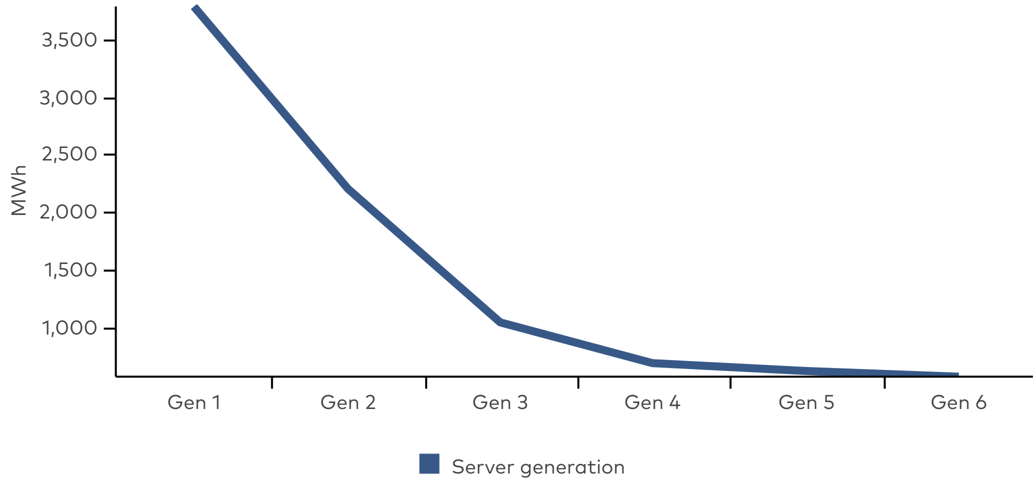

Figure 10. Use Phase Annual Energy Consumption for 200M ssj_ops Workload for average on-premises non-virtualized servers. Based on (IEEE, 2022).

The study found that similar, and sometimes better, energy performance improvements could be achieved by upgrading the last generation servers to a component level, compared to installing the newest generation.

The study concludes that there are many situations, where upgrading existing servers or refreshing with refurbished servers, make the better economic case, compared with refreshing to the newest generation servers. It should, however, be stressed that the market is changing fast, and information, data and knowledge can quickly become outdated.

4.3 Avoidance and reduction of highly critical raw materials and plastics

4.3.1 CRMs

Input from stakeholders

Question: Do you envisage any changes in the future that could influence the presence of some raw materials or their substitution? (for example, supply chain issues of certain materials, increase of prices, etc.)

Answer: *"If predictions are correct on the amount of time left for raw supply of Critical Raw Materials (some of which are expected to run out in decades), this would have a large influence.*

There is also the political risk associated with some of the source countries, which are at risk of instability or a rift with Europe. However, this point is just as applicable to the components themselves, which are manufactured in a limited number of countries worldwide.

This is a strong argument for developing not just recycling technologies but also manufacturing capability using recovered material." – Refurbisher

4.3.1.1 Recycled content

Increasing the use of recycled CRMs in components such as PCBs and HDDs could reduce the use of virgin CRMs. However, as very few CRMs are recycled so far (there is a very limited supply of recycled materials) it is still too premature to introduce an ecodesign requirement on minimum share of recycled content for CRMs. In the longer term it could be a relevant measure when a stable secondary CRM market is established. A stable market requires that the CRMs are recycled and offered for sale on a regular basis and that the materials are bought by the manufacturers.

Currently there is neither a supply of nor a demand for recycled CRM, this is elaborated on in Section 4.5. It is therefore recommended to focus efforts on supporting the development of relevant recycling capacity in order to create an increased supply, before introducing requirements regarding the minimum share of recycled content, to push for a larger demand. In addition, it is recommended to focus on the recycling of a limited number of selected CRMs used in larger quantities in servers and data storage products, or ones where larger quantities could be achieved when combining waste flows from other products.

4.3.1.2 Banning certain CRMs

Banning of materials is controversial within the ecodesign framework because requirements should be based on environmental performance of the product. However, the current ecodesign regulation for electronic displays includes a requirement that prohibits the use of flame retardants in the enclosure and stand of electronic displays[49] (See Figure 11).

4. Halogenated flame retardants
The use of halogenated flame retardants is not allowed in the enclosure and stand of electronic displays.

Figure 11. Prohibition in ecodesign regulation for electronic displays. Commission Regulation (EU) 2019/2021.

49. Commission Regulation (EU) 2019/2021 laying down ecodesign requirements for electronic displays. Annex II, D. 4.

Restriction of substances will probably be possible to implement within the ESPR.

In the preamble 22 of the proposed regulation[50] it is mentioned that:

- Union law on chemicals and food, however, does not allow addressing, through restrictions on certain substances, impacts on sustainability that are unrelated to chemical safety or food safety. To overcome this limitation, *this Regulation should allow, under certain conditions, for the restriction, primarily for reasons other than chemical or food safety, of substances present in products or used in their manufacturing processes which negatively affect products' sustainability.*

4.3.1.3 Substituting CRMs

From stakeholders it was stated that the potential for substituting specific CRM is very limited, as the materials are used because of very distinct properties.

A 2023 study by the JRC highlights that examples of material substitution in the ICT sector do exist, but that the majority of potential substitutes are currently in the research and development stage, and that market-ready solutions are scarce (JRC, 2023a).

Input from questionnaire

Question: Does the use of these materials (CRMs) influence any material efficiency aspect of products, i.e., durability, reparability, recyclability? And if yes how?

Answer: *"The physical properties and behaviour of the various materials at atomic level is very particular and the potential for **substitution** or change of design is very limited / impossible for many components in the foreseeable future." – Academic*

They list as examples:

- Ceramic capacitor producers, who have shifted from palladium based to Ni-based electrode systems, because of rising cost and supply uncertainty of
- Permanent magnets, where research and development have focused on reducing dysprosium and terbium usage. The JRC expects that complete elimination of these two CRMs in permanent magnets will be possible.

50. Proposal for a Regulation of the European Parliament and of the Council establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive 2009/125/EC. COM/2022/142 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A0142%3AFIN

The substitutes need to meet the criteria of the CRM it substitutes on function, properties, manufacturing readiness and industrial and end-user uptake. However, as new innovations are continuously made, and both price and supply security are of importance to the manufacturers, market driven substitution of some CRMs might happen regardless of regulation. To assist the development the European Commission could support research in CRM substitutes and choose it to be an Important Project of Common European Interest (IPCEI)[51]. Energy efficient chips and compound materials are already on the list of technology fields currently being supported. Using low CRM solutions could also be added as a criteria in the GPP.

4.3.2 Plastics

4.3.2.1 Recycled content

Input from questionnaire

"We need to understand what is important to us. Is it the use of PCR [post-consumer recycled plastic] in our products or overall lowering of Carbon Footprint. Many of the options we are currently exploring in Renewable materials have significantly lower in carbon emissions than PCR options"
– Manufacturer

Setting requirements on a minimum share of recycled plastic in servers and data storage products, would entail a reduction in the use of virgin plastics. Depending on the quantity used, it could also increase demand for specific types of recycled plastics, which would further incentivize investment in recycling capacity. One stakeholder highlighted, however, that new servers primarily consist of metals like steel and iron. Plastics play a smaller role, and their specific functionalities are crucial for them to hold in the high-temperature environments in data centers. Due to the performance requirements, the stakeholder saw the possibility of incorporating post-consumer recycled content into plastics as being limited.

4.3.2.2 Standardization

The supply of recycled engineered plastics could be improved, by limiting the number of different plastics used in servers and data storage products and standardizing which to be used. It has the potential to create larger and cleaner waste streams and might facilitate the creation of closed loop recycling.

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51. IPCEI on Microelectronics – Important Project of Common European Interest (ipcei-me.eu)

Input from questionnaire

"We would have to get multiple suppliers of the same components to agree on both the material types and material manufacturers. This would no doubt drive costs." – Manufacturer

PolyCE (post-consumer high-tech recycled polymers for a Circular Economy) has identified a significant challenge in the processing and recycling of plastics sourced from electrical and electronic products, which stems from the extensive variety of different polymers used (PolyCE, 2020).

A practical solution to address this issue would involve manufacturers reaching a consensus on the specific types of plastics and polymers they incorporate into their products. This concerted effort would lead to larger volumes of purer material streams, rendering it more financially feasible to invest in advanced recycling technologies.

The PolyCE project recommends the utilization of polymers with well-established high recyclability rates, such as ABS, HIPS, PS, and PP, particularly in components like housings and frames, which also have significant weight considerations.

The standardization of plastic types used, is also in accordance with the recommendations of the CEDaCI project (WeLOOP, 2020).

4.3.2.3 Reducing the amount used

As part of the CEDaCI project what they call 'a circular economy ready server' was created, which is optimized in terms of resource minimization, ease of disassembly, and improved recyclability and reusability (Kerwin et al. , 2022). At the stakeholder meeting it was emphasized by one of the authors of the study, that the standard server compared to was from around 2014, and that a newer comparison they had made, showed smaller savings achieved with their server design. The not yet published data from the comparison between the CEDaCI server and a typical server model from 2017, was afterwards shared, and included in Figure 13 below. In comparison to the standard server from 2014, the CEDaCI server managed to significantly decrease the overall weight, the total number of main assembly components and fastenings and the amount of plastic used. Compared to the typical server model from 2017, the reduction achieved with the CEDaCI server are more modest. The data indicates that the total mass, components, fastenings and plastic content is being optimized in newer server models. The plastic content in the typical server model from 2017 amounts to approximately 2% of the total server mass. This aligns with the input received from a European waste disposal stakeholder in the ongoing study for the review of the Commission Regulation 2019/424 (ICF, 2023). Here the stakeholder estimated the plastic content at 1% of the total server mass.

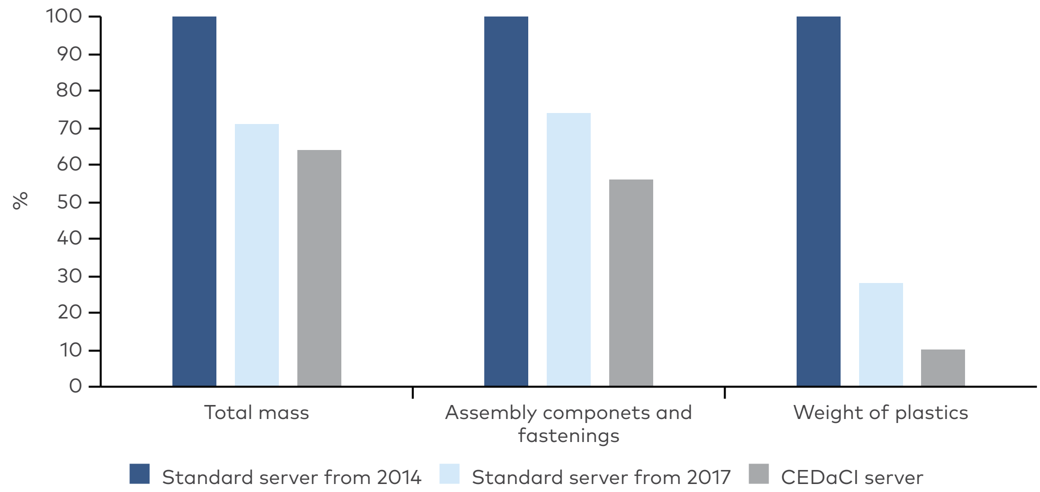

Figure 12. Reductions achieved between the CEDaCI servers and a standard server from 2014 and 2017. Own creation based on data from: (Kerwin et al., 2022) and the CEDaCI project[52].

The report does not list the CEDaCI achievements on limiting the amount and number of CRMs, but it states that the content of CRMs in non-electronic components should be reduced – e.g. in paints (Kerwin et al. , 2022).

4.4 Reuse

Reuse can be carried out on different levels. Products/components can be directly reused as "equivalent to new" or the product/components can be disassembled, and the useful/operational parts sold to spare parts providers or reused internally. Non-operating components can be refurbished or remanufactured.

According to WeLOOP (2020) there is already an established circular thinking system in datacentres, where the equipment is repaired and recycled, but there is a lack of efficiency due to different interests and approaches of stakeholders along the different life cycle stages.

Some components from servers and data storage products are already to some extent reused. According to the JRC (2015), the most frequently reused components are HDD (48%), and memory cards (40%). Other components such as the motherboard, CPU and enclosure are only to a very small extent reused (below 5%).

52. The data was supplied by an author on the CEDaCI project. The project is funded by Interreg NWE and partners with London South Bank University UK, WeLOOP France, TND France and OI, UK

Inputs from questionnaires

Question: What designs could inhibit or hinder the reparability and reusability of products and components?

Answer: *"Current designs – lack of modularity, too many fixings, inconsistent location across models and generations" – Academic*

Question: What other requirements could improve the reparability of products and components, or more generally their durability?

Answer: *"Modularity; consistent design of fixing points and simple to release fixings." – Academic*

Common maintenance practices for servers, storage and associated network equipment include for instance disk cleanup and scan (for early detection of potential hard drive crash), cleaning tape drives, monitoring fans and system temperature (especially for CPUs and drives), or upgrading drivers and firmware.

According to JRC (2015) the two most important things to ensure the reusability of servers is the availability of firmware updates and the possibility of secure non-destructive data deletion.

4.4.1 Reparability

The ecodesign regulation for smartphones and tablets (EU/2023/1670) could serve as an example for repair requirements for servers and data storage products even though the products are very different. Relevant repairability requirements for servers and data storage products could be:

- requirement for the availability of spare parts
- a list of spare parts that should be available (list should include main components of the server and firm- and software updates)
- period for availability of spare parts (for smartphones until at least 7 years after the date of end of placement on the market)
- maximum delivery time of spare parts
- part pairing should be avoided (whether this is relevant should be further investigated)
- access to repair and maintenance information
- information on prices of spare parts

Requirements in line with the above are already introduced for various products under the ecodesign framework except for the price information which so far only is introduced in the regulation for smartphones and slate tablets.

For servers and data storage products a period for availability of spare parts should at least be 8–10 years (should be longer than for smartphones).

The repair information should at least include:

- the unequivocal product identification
- a disassembly map or exploded view
- wiring and connection diagrams, as required for failure analysis
- electronic board diagrams
- a list of necessary repair and test equipment
- technical manual of instructions for repair, including marking of the individual steps
- diagnostic fault and error information (including manufacturer specific codes, where applicable)
- component and diagnosis information (such as minimum and maximum theoretical values for measurements)
- instructions for software and firmware (including reset software)
- information on how to access data records of reported failure incidents stored on the device, where applicable
- information on how to access professional repair, including the internet webpages, addresses and contact details of professional repairers registered in accordance with points 2 (a) and (b)
- Without prejudice to intellectual property rights, third parties shall be allowed to use and publish unaltered repair and maintenance information initially published by the manufacturer, importer or authorised representative and covered by point (e) once the manufacturer, importer or authorised representative terminates access to that information after the end of the period of access to repair and maintenance information.

4.4.2 Modularity

This is a key aspect when promoting reuse and repair of servers and data storage products. It is also linked to durability, as it facilitates the removal, replacement, and repair of specific parts. It further makes it easier to replace and repair components and can create a more homogenous waste stream of product parts that need similar EoL treatment.

Inputs from questionnaires

"These products are intended to be repaired while in operation, allowing components like hard drives to be replaced seamlessly. Certain parts, depending on the product's economic considerations, might be more integrated, but the overall design prioritizes repairability." – Manufacturer

"From my perspective servers are not easily repairable. Many components that break are often replaced with new ones, leading to the discarding of old components without attempts at fixing. There needs to be a shift towards longer-term thinking, especially in the light of resource scarcity considerations." – Academic

There seems to be a general discrepancy in the view of server modularity depending on who is asked. Servers are seen as highly modular by some, as their different parts can be taken out and replaced, while the server is still in operation. However, looking at the modularity within each of the server's parts, others argue that the degree of modularity is minimal. Increasing modularity in servers would mean making different components within parts easier to replace when broken. This would entail the avoidance of discarding the whole part, when a smaller component breaks, and would make it easier to remove the parts containing the majority of CRMs to be send to specialized treatment.

The modularity of racks of servers and the accessibility of the equipment (especially storage equipment) is already included in some standards (IEC Technical Report 62635:2012 or PAS 141:2011). This is already an advantage in respect to other industries, as it permits the creation of a single-product waste stream when the servers are located in high scale data centres. Although current standards do not consider the content of CRMs, a life cycle approach is used to optimise the processes of dismantling, reuse, refurbishing and recycling from the design phase (WeLOOP, 2020).

According to the EU preparatory 2015 many subassemblies including disk drives and power supply units are hot-swappable, meaning they can be exchanged while in operation. Also, the top covers of the servers are usually removable for easy access to the main subassemblies. The inside of the chassis provides frames or rails for fastening the subassemblies such as the mainboard and cages for power supply units and fan units. The chassis slides into the rack on standard rails and is fixed with quick to open fasteners. Larger units (>4U) have metal or plastic handlebars on the outside for better handling during installation.

4.4.3 Disassemblability

Increasing disassemblability by e.g. using fewer fasteners, and fasteners requiring the same tool to remove, could make it easier, and thus more cost efficient, to repair and replace parts, and to manually dismantle the products at their EOL, in order to send individual parts to undergo special recycling processes.

Input from stakeholders

"Servers etc. are not designed for disassembly; easy replacement of parts is by accident rather than intention! Some components can be hot swapped and replaced but on the most 'broken' components are not repaired, they are disposed of." – Academic

"These products are intended to be repaired while in operation, allowing components like hard drives to be replaced seamlessly. Certain parts, depending on the product's economic considerations, might be more integrated, but the overall design prioritizes repairability." – Manufacturer

Disassembly is a key aspect that affects the feasibility and success of repairs and recycling operations and improves the economics and output of recycling. Regulation 2019/424 on servers and data storage products already sets requirements for disassembly, but newer ecodesign regulations on other products include more detailed requirements in this area making use of the repair standards developed under mandate M/543.

As part of the work of CEDaCI two servers were dismantled (WeLOOP, 2020). For the first server they found that the motherboard and other CRM-rich PCBs were attached with screws, which were removed using 3 different sizes of screwdrivers. It took quite a long time to remove the necessary screws to separate all the components (~50 units). The second server was easier and faster to disassembly and fewer screws facilitated the process although it had the same type of modular assembly and the same components. The total number of PCBs was higher but only the motherboard PCB from the PSU needed screwdrivers to be removed. There were only 34 screws in this server (18 and 8 from each PSU).

The ecodesign regulation for smartphones and tablets (EU/2023/1670) is the first ecodesign regulation that includes detailed requirements regarding fasteners, tools, working environment, and skills. These requirements could serve as inspiration for disassembly requirements for servers and data storage products even though the products are very different. Relevant requirements for servers and data storage products could be:

- fasteners shall be removable
- the process for replacement shall be feasible with no tool, or with basic tools
- the process for replacement shall be able to be carried out in a use environment
- the process for replacement shall be able to be carried out by a generalist or expert (depending on the component)[53].

It could be considered to require that it should be possible to use the same tool for all screws (if screws are used) and that screws should only be used when it is not possible to use other types of fasteners, where tools are not required. The ecodesign regulation for smartphones and tablets mentions in regard to fasteners that they should be removable, resupplied or reusable. For servers and data storage we consider it especially relevant to require that fasteners are removable. There should also be made a distinction between the need for disassembly and the need for dismantling. If a part is only intended to be removed at the recycling stage, in order to send it to a specialized recycling process, fasteners can be of a type that is broken during the dismantling process.

The ecodesign regulation for smartphones and tablets also mentions regarding tools that the process for replacement shall be feasible with a set of tools that is supplied with the product or spare part. We do not consider this relevant for servers and data storage products as they will primarily be repaired by professionals (not consumers).

The standard EN 45554:2020 includes the relevant definitions regarding fasteners, tools, working environment and skills level mentioned above.

4.4.4 Standardization of design

The design standardisation could greatly improve the reuse of parts, both among brands and generations of servers, and would allow for upgrading products with newer parts, rather than replacing the product as a whole.

Input from stakeholders

"Upgrading to a newer CPU often requires discarding the entire motherboard due to incompatible sockets, resulting in unnecessary waste. This practice, especially when only one generation separates the CPUs, is primarily motivated by business considerations rather than technical necessity". – Academic

53. In the ecodesign regulation for smartphones and tablets the used skill levels are layman for spare parts available to consumers or generalist for other spare parts.

> *"That the same fan cannot be used across different servers, despite similar internal functional components, and that fixings are inconsistently placed across different models are examples of problematic practices, that leads to unnecessary waste." – Academic*

Multiple stakeholders highlighted the issues posed by a lack of design standardization between brands and generation, which limits the possibility of replacing and upgrading components, and also limits the reuse of components as they can be used in a smaller range of products.

This is supported by the findings of the CEDaCI project where the design of 16 servers from different brands and generations was assessed (Kerwin et al. , 2022). The study found that there was no standardization on the overall design. The lack of design standardization results in parts from different brands and models not being interchangeable, which creates a barrier for the reuse of components and hinders the possibility of upgrading systems with newer components. Thus, it is recommended that specific parts are standardized and simplified, to minimize material use and to allow for easy replacement of modules.

4.4.5 Secure non-destructive data deletion

There are multiple methods available for secure data deletion of servers and data storage devices, see Table 20. Data deletion using software, also known as clearing, is the only non-destructive method of data deletion and thus the only one which allows for the subsequent reuse of the product.

4.4.5.1 The importance and state of secure non-destructive data deletion

A JRC study from 2015 identifies the possibility of using secure non-destructive data deletion, together with the availability of firmware, as the most important thing to ensure reusability of servers (JRC, 2015).

The Commission Regulation (EU) 2019/424 has already set ecodesign requirements on the availability of built-in functions for secure erasure of data (clearing) (European Commission, 2019). In the 'ICT Task Force study: Final Report' it is stated that such a function is expected to provide sufficiently high assurance of data erasure for many companies and is expected to increase the reuse of enterprise servers and data storage products (JRC, 2023b).

The 'Ecodesign preparatory study on enterprise servers and data equipment' (European Commission, 2015b) cites some of the findings of the 'The Green Grid SNIA Emerald Analysis Working Group' and 'SNIA Emerald Working Group's assessment of current practices in storage device sanitation'. They find that companies generally see software overwrites as sufficient for internal reuse of servers or for external reuse of servers where the information on the servers is not sensitive. On the other hand, they see it as a necessity to have the servers physically destroyed, if they contain sensitive data and are to be reused externally.

Speaking with stakeholders the importance of secure non-destructive data deletion was confirmed. However, issues related to time, price, trust and knowledge was also brought up, and should be addressed. It was estimated through a questionnaire distributed by a stakeholder from an industry organization that in approx. 80% of the cases where destructive data deletion methods are used, non-destructive measures would be a viable option. The general impression from speaking with stakeholders is, that the majority of servers are shredded, when they are taken out of service by the owner. The reasons that the servers are shredded rather than undergoing non-destructive data deletion and reselling is brought up by the stakeholders as being the following:

- Shredding is seen as cheaper and faster by large enterprises
- There is a lack of trust in the sufficiency of data deletion software
- There is a lack of knowledge about the possibility of secure data deletion and resale

Large data centres might be contractually obligated to destroy the servers when they are taken out of service.

Input from stakeholders

"Based on questionnaire: for 78.2% of cases where a destructive method is used, non-destructive data deletion would be a viable option. But using a destructive method is cheaper." - Stakeholder" – Industry organisation

"Data deletion possibilities are not sufficient with regard to security. The normal practice is shredding" – Academic

"The data deletion functionality is a tool that small companies might use. Large enterprise will not use this software. It will take too long time to do the data erasure on a lot of servers" – Industry organization

"There is uncertainty regarding data deletion […]. They [small companies] are not aware of the possibility of resale […]. Many are also not aware of the possibility of secure non-destructive data deletion" – Refurbisher

It was brought up in conversations with stakeholders, and confirmed at the stakeholder meeting, that using built-in data deletion software could be used by smaller companies but is not a viable option in large data centres, simply because of the amount of time it will take. The economic benefits of reselling the servers are also too small and not seen as worth the effort nor the risk for large companies. Here the risk would be that of data leakage. As is can be seen in the two data deletion standards assessed below, ISO/IEC 21964 and NIST Special Publication 800-88r1, using data deletion software is also not recommended for products that leaves the company, and which might contain sensitive information. If a company cannot determine whether their servers contain sensitive information or not, it is easy to see why shredding would be chosen over a software data deletion method. One stakeholder also brought up that large data centres who buy large amount of servers, might be able to buy them at a highly reduced price, but with the requirement that the servers are destroyed when taken out of service. This, the stakeholder expected, was in order to not flood the second-hand marked with cheap and relatively new servers, which would negatively affect the manufacturers possibility of selling new products.

For companies that have their servers on premise, the issues were seen as largely relating to a lack of knowledge and trust. It was the impression of an interviewed reseller, that many smaller companies were not aware of the possibility of using data deletion software and were generally uncertain as to how they should handle their servers and data storage devices when they were taken out of service. Thus, they often just ended up in a storage room. Again, a lack of trust among the companies who knew about data deletion software was brought up. This lack of trust is not seen as fully addressed the Commission Regulation (EU) 2019/424 as the specified data deletion software does not guarantee a complete deletion of data, to a level where the data cannot be retrieved by any means. As standards tend to only recommend it in a limited number of cases, it does not help to establish trust in the method.

Based on the inputs from stakeholders the following improvements are proposed:

- Servers and data storage devices should contain visible information about the presence of data deletion software, with the manufacturers guarantee of sufficiency.
- The method for data deletion that the software uses should be standardized and should be to a level where recreation of data is impossible by all means.
- A harmonized standard for proper handling of data carriers when taken out of service should be created, and the recommendations on data deletion methods should be updated to focus on non-destructive measures.
- The practice of manufacturers requiring buyers to destroy the servers when taken out of service should be further investigated.
- The data deletion software should create a certificate showing that the data has been securely deleted, to be used in GDPR compliance.

It should be noted that one stakeholder brought up that the presence of secure data deletion software on the servers might negatively affect some of the companies working with reuse and reselling, as part of their business is to take care of the data deletion. When the owners of the servers can delete the data themselves, they might be more inclined to just dispose of the servers rather than sending them to be reused. When the company that takes care of data deletion also resells the used servers as part of their business model, the current way of data being deleted by external companies, might make for a higher reuse rate.

4.4.5.2 Data deletion and management standards

As is shown in Table 8 there exists numerous standards on how to delete data. From both literature and stakeholders, it was indicated that the standard NIST 800-88 is the most widely applied.

NIST defines sanitization as:

> ***"Media sanitization refers to a process that renders access to target data on the media infeasible for a given level of effort." – (NIST, 2014)***

This is close to the wording used in the current ecodesign regulation (EU) 2019/424:

> ***"'secure data deletion' means the effective erasure of all traces of existing data from a data storage device, overwriting the data completely in such a way that access to the original data, or parts of them, becomes infeasible for a given level of effort" –* (EU) 2019/424[54]**

The wording "infeasible for a given level of effort" is vague and does not assure a company using a data deletion software living up to this definition, that their data will be irreversibly deleted. Other definitions exist that are more stringent, such as the definition used by the International Data Sanitization Consortium (IDSC):

> ***"Data sanitization is the process of deliberately, permanently and irreversibly removing or destroying the data stored on a memory device to make it unrecoverable. A device that has been sanitized has no usable residual data, and even with the assistance of advanced forensic tools, the data will not ever be recovered" – IDSC[55]***

The definition by IDSC requires that the data cannot be recovered after deletion by any means. Incorporating a definition like this into the ecodesign regulation, would entail that companies can have more trust in the level of security the data deletion software provides.

This NIST standard is assessed below.

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54. Commission Regulation (EU) 2019/424 laying down ecodesign requirements for servers and data storage products https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R0424
55. IDSC, Data Sanitization Terminology and Definitions. Data Sanitization Terminology and Definitions - International Data Sanitization Consortium

NIST Special Publication 800-88r1 - Guidelines for Media Sanitization

Another frequently applied standard for data deletion is the NIST 800-88r1 (NIST, 2014). This standard makes three security categorizations similar to the ISO/IEC 21964.

The flow chart below shows the recommended data deletion method depending on the security category and the intended application of the product after data deletion.

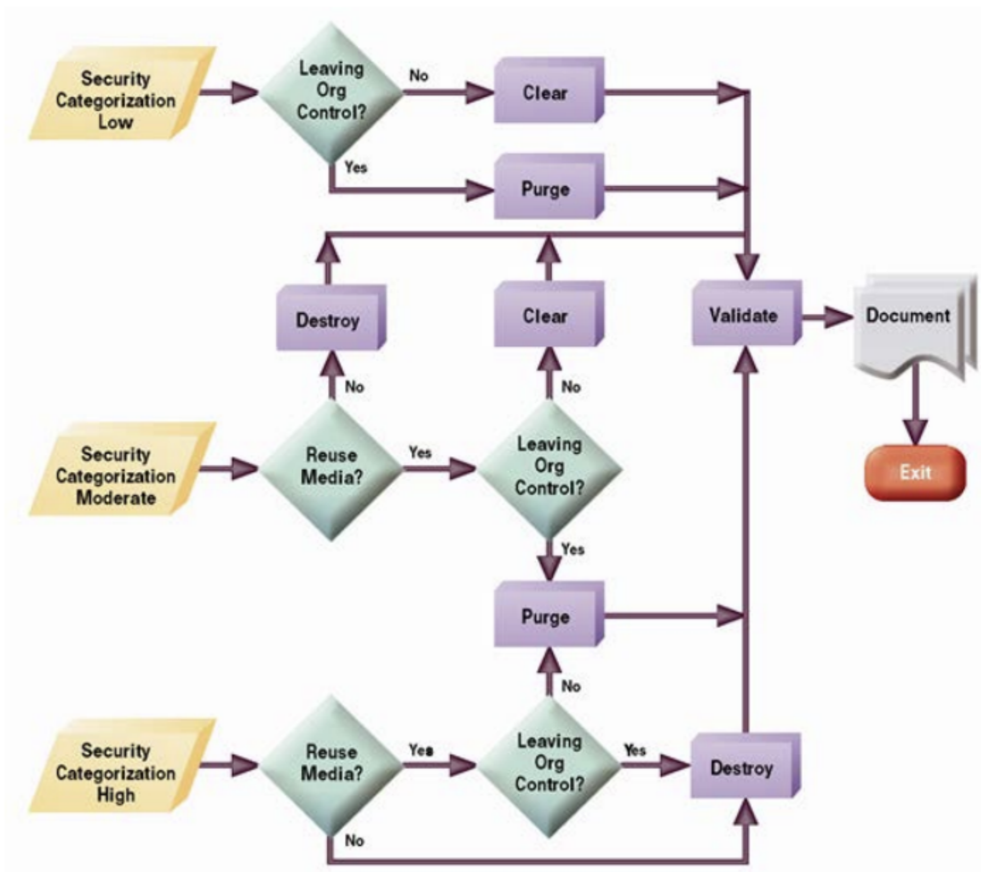

Figure 13 Sanitization and disposition decision flow. (Taken from (NIST, 2014))

As the flow chart shows this methodology allows for non-destructive data deletion methods for security category 'Low' and 'Moderate'. The sanitization actions 'Clear', 'Purge' and 'Destroy' are defined in the standard as:

- **Clear** applies logical techniques to sanitize data in all user-addressable storage locations for protection against simple non-invasive data recovery techniques; typically applied through the standard Read and Write commands to the storage device, such as by rewriting with a new value or using a menu option to reset the device to the factory state (where rewriting is not supported).
- **Purge** applies physical or logical techniques that render Target Data recovery infeasible using state of the art laboratory techniques.
- **Destroy** renders Target Data recovery infeasible using state of the art laboratory techniques and results in the subsequent inability to use the media for storage of data.

Where the sanitization action 'Clear' is always of a non-destructive nature, the action 'Purge' can be both non-destructive and destructive in the sense, that this action also includes degaussing, which is a method that do not allow for reusing the product. The flow chart further shows that in situations where the product is not intended for reuse, it is recommended that the product is destroyed. This is problematic, as both the recycling value and the possibility for CRM extraction are lowered when the product is destroyed.

Information on the method, application and subsequent reusability of the products is presented in the table below.

Table 20 Details on data deletion measures. Adapted from (WeLOOP, 2020).

Data deletion method	Reusable	Works with HDDs	Works with SSDs
Data overwrites	Yes	Yes	Yes
Shredding	No	Yes	Yes
Crushing	No	Yes	No
Degaussing*	No	Yes	No

Furthermore, the scrap value of the equipment is estimated to be highest if it has undergone data deletion by degaussing or software overwrites (WeLOOP, 2020). The scrap value is lower if crushing has been undertaken, and lowest if the equipment has been shredded.

4.4.6 Firmware and software obsolescence

Input from stakeholder

"Firmware and software redundancy/expiration are a way for manufacturers to force procurement of new products even when old products still work and meet user requirements! Its bad practice and a way of controlling the market."
– Academic

The Ecodesign regulation (EU) 2019/424 requires that firmware updates and security updates should be available for at least 8 years, after the last product of a certain product model is placed on the market. The regulation does not, however, tackle the issues of software obsolescence, which is likely due to the fact that most software is rarely provided by the manufacturer together with the product. However, the distinction between firmware and software does not always seem clear, and from our conversations with stakeholders, it seems that the understanding of the definition varies. This will be addressed further in the subsection of software.

Firmware

Input from stakeholders

"Change the life of firmware – at the end of the 8-year period make it open source". – Industry organization

"Users of electronic products should have the right to firmware updates for corrections free of charge". – Academic

"Firmware has been included in the Ecodesign Directive. However, this is specific to servers and server manufacturers and not to the components. It means that reuse can be blocked with vendor lock-in of components to particular makes of servers." - Refurbisher

The JRC study from 2015 identifies the availability of firmware as the most important thing to ensure reusability of servers, together with the possibility of secure non-destructive data deletion. If a second-hand server or component does not have the most up-to-date firmware, it will likely not be compatible with the needs of the end-user, and consequently it will not be reused (WeLOOP, 2020).

Thus, ensuring access to firmware updates for the functional lifetime of the server or component is crucial for its reuse. From our conversations with stakeholders, the importance of regulation on firmware was confirmed. However, some adjustments to the current regulation were proposed, as some stakeholders found, that not all issues related to firmware obsolescence was currently addressed.

These included that the firmware should be made open source after the 8-year period, that all firmware updates should be provided free of charge, that the required update frequency should be specified, and that the regulation should be extended to cover all components and not just the server as a whole.

Software

As part of the 2020 Circular Economy Action Plan important actions to increase circularity is identified, and among these is the availability of updates for obsolete software. A product can both have embedded system software which comes with the product and application software which can be added to the product.

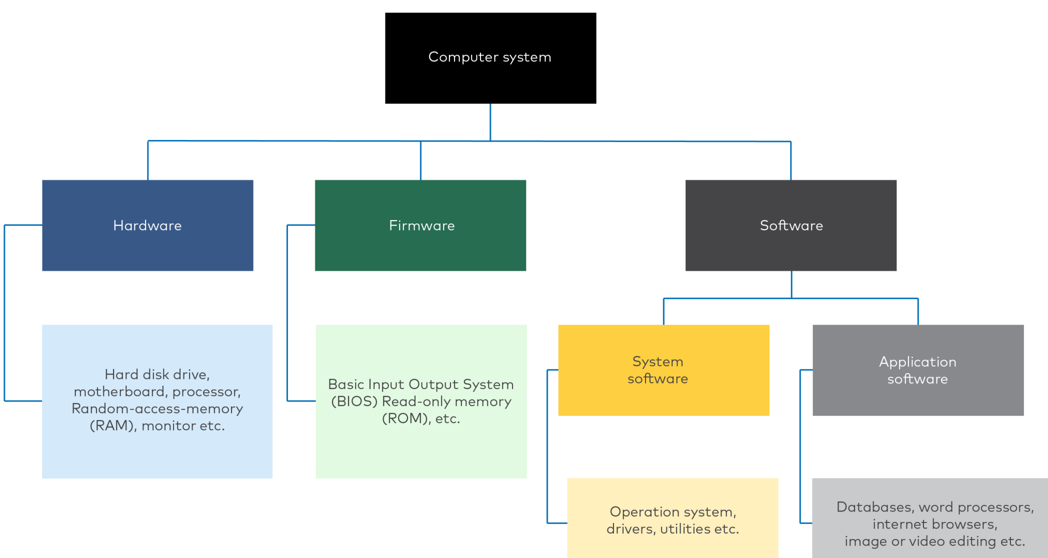

Figure 14. Overview of hardware, firmware, and software in a computer system (own compilation)

Software can both be the cause of hardware obsolescence, in the case that a necessary software update sets requirements to the hardware that it cannot meet, or the software can become obsolete itself. Software can become obsolete either due to direct software-induced effects or indirect software-related effects. These are described in the table below.

Table 21 Examples of direct and indirect software obsolescence (JRC, 2023b).

Type of software obsolescence	Example
Direct (software induced)	• Functional software failure • Built in software-controlled shutdown or counting devices. • Software inefficiencies can lead to higher performance load (software bloat) and hardware degradation
Indirect (software related)	• Functional software deficits due to changing system environments such as lack of upward and downward compatibility with other software and data formats or incompatibility with new hardware. • Expiry of software licences or cloud platforms - Loss or limited user friendliness (usability)

The JRC's 'ICT Task Force study: Final Report' includes a review of case studies on software induced obsolescence found in literature and concludes that only in a few cases is obsolescence due to direct software-induced effects.

According to Asset Guardian Solutions Limited[56] (2017), there are several causes of software obsolescence, both direct and indirect:

- Hardware: New hardware may not support old software, and it may not be possible to purchase old hardware that is supported. Obsolescence issues with hardware can cause obsolescence issues with software. The reverse is also true where new software does not run on old hardware. So, where strategies involve upgrading software, the impact on hardware also has to be considered.
- "Commercial off-the-shelf" (COTS) software12: Software suppliers obsolete their software as part of their business model, to encourage users to invest in upgrades.
- Loss of software integrity: Uncontrolled changes leave documentation out of date and software unsupportable over time. Poor revision control, back-ups and media management damage the integrity of the software making it very difficult to support changes.
- Data formats change: Old software may employ data formats for saving information that themselves become obsolete and are not compatible with newer operating systems.

56. Asset Guardian Solutions Limited (2017): Obsolescence Management of Software Components, Whitepaper, Asset Guardian Solutions Limited.

- Suppliers do not sell licenses anymore: Suppliers of a system may stop selling or renewing licenses for old software preventing it from running (or running legally and properly licensed).
- Loss of expertise for old systems: Software may use old programming languages and old programming tools with which younger engineers have no experience. Knowledge of the requirements of a system and experience of the equipment under control may be held by older engineers. Across industry, it is estimated that 50% of skilled labour will retire in next 10 years, so this can lead to obsolescence issues.

Software updates are installed during the use of products, i.e. a certain time after the product has been placed on the market and has already been in use. Software updates can have multiple purposes, e.g. security updates, fault elimination or software enhancement, improving the operation of hardware, peripherals, the performance or overall lifetime, as well as adding new programmes, functions and features (Viegand Maagøe et al., 2021). The potential benefits of installing or drawbacks when rejecting them might be different depending on consumers' needs. For example, ensuring that the device remains cyber-secure after newly discovered cyber security vulnerabilities is rather important and might have severe consequences, if the update is not installed, whereas the availability of new convenience features might not be so relevant for some consumers. Software updates are usually provided a certain time after placing the product on the market through external communication between the appliance and the manufacturer, third parties or even other users. The initial product functioning, but also the energy and resource efficiency of appliances can be modified through software updates. To avoid potential misuse of software updates in the sense that updates have the effect of changing the initial product performance and deteriorating the energy efficiency or other performance parameters in a way that would make the product non-compliant with the ecodesign requirements, most Ecodesign regulations adopted at the end of 2019 include for the first time a dedicated article on circumvention. Circumvention in this context is a products ability to detect it is being tested and alter its performance during the tests to meet requirements that it would under normal settings not meet.

As software is generally not supplied by the manufacturer with the product, regulation on software induced obsolescence might not be possible to address in Ecodesign, but could be implemented in e.g., GPP.

4.4.7 Digital Product Passport for Critical Raw Materials Reuse and Recycling

So far, the reuse and recycling of CRMs are limited. The question is whether more information could improve reuse and recycling of these materials. The current ecodesign regulation for servers and data storage products has included some information requirements but only for a few CRMs in specific components. One study has assessed existing critical raw materials information management and investigated the information needs by conducting a survey, with 10 manufacturers, producer responsibility organizations, collectors, and recyclers. The aim was to develop a conceptual Digital Product Passport for the reuse and recycling of CRMs (Koppelaar, et al., 2023).

The study developed an approach for a Circular CRM Supply Management System Architecture which take into account the necessary steps, needs for exchange of information, registering of data and verification. The developed architecture is shown in Figure 15.

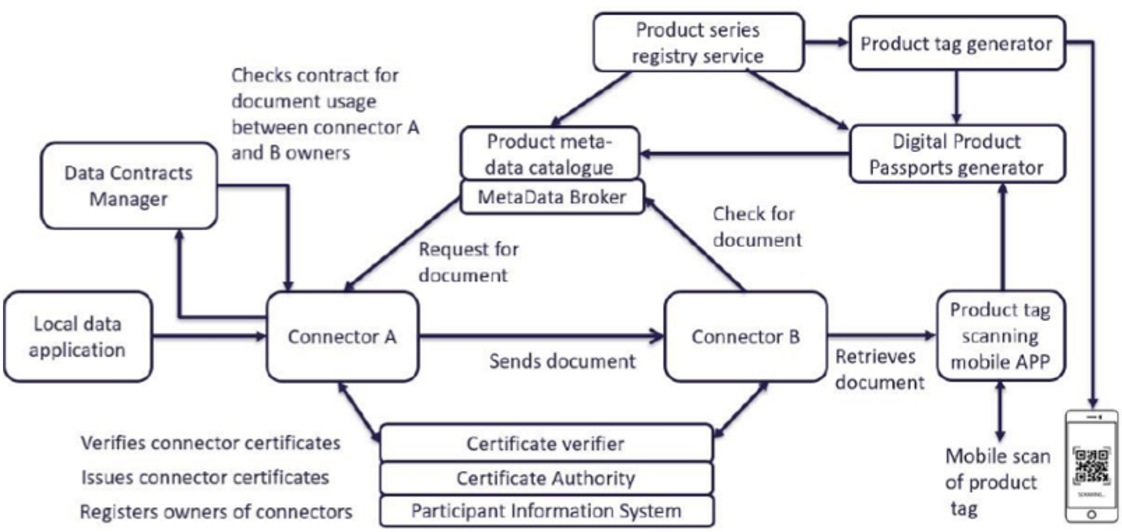

Figure 15 IT architecture of the circular CRM supply management platform using Digital Product Passports based on the International Data Spaces reference (Koppelaar, et al., 2023).

The proposed IT infrastructure to implement these information processes is based on a data spaces model that facilitates direct exchanges of documents between two organizations, such as a manufacturer and a recycler, to improve trust and security. A total of 13 IT components are proposed based on the International Data Spaces Association reference brokerage platform. To govern the information exchanges six existing and two upcoming standards are proposed as developed by European and global standardization bodies.

In addition, the study provides the following conclusions:

- no critical raw materials specific life cycle product/materials information management is in place today among the involved 10 organizations.
- the core needs of the 10 organizations to improve critical raw materials reuse and recycling include:
    - improved knowledge about the secondary raw materials market for CRMs for manufacturers
    - obtaining insights in the CRM content of products for collectors to enable separate collections or pre-sorting of products and potential extraction of CRM-containing components
    - having visibility on the CRM content in incoming flows of products and materials for recyclers to improve the disassembly and pre-treatment before recycling
    - feedback from the recycler to the manufacturer on what happens with products during the recycling phase.
- the information processes assessed that a Circular CRM supply management system needs to include:
    - a Digital Product Passport with a documentation register at product series level accessible via physical product tags
    - CRM contents documentation prepared by the manufacturer with information on the materials content
    - a list of high CRM content components in the product
    - a sorting of products with high and low CRM content at the collection stage
    - a disassembly map of a product from the manufacturer to improve component extraction for reuse/recycling
    - and feedback on CRM recycling performance of products and components from recyclers to manufacturers.

Cirpass

Work on developing and preparing of the ground for the gradual piloting and deployment of a standards-based Digital Product Passport (DPP) aligned with the requirements of the Ecodesign for Sustainable Product Regulations (ESPR) is ongoing under the European CIRPASS project, with an initial focus on the electronics, batteries, and textile sectors (CIRPASS, n.d.).

4.4.8 Part pairing

The increasing trend in electronic products towards part pairing is posing a major obstacle for repair and reuse according to The Right to Repair Europe coalition (Right to repair , 2021). Part pairing refers to the action of manufacturers encoding firmware in spare parts with a serial number (serialised parts), which lets the device detect if the spare part is a genuine Original Equipment Manufacturer (OEM) part or not. Serialisation in itself is not a barrier to repair and reuse, however it can be used to detect non genuine or second-hand spare parts and limit the access to repair and reuse by part pairing. The argument from the manufacturer side is, that it can be a necessity for security reasons, however, it also complicates the repair and reuse of products and parts, as non-OEM repairers cannot replace the parts without functionality loss.

In terms of part pairing one stakeholder highlighted that specific manufacturers have implemented restrictions in their server systems. These restrictions particularly involve certain types of CPUs and might extend to other manufacturers, making it challenging for independent providers to integrate new or upgraded parts due to software code limitations. He saw a growing trend in part pairing issues and underscored the need for attention from the Ecodesign for Sustainable Products Regulation (ESPR) in addressing these hindrances in the electronics and server industry.

Ecodesign requirements for servers and data storage devices could address the use of part pairing in a similar way as have been done in the smartphone regulation[57]. In the regulation is stated the following:

"From 20 June 2025 or from one month after the date of placement on the market, whichever is later, manufacturers, importers or authorised representatives shall, at least until 7 years after the date of end of placement on the market:

a. In case the parts to be replaced by spare parts referred to in point 1(a) are serialised parts, provide non-discriminatory access for professional repairers to any software tools, firmware or similar auxiliary means needed to ensure the full functionality of those spare parts and of the device in which such spare parts are installed during and after the replacement
b. In case the parts to be replaced by spare parts referred to in point 1(c) are serialised parts, provide non-discriminatory access for professional repairers and end-users to any software tools, firmware or similar auxiliary means needed to ensure the full functionality of those spare parts and of the device in which such spare parts are installed during and after the replacement

57. EUR-Lex - 32023R1670 - EN - EUR-Lex (europa.eu)

c. Provide, on a free access website of the manufacturer, importer or authorised representative, a description of the procedure for the notification and authorisation of the intended replacement of serialised parts by the owner of the device referred to in point (d); the procedure shall allow for remotely providing the notification and authorisation
d. Before providing access to the software tools, firmware or similar auxiliary means referred to in points (a) and (b), the manufacturer, importer or authorised representative may only require to have received a notification and authorisation of the intended part replacement by the owner of the device. Such notification and authorisation may also be provided by a professional repairer with the explicit written consent of the owner
e. Manufacturers, importers or authorised representatives shall provide access to the software tools, firmware or similar auxiliary means referred to in points (a) and (b) within 3 working days after having received the request and, where applicable, the notification and authorisation referred to in point (d)
f. The access to the software tools, firmware or similar auxiliary means referred to in point (a) may, as regards professional repairers, be limited to professional repairers registered in accordance with points 2(a) and (b)."

Another approach could be to investigate alternative means to ensure security which does not impede the possibility of repairing and upgrading, such as central storage of authentication data or multi-step authentication. Security measures such as these, transfers the responsibility and decisions related to security from the manufacturer to the owner of the product.

4.5 Recycling of CRMs and plastics

If the servers cannot be reused, either due to they are breaking, becoming obsolete or having undergone destructive data deletion measures, and the server has been picked for usable parts, the rest goes to recycling.

There is no specific information in literature about the recycling of WEEE from DCI equipment, however, in general recycling of WEEE is based on the recovery of basic metals such as steel, copper and aluminium, but additional steps tend to be added, in order to extract precious metals such as gold (WeLOOP, 2020). Plastics and CRMs are the most problematic materials to recover.

4.5.1 Current status regarding CRMs

The extraction of CRMs is underprioritized and the extraction rates are minimal. Many factors are making the extraction of CRMs a complex matter.

To name a few:

- The CRMs are present in very low concentrations, and can only be recovered through refining at the end stage
- They are often mixed with other materials
- The content of CRMs is highly heterogeneous, and vary between manufacturers
- The recyclers cannot know for certain, which CRMs are in the scrap or the amounts
- There is volatility in the demand for CRMs, which impedes investment in new capacities
- For many of the CRMs found in servers there is currently no marked for recycled material.

Furthermore, the extraction faces inherent difficulties as the processes needed for the extraction of one material tends to complicate or hinder the extraction of another. On top of this, there are broader aspects such as the lack of a well-established market for reused CRMs, volatility in their prices, and a rapid technological development on the product side, which further complicates things.

If proper recycling of CRMs is established, it could contribute to increased material efficiency through avoidance of virgin material extraction and bring about economic benefits as a result of recovering valuable materials. To get this, there needs to be a marked demand and long-term security of demand for recyclers to invest in technologies that can recover a larger number of CRMs. Roughly speaking the market can be seen as caught in a situation where there is no supply of recycled CRMs because there is no demand, and there is no demand because there is no supply. However, other factors also come into play, as there can be physiochemical barriers that hinder the extraction of some CRMs, and the small concentrations might make it economically infeasible to extract them.

As the EU is strongly reliant on imports of most CRMs and as some CRMs are facing a very high supply risk, it is becoming increasingly clear that the linear economy has to be replaced with a circular one.

For servers and data storage devices, it will require that initiatives are implemented both on the demand and supply side. Recyclers need economic security and knowledge on the type and amount of CRMs in the products, and the manufacturers needs incentives to use recycled CRMs and has to be sure that they meet the same quality requirements as their virgin counterparts. As the parts for most servers and data storage devices are manufactured outside Europe the effects of the European initiatives would be indirect.

Currently the recycling rates of CRMs from servers is estimated at around 1%, and there is thus both a large room and need for improvement (WeLOOP, 2020). Although still limited, processes are starting to be implemented In Europe, to recycle a larger range of CRMs, such as platinum, palladium and rhodium found in capacitors, HDDs and coatings, as well as cobalt found in PCBs and Power Supply Units (WeLOOP, 2020). However, the rest of the CRMs are still usually not recovered from servers at EoL. The cobalt contained in lithium batteries is already recycled at a commercial scale (JRC, 2015). General WEEE recycling is also low, 32%, with much of the remaining waste being exported out of Europe, resulting in a loss of thousands of tons of valuable resources (Andrews & Whitehead, 2019).

Both literature and stakeholders indicate that the recycling of PCBs is primarily done with the aim of extracting precious metals. PCBs are either classified as high-value PCBs, with >400 ppm of gold concentration, or classified as poor PCBs (low value), with a low concentration of gold (WeLOOP, 2020).

There are different processes used to extract CRMs. One stakeholder stated that smelting is a typical process used for extracting gold from PCBs. Smelting does not allow for subsequent extraction of some CRMs. It is a general barrier for the efficient recycling of CRMs from PCBs that the processes suitable for the extraction of one material limits or hinders the subsequent extraction of others. This means that only the highest value material will be extracted. As technology evolves products are becoming increasingly more complex and heterogeneous, aggravating this issue. The fast technology evolution in the products, is even stated in the ICT Task Force Study from 2023, as being the main obstacle to recover metals from PCBs (JRC, 2023b).

The CEDaCI Situational Analysis includes an overview of recycling rates for several CRMs in servers and information about their recycling. Table 22 shows that cobalt and magnesium have a relatively large recycling rate, whereas elements such as beryllium, platinum group metals and rare earth elements sees almost no recycling.

Table 22. Recycling rates of some CRMs in data centres (DCs), together with the EU import reliance, where the CRMs are present and how they are recycled (WeLOOP, 2020).

CRM in data servers	EU import reliance	Recyc-ling rate	Use in data centers	Recycling
Antimony (Sb)	100%	1–10%	Flame retardant in PCBs	Mainly recovered from lead-acid batteries. Sb from PCBs goes to the slag in pyro routes
Beryllium (Be)	100%	0%	As an alloying element in Cu alloys	Not recycled form old scrap, only from new.
Cobalt (Co)	32%	68%	The cathode in LIB (PSU and PCB)	LIB can be recycled, and Co recovered
Magnesium (Mg)	100%	39%	An alloying element for Al alloys	It is recycled in the aluminum recycling process
Platinum-Group Metals	100%	0–10%	Found in capacitors, HDDs, and coatings to enhance conductivity	Pt, Pd and Rh have well developed recycling processes.
Rare Earth Elements	100%	<1%	Nd and Dy in magnets of HDDs	Recovery of REE is not currently economic. There is a lot of research in the field.
Silicon metal (Si metal)	64%	-	Connectors and transistors (flash memories in SSDs and PCBs]	It is not currently recovered from old scrap
Tantalum (Ta)	100%	10–25%	Capacitors in PCBs	It is not currently recovered from old scrap

In the report from JRC (2015) it is stated that the PCBs in servers contain almost all the valuable metals. PCBs can be found in HDDs and SSDs, optical disc drives (ODDs) and power supply units (PSUs). The PCB containing the highest amount of precious and critical materials is the server mother board (WeLOOP, 2020).

Four key techniques are currently practised to try and reuse PCBs: fully manual segregation, fully manual segregation with reuse of some components, semi-automated separation with commercial shredding, and semi-automated separation with commercial smashing (JRC, 2015). The ‘fully manual segregation with reuse’ manages to save the highest value from the PCB, and a value much higher than the cost of the recycling process.

The CEWASTE project, finalised in 2021, was meant to contribute to an improved recovery of valuable and critical raw materials (CRMs) from key types of waste through traceable and sustainable treatment processes (CEWASTE, 2021). NdFeB-magnets were identified as key CRM equipment for the development of the CEWASTE requirements. In their final report, the authors describe the recycling process of NdFeB magnets as a new and emerging process. New and pilot-scale recycling process for NdFeB magnets are being developed, and currently Nd recycling is not within the established REE recycling technologies and practices. For recycling, NdFeB magnets need to be separated from HDDs and other equipment to enable their further processing. Several pretreatment options have been developed by private companies and in projects.

Input from stakeholders regarding recycling of CRMs

The literature findings presented above were confirmed through conversations with stakeholders, see some of the questions and answers on the next page. It was the experience of the interviewed stakeholders that it was difficult for the recycling industry to keep up with the development on the manufacturing side, and as there is no communication or legislation connecting the two, products tend to be designed without consideration of its EoL. Combining this with a non-existing market for recycled CRMs, low concentrations in the products, and the need for specialized novel recycling processes to extract the CRMs, makes increasing the recycling rate of CRMs a challenging matter.

Question. What recycling technologies and processes are currently available or under development for servers and storage products components?

Answer 1*. "We have been involved in providing equipment for developing pyrolysis technology and have also spoken to recyclers about bioleaching. So far, both treatments focus on PCBs only and predominantly for gold recovery. However, we are hoping this will change going forwards." – Refurbisher*

Answer 2. *"TND in France have developed thermal and chemical processes to reclaim Ag, Pb, Ni, Pb, Ta as well as Fe, Al, Cu and Au from electronics and servers.*

There are a number of EU and industry funded research programmes developing e.g. battery and magnet recycling technologies. Look at MET4TECH – a UK consortium who are working in this area." – Academic

Question. Which CRMs are recycled today with which technologies? What is the typical cost of recycling compared to virgin materials? What percentage of CRM present in the component is recycled?

Answer. *"No company we know of are actually commercially recovering CRM at scale. All those working on CRM recovery are at the research and development stage. They make their money from gold recovery." – Refurbisher*

Question. For which CRMs do you see the largest potential for recycling in the future?

Answer 1. *"Cobalt is one that is most often mentioned by recyclers directly." – Refurbisher*

Question. What are the main obstacles and challenges for the commercial development of recycling of servers and data storage products? Are there problems related to the value chains?

Answer 1. "*Lack of incentives to develop recycling infrastructure; the electronics industry is developing far more quickly than any end-of-life strategies and treatment because there is no robust guidance or legislation, and it is too easy for recycling companies to engage in illegal and irresponsible practices." – Academic*

Answer 2. "*Critical mass is the primary problem with developing the technology. Recyclers working on new methods are competing with other more proven technologies, like smelting, who can pay more per tonne. This makes it uncompetitive at the moment.*

Likewise, there is no open market for the sale of recovered CRM and no company that I have heard of using the recovered materials in their manufacture. This means there is a low to non-existent market for recovered CRM as far as I am aware." – Refurbisher

4.5.2 Current status on plastics

Plastics originating from servers and data storage products are generally expected to undergo recycling through either mechanical or chemical methods, depending on their specific characteristics (JRC, 2015). Portions of materials that do not contain a sufficient concentration of certain compounds and lack established industrial-scale recycling processes is assumed in the Joint Research Centre study to undergo incineration for energy recovery and/or disposal in landfills. In some situations, the plastic fraction might also be used as a fuel in the pyrometallurgical recovery of CRMs (WeLOOP, 2020).

The ICT task force study from 2023 lists which plastics in ICT products, that have sufficient concentration and where industrial scale recycling processes are established (JRC, 2023b). The ICT task force study from 2023 lists which plastics in

ICT products, that have sufficient concentration and where industrial scale recycling processes are established (JRC, 2023b). These are ABS, PP, PA, PC, PC/ABS, HIPS, PE (polyethylene). The other plastics that currently occur in ICT products is not economically viable to recycle. The table below combines the bill of materials from the JRC study from 2015 (See Table 12) with the information on recyclable plastics from the JRC study from 2023 (JRC, 2015) (JRC, 2023b).

Recyclability	**Plastic types**	**Percentage of plastics in server**
Recyclable	ABS, PP, PA, PC, PC/ABS, HIPS, PE	37%
Non-recyclable	PBT-GF30, PCABSFR40, PCGF, EVA, PCFR40, PVC, PUR, Synthetic rubber, GPPS, Undefined	63%

Figure 16. Share of plastics in servers that are of a recyclable type. The data is based on the Bill of material (BoM) on a standard server from (JRC, 2015) and a list of recyclable plastics in servers from (JRC, 2023b).

The data shows that for this case, only 37% of plastics found in the server are of a type that is recyclable. This does not account for the plastics being present in composites, being uneconomical to separate or contain additives that makes them non-recyclable.

One issue relating to the incineration of plastics from WEEE is the potential content of additives that, when the plastics are disposed of without proper care, can be released into the environment, leading to various risks for humans, plants and animal life (JRC, 2023b). These additives can be Brominated Flame Retardants (BFRs), plasticizers, or metal-based stabilizers. Stronger regulation restricting the use of hazardous chemicals is mitigating but not solving this issue. Also, a potential future ban on exports of plastics waste to non-OECD countries, could help ensure that hazardous plastics are properly disposed of (EU Monitor, 2023).

The ongoing study for the review of the Commission Regulation 2019/424 (ecodesign for servers and data storage products) have from a European waste disposal stakeholder gotten information regarding the breakdown of material usage, recycling, energy recovery and landfill for enterprise servers. It shows, contrary to what it indicated from literature, a low amount and high recycling rate for plastic at 98%. See Table 23.

Table 23. Inputs in the end-of-life phase of collected enterprise servers. Source: Ongoing study for the review of the Commission Regulation 2019/424 (ecodesign for servers and data storage products). Draft task 4 report. (ICF, 2023).

	Plastics	Metal	Electronics	Misc.
Mass ratio within server	1%	68%	31%	0%
Reuse	0%	0%	1%	0%
Material recycling	98%	98%	43%	50%
Heat recovery	0%	2%	56%	0%
Non-recovery incineration	0%	0%	0%	50%
Landfill	2%	0%	0%	0%

This paints a different picture of the recycling rates of plastics and the share it makes up of the whole server weight, compared to the findings of the JRC study from 2015. It is, however, in alignment with the trend on plastic content indicated by the data of the CEDaCI project presented in Section 4.3.2, which looks at typical servers form 2014 and 2017. As the data presented in the new review of the Commission Regulation 2019/424 is based on the input from only one stakeholder it might not be fully representative, however, as it aligns with the data of the CEDaCI project it gives a strong indication that there has been a change towards lower plastic content in newer server models.

If the data from both sources are correct, the discrepancy can be due to either difference in composition between brand and models, or a more general change towards less plastics in newer designs.

The PolyCE project from 2020, also names one of the current barriers to processing and recycling plastics coming from electrical/electronic products as being sheer number of different polymers in the products (PolyCE, 2020). The project's recommendation is to use polymers with known high recyclability rates, such as ABS, HIPS, PS, and PP, in parts such as housings, frames, etc. which are significant also in terms of weight. The statement here is relating to all electrical/electronic products and not just servers and data storage devices.

It should be further assessed whether plastics in newer servers still face issues related to recyclability. If so, a solution to reduce the variety of plastics would be manufacturers agreeing on the types of plastics to be used in their products; this would scale up more pure material stream volumes and make it financially more viable to invest in new recycling technologies.

This requires communication and agreement between different product, part and component manufacturers as well as designers. To increase the effect, the standardization could also be made horizontal, to cover all electronic products on the market.

4.5.3 Use of recycled plastics

Industry best practices have shown that it is feasible to use recycled plastics in a number of ICT products when innovative solutions are explored for particular products or components, as gathered in the report from DIGITALEUROPE's Best Practices in recycled plastics (DIGITALEUROPE, 2016).

However, according to DIGITALEUROPE, while the merits and opportunities of using recycled plastic are numerous, there are just as many barriers and challenges, which should not be ignored. These are among others:

- Using recycled plastics in EEE products create additional challenges in complying with EU chemical substance regulations such as RoHS and REACH since recycled plastic content introduces a risk of unknown contaminants.
- The market for recycled plastics in terms of quality, quantity, dependability and price is uncertain, and the roll-out potential seems to be difficult to assess for producers. Furthermore, a switch in an existing product to recycled content requires expensive re-testing to ensure compliance with safety regulations and quality/durability requirements.
- Recycled plastics are likely to come from several different suppliers, which are smaller in size than typical suppliers of virgin plastics. Hence, they are less able to meet fluctuations in demand volume as they cannot control the rate of source materials arising without holding expensive feedstock or finished material buffer volumes.
- Consumer acceptance needs to be tackled. Cosmetic blemishes from recycled content may not affect technical performance of a product but can still influence aesthetic factors. So, it is difficult to expect the wide use of recycled plastics for the products whose design and look can play a critical role in consumer purchase decisions.

We will collect the information available from technical literature and stakeholder feedback to describe the current best practices to incorporate recycled materials in servers and storage products, and other ICT devices, and which legal, economic, and technical barriers they encounter.

4.5.4 Recycling routes

This section will give a more detailed insight into the recycling routes and processes in order to establish the necessary knowledge base to enable the evaluation of the proposed policy options.

The study by the JRC in 2015, found that enterprise servers were primarily B2B products, which were handled at their EOL by the Original Equipment Manufacturers (OEMs), and that they rarely went to other recycling facilities (JRC, 2015). The process diagram below shows a typical route for an enterprise server at its EOL.

The diagram in Figure 19 shows the typical steps that are taken before an enterprise server is deemed unfit for reuse and send to recycling. It shows that the server will be sent for recycling, either if it has been repaired before, cannot be repaired, or if there is no demand for it.

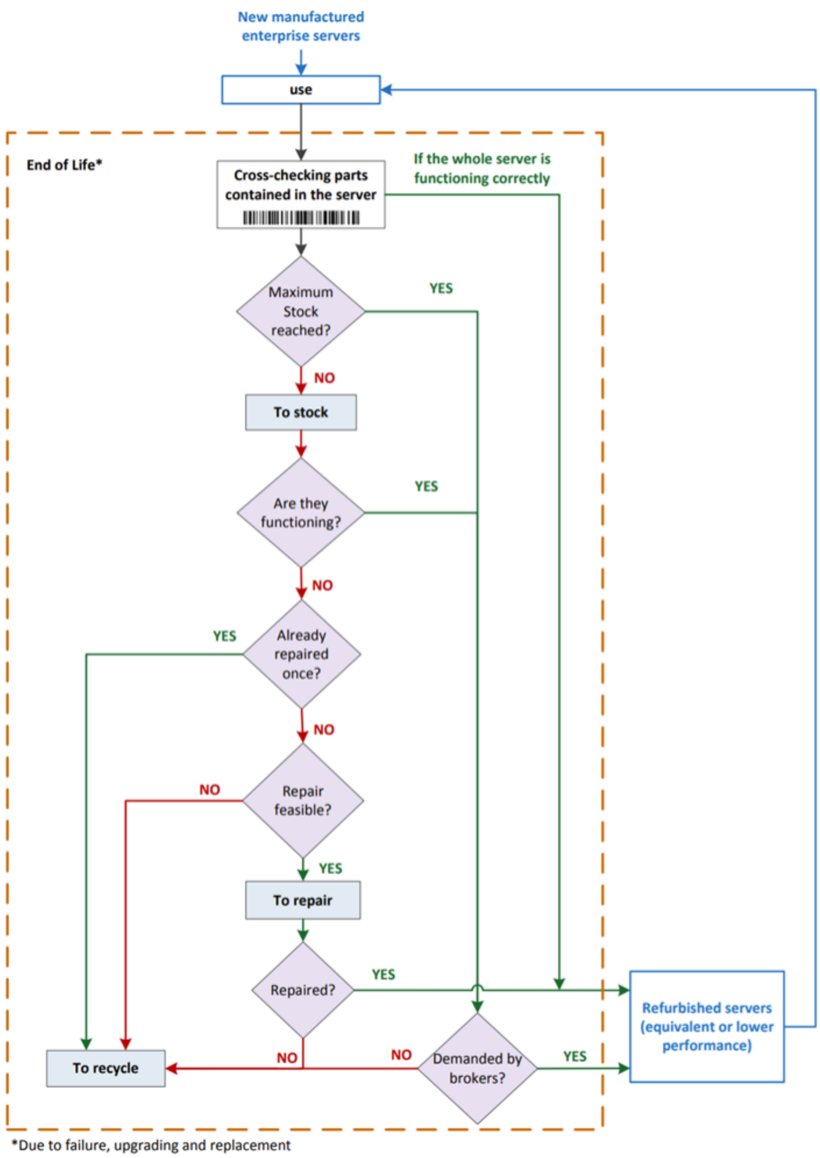

Figure 17. Diagram showing typical steps that are taken before an enterprise server is deemed unfit for reuse and send to recycling.

Generation 3 servers and older that enter refurbishing companies are generally sent for recycling, generation 4 are used to harvest certain parts, and generations 5 to 7 are resold or kept in stock due to demand on the second-hand server market (JRC, 2015).

Input from stakeholders

"The PCBs are categorized as either rich or poor mainly based on precious metal content. We do not recover PCBs manually unless the servers are expected to contain rich PCBs. If the servers are expected to contain poor PCBs then the whole server is shredded, and the PCB parts separated from the rest afterwards based on colour. The PCBs are subsequently sent to specialised companies like Umicore and Aurubis for material recycling." – Recycler

"It would be helpful to standardize the colour of the PCB, to allow for better separation after shredding." – Recycler

"We both dismantle data centres at their EOL, receive server discarded when refreshed with new ones and receive servers from consumers. In all cases the servers go to the recycling facility and PCBs are send to specialised material recyclers." – Recycler

Looking at a PCB entering a recycling facility, it will typically undergo three stages, disassembly, treatment, and refining (JRC, 2023b). In the disassembly stage the various parts are separated and sorted into individual waste fractions, to undergo selective recycling treatments. In the treatment stage the non-hazardous fraction is shredded and grinded, and then separated between metal and non-metal. In the last stage, the separated materials are then refined to obtain a useful secondary resource. The CRMs in WEEE are predominantly found in the routes of copper, lead, iron, or aluminium. Depending on which route the CRMs are in, different options to try to extract them exists. The information in Table 24 is based on the current processes in use, and it might be possible to achieve different results with innovative solutions.

Table 24. Overview of possible CRM extraction depending on route (JRC, 2023b).

Route	Possibility for extraction of CRMs
Iron	If the waste is treated by the iron-making industry, none of the materials is recovered. Only Co and Si could be part of different steel alloys. Treatment of WEEE is not efficient
Aluminium	It is a similar scenario to the iron-making industry: only some elements are reintroduced in the economic system exclusively as alloy, such as Mg. This is currently the main route of Mg from WEEE recycling.
Copper	it is the most common route for recycling of WEEE: Co, PGM and PM can be recovered by pyro or hydrometallurgical processes. On the other hand, Sb can be recovered in alloys, but REE or Si are lost in the slag
Lead	Co and Sb can be recovered, as well as the PGM and PM. This route is also used in recycling of WEEE, especially as a complementary route to the copper smelting route.

There are 9 companies globally who recycle PCBs at a larger scale. They are based on copper and lead production processes, obtaining precious metals from the by-products of these processes (WeLOOP, 2020).

To extract the metals from PCB derived material streams, four different methods are typically used, each with its own advantages and limitations. These are presented in Table 25.

Table 25 Description of the advantages and limitations of the four currently available methods for PCB recycling (JRC, 2023b).

Method	Advantages	Limitations
Pyrometal-lurgy	• the PCB can be used without any pretreatment, • very fast processing time • produces cu rich allow that can be separated and processed further.	• energy intensive • high investment cost • corrosion resistant reactor/furnace design is required • low efficiency in the conversion/recovery of metals • downstream hydrometallurgical and electrometallurgical techniques required to reach higher yields
Hydrometal-lurgy	• easy to apply, manage, high selectivity, fast reaction kinetics, and good extraction efficiency for different metals • single/multi-stage leaching can be done in two stand-alone reactors/ vessels, at a low cost • low gas emission, less operational temperature • no slag generation and high recovery rates	• protection of workers/safety is required due to the use of toxic chemicals (lixiviates) • produces large quantities of leachate • special corrosion-resistant equipment are required • high cost for the selective recovery of the desired metal • requires multiple chemicals to recovery different metals
Bio-hydro-metallurgy	• considered as an upgraded, modern and green technology • both precious and base metals can be recovered from e-waste • low operational temperature, energy requirement, low investment/operating cost • selective leaching of metals can be achieved by using different microorganisms	• difficulty in maintaining the purity of the inoculated microorganism, and reproducing the results in lab-scale and pilot-scale bioreactors • microorganisms require nutrients and carbon source to support its growth • toxicity of specific metal components present in e-waste can affect the activity of the microorganism • long processing time compared to other technologies for e-waste refining
Pyrolysis	• the e-waste can be used in its "as available" form, irrespective of the discarded electronic or electrical appliance • very short processing time • reduces e-waste volume • produces gases, oil and even metal containing char that can be processed further.	• energy intensive, high investment cost • requires further treatment of the toxic gases produced • low metal recovery rates and less purity of the final product • requires post-treatment to increase the recoverability of the metals from e-waste

Most PCBs go through either pyrometallurgical or hydrometallurgical routes, depending on whether the desired metals are found dissolved in the molten portion or in the slag. Typically, base metals will be extracted using pyrometallurgical processes, whereas precious metals are extracted with hydrometallurgical processes (WeLOOP, 2020). These processes do, however, not focus on recovery of CRMs and thus most often the CRMs are wasted.

The recycling of PCBs is the most complex process, but it has the highest potential for creating environmental benefits (WeLOOP, 2020). The mass of CRMs in PCBs is low but the number high, and the economic opportunity to recycle specific CRMs is highly affected by developmental changes in concentrations. An example is silicon metal, which is found in higher concentrations in SSDs than in HDDs. As SSDs become more widespread in the industry, the economic case for recycling silicon metal will improve, whereas the economic case for REE and neodymium, which is found in higher concentrations in HDDs, will worsen.

4.5.5 Recycling process

To give a better understanding of the processes, an example from one of the big PCBs recyclers, Umicore, is given. The example is taken from the paper 'A situational analysis of a circular economy in the data centre industry' by WeLOOP. According to the paper, the process used by Umicore is the one that allows the highest number of elements recovered and the smallest amount of losses reported.

Umicore's integrated smelting facility in Hoboken, Belgium, is mentioned in other sources as well as the most advanced plant for recovery of CRMs from WEEE (Charles et al., 2020). This is despite the fact the plant is from 2006, and thus around 17 years old (Hagelüken, 2006).

Input from stakeholder

"One of the main challenges is to identify what kind of WEEE contains CRM or where the CRM is placed, since nowadays the recyclers don't have any information about the wastes they receive. We don't know anything about the materials presented in the residues, except the most common ones, iron, copper, aluminium... In addition to this, the heterogeneity of the wastes complicates the localization of CRM." – Recycler

Umicore smelts the feed materials at 1200°C, in order to separate it into a copper bullion and lead rich slag, see Figure 18 (WeLOOP, 2020). One of the stakeholders questioned for this report, stated that the smelting process burns away some CRMs which are consequently lost. The Umicore process is, however, able to extract the CRMs antimony, bismuth, and the platinum-group metals platinum, palladium, rhodium, ruthenium and iridium. The elements antimony, bismuth platinum, palladium and ruthenium are mentioned in other sources as being present in servers and data storage products.

The recycling processes comes with an environmental burden, related to energy use as well as the use and creation of hazardous substances. Thus, the benefit of recycling needs to be compared with its environmental cost.

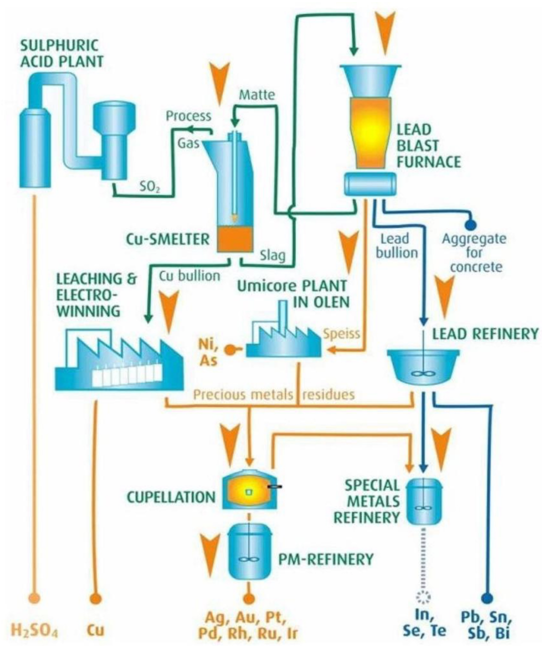

Figure 20. Process diagram showing the recycling processes at Umicore (Hagelüken, 2006).

In Table 26 below the CRMs recycled by Umicore is compared with the CRMs found to potentially be present in servers and data storage products. The comparison shows that only a fraction of the CRMs is recycled, and the CRMs found in highest content in the data storage devices, Neodymium for HDD and Silicon metal for SSD, is not recycled at all.

Table 26. List of which CRMs found in servers and data storage products, which can be recycled by Umicore.

Compartment	CRM		Recycled at Umicore
Batteries	Cobalt	Co	-
	Lithium	Li	-
HDD	Dysprosium	Dy	-
	Neodymium	Nd	-
	Praseodymium	Pr	-
	Terbium	Tb	-
	Chromium	Cr	-
	Platinum	Pt	X
	Ruthenium	Ru	X
SSD	Silicon	Si	-
	Tantalum	Ta	-
	CRMs in PCB		-
PCB	Magnesium	Mg	-
	Neodymium	Nd	-
	Palladium	Pd	X
	Silicon	Si	-
	Platinum	Pt	X
	Antimony	Sb	X
	Gallium	Ga	-
	Germanium	Ge	-
	Tantalum	Ta	-
	Cobalt	Co	-
	Strontium	Sr	-
	Dysprosium	Dy	-
	Titanium	Ti	-
	Tungsten	W	-

Connector	Antimony	Sb	X
	Beryllium	Be	-
	Chromium	Cr	-
	Cobalt	Co	-
	Palladium	Pd	X
	Silicon	Si	-

4.5.6 Input from stakeholders

Through an involved industry organization 8 refineries were approached to get more insights into their view on the possibility of recovering more CRMs. Only one refinery replied. The reply is shown in the table below:

Table 27 Input from refinery on the potential for increased CRM recovery. The answers are based on their own recycling activities.

Statement	Please List the CRMs
Currently recovered	Pd, Sb
Able to recover, but do not recover due to a lack of demand	
Able to recover, but the amount is too small to make it economically viable	
Not able to recover as it is lost in the process of recovering something else	Be, Cr, Co, Li, Mg, Si, Dy, Nd, Pr, Tb
Not seen as technically feasible to recover with technology currently on the market, because of its physiochemical properties	Be, Cr, Co, Li, Mg, Si, Dy
Not aware of being present in the material you receive, and not expected to have a potential for recovery	Nd, Pr, Tb
Not aware of being present in the material you receive, but seen as having a potential for recovery	

As the table shows the refinery recovers 2 CRMs, and the remaining 10 CRMs listed is found not to have a potential for recovery either because it is lost in the recovery of something else or because of the current technologies. The refinery was also not aware of Neodymium, Praseodymium and Terbium (three of the listed Rare Earth Elements) being present in the products they receive.

4.5.7 Identified projects and companies working with CRM recycling

Below are listed selected projects and companies working with recycling of CRMs from WEEE.

Table 28 Identified projects and companies working with CRM recycling.

Project/company	Description
Umicore	Global materials technology and recycling group. Brought up in literature as having employed the recycling technologies with the highest recovery rate of CRMs on the market.
Igneo	Recycles WEEE with Palladium as the only CRM
The Italian Flagship Project	An Italian project which has as one of its projects to create integrated technological solutions for zero waste recycling of Printed Circuit Boards (PCBs)
Korea Zinc	Does lead and zinc refining from WEEE with Cadmium, Cobalt, Palladium and Platinum as CRM output.
REE4EU	Is an EU funded project which produces an intermediate alloy from permanents magnets, in order to facilitate recycling of the REEE contained within
UrbanGold	Develops and designs new metallurgical recycling processes for close material loops
REEPRODUCE	The REEPRODUCE project aims to establish a European REEs-based permanent magnets recycling value chain at industrial scale
Revac	Revac AS is among the largest companies in Europe within the treatment of e-waste (electrical and electronic appliances/products)
Aurubis	They process complex concentrates and recycled raw materials into metals of high purity. In addition to the core metal copper, these include precious metals such as gold, silver and platinum group metals, but also metals such as lead, nickel, tin, zinc and selenium.

Indumetal	Indumetal Recycling is of the main players in the recycling of electrical and electronic equipment (WEEE) and complex scrap in Europe
Terra Nova Development	Develops and industrializes processes for the recovery of metals contained in electronic waste, batteries and certain special wastes.
Reverse metallurgy	The aim of the "Reverse Metallurgy" project is to create, in Wallonia, an internationally recognized platform for industrial, technological and scientific excellence in the field of recycling
JGI Hydrometal	Provides recycling solutions for the recovery of non-ferrous metals
Weee Metallica	Runs an industrial facility exclusively dedicated to printed circuit board recycling

4.5.8 Economy of recycling

For various materials including several CRMs, recovery do not take place because the recycling processes are not deemed economically feasible with current technologies (JRC, 2023b). The study assessed the feasibility of the recycling for a number of key components and CRMs typically found in ICT products, a selection of these is shown in Table 29. The information in the table is not specifically for Neodymium magnets and PCBs in servers and data storage devices, but it is assumed that the listed content and economic feasibility would also be applicable to servers and data storage devices.

Table 29. Feasibility of recycling a number of key components and CRMs typically found in servers (JRC, 2023b).

Source component	CRM	Currently economically feasible
Nd-magnets	Nd, Pr, Dy, Gd, Tb	No
PCBs	Au, Ag, Bi, Pd, Sb	Yes

5 Environmental impacts

5.1 Impacts for servers and storage products

As other ICT, the most relevant stages of their life cycle for servers and data storage products are material extraction (mining and extraction process) and use due to intensive energy consumption. This can be simplified by the results of the previous Ecodesign preparatory study for servers and data storage products, as shown in Figure 19 and Figure 20 for respectively blade system servers and rack servers (European Commission, 2015b).

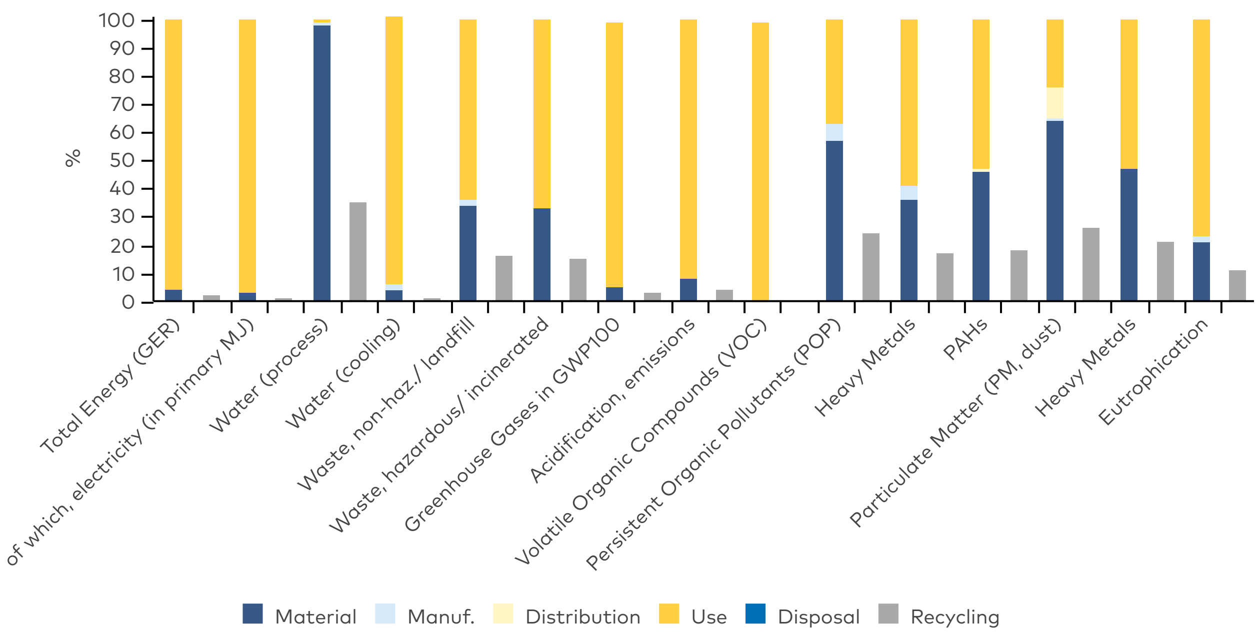

Figure 19. Distribution of environmental impacts by life cycle phase for blade server system. Source: (European Commission, 2015b)

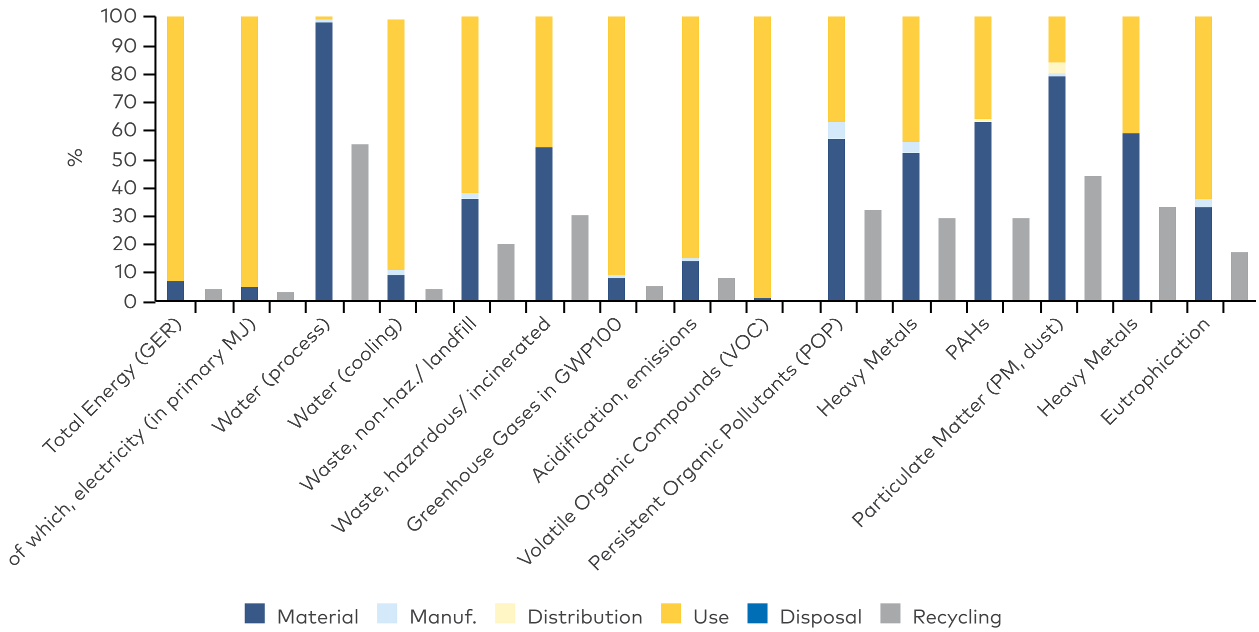

Figure 20. Distribution of environmental impacts by life cycle phase for rack servers. The text for pillar 3 and 4 is missing in Figure 22. It should be "of which, electricity (in primary energy MJ) as in Figure 21. Source: (European Commission, 2015b)

For more details on the distribution of these impacts on the different components of servers and storage products, CEDaCI has assessed the design and material composition of two servers (named SV.1.1 and SV.1.2) and two switches (WeLOOP, 2020). The equipment was dismantled and the environmental impacts of reusing and replacing components were assessed by screening-LCA to identify the environmental hotspots (WeLOOP, 2020). In addition, the motherboard (main PCB) from SV.1.1 was characterised to study the material composition.

The assessment does not include all life cycle stages, as described in Figure 21:

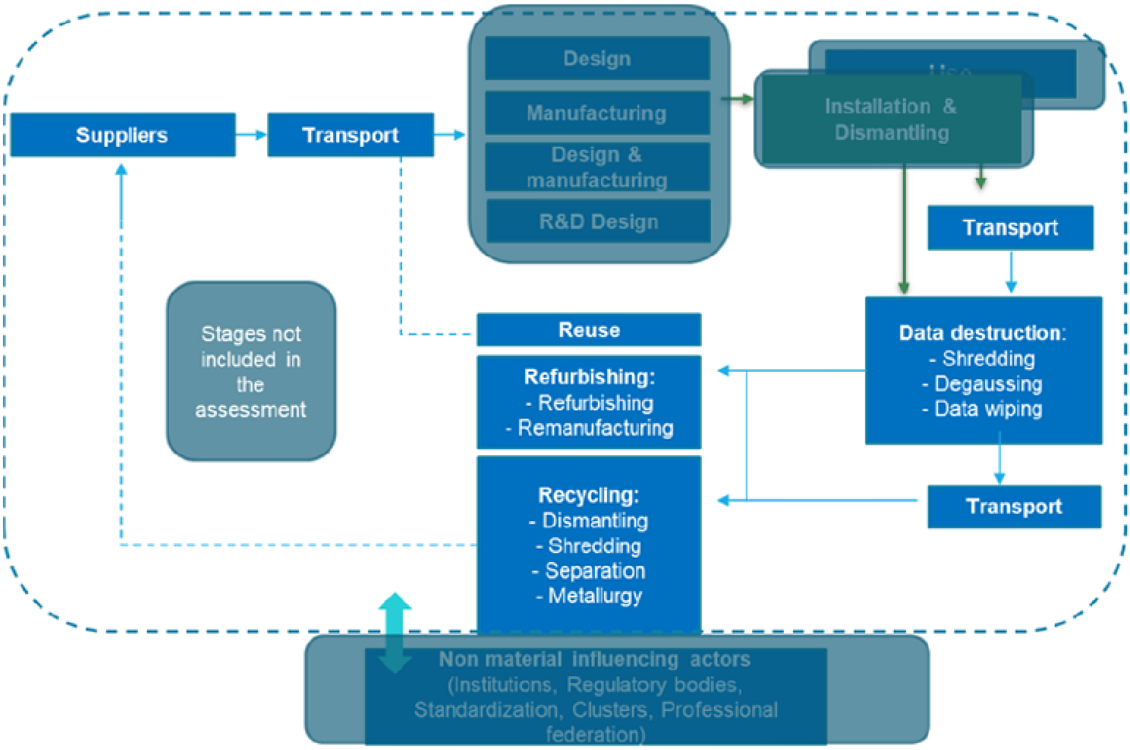

Figure 21. Life Cycle stages included in the assessment - 'greyed out' stages excluded (WeLOOP, 2020).

The results show the need to reduce the use of primary raw materials for servers and switches, especially for PCBs[58] to minimise the overall environmental impacts of data centre equipment. These components include metals in their composition (such as gold (Au) or silver (Ag)) that require large amounts of energy and chemicals for extraction and processing into a usable state and as a consequence, the environmental footprints of these materials are very high. Recycling PCBs is very beneficial to the environmental performance of data centre equipment if the recovery of materials (a minimum of gold, silver, copper, lead and platinoids) is of a high enough quality to be reused in new PCBs, and that the methods used by recyclers registered in the proposed take-back scheme are followed.

It is also concluded that the PCBs are both the component with the highest environmental impact and with the highest scrap price. PCBs have been identified as the most environmentally impactful components of DC equipment and the ones with the highest economic and environmental benefits if recycled by take-back schemes. In addition, it is stated that 85% of the embedded emissions related to data centres stem from IT, largely because the IT equipment is regularly replaced over the facility's lifetime.

58. Figure 37 and 38 in the referenced report

5.2 Impacts from mining

The EU's industry and economy are reliant on international markets to provide access to many important raw materials since they are produced and supplied by third countries. Although the domestic production of certain critical raw materials exists in the EU, notably hafnium, in most cases the EU is dependent on imports from non-EU countries.

The supply of many critical raw materials is highly concentrated. For example, China provides 98% of the EU's supply of rare earth elements (REE), Turkey provides 98% of the EU's supply of borate, and South Africa provides 71% of the EU's needs for platinum and an even higher share of the platinum group metals iridium, rhodium, and ruthenium. The EU relies on single EU companies for its supply of hafnium and strontium. The risks associated with the concentration of production are in many cases compounded by low substitution and low recycling rates.

According to JRC ICT Task Force report on Material efficiency (JRC, 2023b), and many other scientific sources, the main environmental impacts of mining activities include:

- **Production of large quantities of extractive waste and tailings:** Gold and silver are among the most wasteful metals, with more than 99 percent of ore extracted ending up as waste. According to the Best Available Techniques (BAT) Reference Document for the Management of Waste from Extractive Industries, some of the metals used in ICT devices such as gold, copper, tungsten has a very high residue-to-product ratio.
- **Risks from collapse of Extractive Waste Facilities:** extractive waste facilities (EWF) in form of dams are built to retain wastes resulting from the treatment of minerals (e.g. slurried extractive waste from mineral processing). These dams can be huge (tens of metres high and heaps even more than 100 m). The collapse of any type of EWF can have short-term and long-term effects.
    - Short-term consequences may include: dangerous flow slides; release of hazardous substances; flooding; blanketing/suffocating; crushing and destruction; cut-off of infrastructure; poisoning; casualties.
    - Long-term effects may include: metal accumulation in plants and animals, contamination of soil, contamination of groundwater, loss of animal life, adverse effects on human health.

- **Acid mine drainage (AMD):** this is one of the most serious environmental impacts associated with mining. At metal mines, the target ore (like gold, silver, copper, etc) is often rich in sulfide minerals such us pyrite FeS2 or pyrrhotite. When the mining process exposes the sulphides to water and air (oxygen), together they react to form sulfuric acid. This acid can dissolve other harmful metals and metalloids (like arsenic) from the surrounding rock. The presence of acid-ingesting bacteria often speeds the process. Waste rock piles, other exposed waste, mine openings, and pit walls are often the source of acidic effluents from a mine site. Acid mine drainage is especially harmful because it can occur indefinitely - long after mining has ended.
- **Metal deposition and toxicity:** Most mining operations use metals, reagents, or other compounds to process valuable minerals. Certain reagents or heavy metals, such as cyanide and mercury, are particularly valued for their conductive properties and thus are frequently used. The release of metals into the environment can also be triggered by acid drainage or through accidental releases from mine tailings impoundments. While small amounts of heavy metals are considered essential for the survival of many organisms, large quantities are toxic. Few terrestrial and aquatic species are known to be naturally tolerant of heavy metals, although some have adapted over time.
- **Loss of Biodiversity and Habitat:** the most obvious impact to biodiversity from mining is the removal of vegetation, which in turn alters the availability of food and shelter for wildlife. At a broader scale, mining may impact biodiversity by changing species composition and structure. For example, acid drainage and high metal concentrations in rivers generally result in an impoverished aquatic environment.

Finally, other social impacts are associated to the extraction of materials used in ICT. These include occupational health and safety violations that have direct effects on worker's lives; employment conditions including long hours, low wages and temporary contracts: forced labour in factories, smelting facilities and mines.

5.3 Impacts from manufacturing

The EU is largely dependent on other countries (mainly from South-East Asia) for supply of high-tech components and assemblies. Relevant environmental impacts for ICT devices are associated to the manufacturing of their semiconductor-based components, such as Integrated Circuits (ICs), and other complex components, such as electronic displays and Printed Circuit Boards.

JRC ICT Task force report describes the manufacture process. The two stages of manufacturing, wafer production and packaging, are not usually done in the same plants. There are two types of production plants involved in the semiconductor industry:

- front-end plants, producing wafers (such as a crystalline silicon) containing a large number of semiconductor chips and,
- back-end plants that package the chips. The package provides protection and electrical connections when the chip is integrated onto a circuit board. The same chips can be embedded in different electronic equipment.

According to JRC (2023b) the main impacts related from semiconductor manufacturing processes are:

- Global Warming: it is the most common indicator used to report on environmental changes. In the microelectronic industry it is all the more important that there is a huge amount of electricity consumed during the energy intensive production processes of semiconductor components. Moreover, a considerable quantity of PFCs is consumed during the manufacturing process.
- Abiotic depletion: chip manufacturing consumes both energy and mineral resources. Other than coal, rare gases, precious metals and REEs should be mentioned. It is a crucial topic for the whole electronic industry.
- Water eutrophication: the quality of water surrounding microelectronic plants is largely damaged by intensive usage of nitrogen and phosphorous acids, especially in wet cleaning processes.
- Imported volume of raw water: stress on water is mainly due to ultrapure water used for production and general plant functioning. Manufacturers are more and more challenged on water control issues.
- Human eco-toxicity: manufacturing, especially for the semiconductor package, rejects a large range of metals, in different physical forms (particulate and solid). The release of metals in water induces potential effects on toxicity. Other specific liquids (resins, solvents, silicon products, bases and acids) must be controlled regarding potential toxic effects during manufacturing and use in plants. The application of the RoHS directive alone strongly contributes to reducing impacts on human health, especially during end-of-life treatment.
- Photochemical oxidation: several steps of wafer and package processing consume solvents producing VOCs and plant facilities damage the quality of air (boilers, air refrigerators). Photochemical oxidation (also called summer smog) accounts for these pollutions.
- Local electricity consumption: this indicator is the most suitable to account for the total energy consumed by equipment and facilities during manufacturing. It helps to identify hotspots.

5.4 Impacts from use phase

There is no impact of CRMs in the use phase. The materials are embedded in the products and are in general not released to the environment during use. However, the use of CRMs is of importance for the performance of the product in the use phase, but this is out of scope for this study.

5.5 Impacts at end-of-life

The end-of-life treatment of CRM's is of great importance for the supply situation for CRMs. If the products/components are reused and the materials recycled the need for "new" CRMs will be lower and the supply risks reduced.

Since enterprise servers are Business to Business products (B2B), a large number of the equipment are managed by Original Equipment manufacturers (OEMs) all the way until their end-of-life rarely reaching recycling facilities and mostly having reusable parts harvested and tested for their possible reuse for second-hand equipment before the rest of the server parts reach the waste treatment sites (JRC, 2020b).

Based on experience with industry, it is seen that servers which are refreshed may be redeployed for less critical applications or sold second hand to other businesses, particularly in less developed markets. Servers high metal content also means they have a scrap value. Furthermore, OEMs are aware of the economic value of their products even when they are technologically obsolete or no longer function. In summary, servers and storage products may not be the main source of e-waste due to their B2B nature.

Various sources conclude that currently there is a very low recycling rate for CRMs (see section 5.9) and that large amounts of valuable materials are wasted at end-of life.

JRC ICT Task Force report (2023b) highlights the issues, including environmental concerns, of CRM recycling. CRMs only constitute a very low share of the total materials in servers and data storage and there needs to be a critical mass of waste to extract the CRMs from the end-of-life waste stream.

In some cases, the recycling of some CRMs is not compatible with the recycling of other materials. For example, PCBs may contain a very small quantity of tantalum which requires a different recycling process than that for the treatment of precious material such as gold. As a result, CRMs are not recovered and fed back to the production stage sufficiently to meet demand. The JRC report (2023b) also points at the complex structure of WM-PCBs is the main obstacle to recovery metals from it.

Recycling processes produce environmental impacts as well, depending on the process used. JRC describes a typical PCB recycling process:

- hydrometallurgical process generates a significant amount of leachates
- pyrometallurgical process is very energy intensive
- bio-metallurgical (biological), with the use of microorganisms for the recovery of metals in a simple, less environmentally impactful, and cost-effective manner

The JRC report (2023b) also indicates that merely 25% of e-waste[59] that is processed in developing countries in Asia and Africa is handled in formal and regular recycling centres with proper protection for their workers. Exposure to hazardous compounds is produced by two ways: direct exposures during recycling work, and indirect exposures through environmental pathways.

JRC highlights that e-waste still ends up being exported illegally, and the use of informal recycling methods which have worse environmental impact than formal recycling processes. Informal recycling methods is attractive from a cost perspective, with the use of nonskilled manual labour, and a disregard of environmental or health hazards. The methods include heating circuit boards by blowtorch method, stripping of metals in open-pit acid baths to recover gold and other metals and open-air burning of components (cables, PCBs, plastic metal assemblies. When toxic material disperses via open burning, it can be found in air, water and sediments near recycling sites, causing damages not only to the workers but residents in the surrounding areas via inhalation, dermal exposure, or the soil-crop-food pathway due to the wind patterns.

5.6 Conclusions Environmental Impacts

The findings of this section highlight the main environmental hotspots of the life cycle of servers and storage products.

When not considering energy consumption (not in scope of this study the most significant impacts is relate to the materials in the products (mining and extraction activities) and recycling.

The importance of the impacts from mining and extracting activities reinforces the need for durability, repairability, and reuse requirements.

In addition, traceability requirements such as chain of custody or due diligence requirements could help reduce the supply of minerals from high environmental risk areas or from illegal mining. Chain of custody refers to the document trail recording

59. E-waste is addressed by the Basel convention https://www.basel.int/Implementation/Ewaste/Overview/tabid/4063/Default.aspx

the sequence of companies and individuals which have custody of minerals as they move through a supply chain. Due diligence also covers the identification and assessment of risks and measures for mitigating them.

As to manufacturing, information requirements based on digital product passport could be explored as a tool to gather information and eventually setting further measures.

Impacts at end-of-life support the need to design the products for optimizing their recyclability. Apart from that, regulations within the ecodesign framework have limited or null capacity to mitigate the issues found around recycling in developing countries. However, this could be addressed by other measures such as public procurement.

6 Policy options

6.1 Introduction

The previous analyses show that servers and data storage products include various CRMs and precious metals, but that the amounts especially for CRMs are small per product and component. The components with the largest content of valuable materials (including precious metals) are the printed circuit boards (PCBs), which also are the components containing the largest amounts of CRMS. The analyses also show that precious metals are largely recycled, but that recycling of CRMs is only carried out for very few materials and only to a much lesser extent. The largest barriers for recycling of CRMs are the small amounts present in the products and the lack of a market infrastructure.

In addition, the analyses show that the actual lifetime of the servers and data storage products is shorter than the technical lifetime and that the lifetime tends to be shorter in large data centres than in smaller server rooms. Important barriers for lifetime extension and reuse are:

- lack of design standardisation between models and brands
- lack of design for disassembly and repair
- firmware and soft obsolescence
- lack of information and trust regarding secure data deletion methods.

Regarding plastics, it is found that data servers and storage products only include a small amount and that the main part is in the fan.

This section uses the information and analysis of previous sections for identification of policy options aimed at regulating scarce, environmentally relevant, and critical raw materials in this case CRMs and plastics. The policy options intend to reduce the use of CRMs and plastics in servers and data storage products, and increase lifetime, reuse, recycling, and recovery.

Focus will be on potential policy options that could be implemented within the European ecodesign framework (including ESPR). Various of the mentioned options will require further analysis and development of standards and some of them will probably be difficult to implement in the shorter term.

In some cases, it is difficult to set ecodesign requirements because it is too premature in relation to the technical development, lack of standards or the requirements are more related to a service than a product. Other policy measures such as public procurement criteria, and voluntary agreements will therefore also be addressed.

The policy options will be structured according to the waste hierarchy as shown in Figure 22. The waste management hierarchy places top priority on avoiding waste generation and reducing waste generation as much as possible. After that reuse and recycling has a higher priority than energy recovery and disposal. It should be noted that some policy options are relevant for more than one level in the hierarchy. No policy options are proposed relating to energy recovery and disposal, as these two waste management options are not circular.

Figure 24. Waste Hierarchy Diagram (Source: Own creation).

6.2 Policy options ecodesign

6.2.1 Avoid

It is not possible to fully avoid the use of CRMs in servers and data storage products, but the use might be minimized, and CRMs should only be used where these materials are necessary for the functioning and performance of the products. A total ban could be considered for specific CRMs with high risk for depletion if it is possible to substitute them with other materials[60]. Plastics can be avoided in many parts as is shown with the CEDaCI Circular Economy-Ready Server Chassis Design (WeLOOP, 2020). Substituting plastic with steel or other metals can allow for a more circular design, but the environmental impacts of the whole life cycle should be assessed before regulation is implemented.

When materials are very expensive and the supply challenged, the manufacturer will typically work to minimize the use. However, this could be supported by the following policy options:

60. The application of any banning requirement will only be possible in case viable substitutes are identified.

Table 30. Proposed policy options for the avoidance of CRMs and plastics

Measure	Specification	Section
Ban the use of CRMs	Ban the use of CRMs in all other parts than in electronic components (where alternatives are available) for instance in the chassis (enclosure or cabinet)	4.3.1.2
	Ban the use of specific CRMs with high risk of depletion and supply (where alternatives are available). Which CRMs would need to be further investigated.	4.3.1.2
Restrict the number of CRMs	Require that only a limited number of CRMs must be used in specific products or components	4.3.1.2
Ban the use of non-recyclable plastics	Require that plastics used should be limited to ones with established high recyclability rates	4.3.2.2
Ban the use of plastics	Ban the use of plastics in specific components (where alternatives are available for instance in non-electronic components)	4.3.2.2

It will probably not always be possible to ban or restrict the use of specific CRMs in servers and data storage products or components due to functionality and/or security issues. So, if a ban is introduced in an ecodesign regulation it will be necessary to include a kind of exception. It could for instance be formulated in this way:

- If it is not possible to avoid the use of a specific CRM due to functionality of the product and/or security issues, the need to apply the CRM should be justified in the technical documentation of the product.

Banning of materials is controversial within the ecodesign framework because requirements should be based on environmental performance of the product. However, the current ecodesign regulation for electronic displays includes a requirement that prohibits the use of flame retardants in the enclosure and stand of electronic displays[61] (See Figure 23).

61. Commission Regulation (EU) 2019/2021 laying down ecodesign requirements for electronic displays. Annex II, D. 4.

4. Halogenated flame retardants
The use of halogenated flame retardants is not allowed in the enclosure and stand of electronic displays.

Figure 23. Prohibition in ecodesign regulation for electronic displays. Commission Regulation (EU) 2019/2021.

Restriction of substances will probably be possible to implement within the Ecodesign for Sustainable Products Regulation (ESPR).

In the preamble 22 of the proposed ESPR regulation is mentioned[62]:

- Union law on chemicals and food, however, does not allow addressing, through restrictions on certain substances, impacts on sustainability that are unrelated to chemical safety or food safety. To overcome this limitation, *this Regulation should allow, under certain conditions, for the restriction, primarily for reasons other than chemical or food safety, of substances present in products or used in their manufacturing processes which negatively affect products' sustainability.*

The proposed requirements would all require further assessment of the feasibility and improvement potentials.

6.2.2 Reduce use

The use of CRMs and plastics could be reduced by various means. All measures increasing the lifetime of the servers and data storage products will reduce the use of materials because fewer new products will need to be manufactured. For measures to extend the lifetime see section 7.4.

Another measure is to reduce the use of virgin CRMs and plastics by increasing the use of recycled materials. As very few CRMs are recycled so far (there is no or very limited supply of recycled materials) it is still too premature to introduce an ecodesign requirement on minimum share of recycled content for CRMs in servers and data storage products. However, in the longer term, when a stable secondary CRM market is established, it could be a relevant policy option. A stable market requires that the CRMs are recycled and offered for sale on a regular basis and that the materials are bought by the manufacturers and components etc. In the shorter term an information requirement about the content of recycled materials could be considered.

62. Proposal for a Regulation of the European Parliament and of the Council establishing a framework for setting ecodesign requirements for sustainable products and repealing Directive 2009/125/EC. COM/2022/142 final. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2022%3A0142%3AFIN. There might be changes in the final act, which is not yet published.

The major hurdle is according to stakeholders the lack of recycling infrastructure, hindering progress toward a circular economy. Redesigning products for easier repair are seen as insufficient without significant improvements in recycling and material collection at the end of life. In addition, the importance of limiting the presence of flame retardants in materials for recycling is emphasized.

It is therefore recommended to assess the possibilities for developing relevant recycling and creating a market infrastructure for recycled CRM. In addition, it is recommended to introduce requirements facilitating recycling and to focus on recycling of a small number of specific CRMs used in larger quantities in servers and data storage products and not on all CRMs used.

The supply of recycled engineered plastics could also be improved, by limiting the number of different plastics used in servers and data storage products and standardizing which types to be used. This would create larger and cleaner waste streams and might facilitate the creation of closed loop recycling.

Potential policy options to support recycling CRMs and plastics are among others:

Table 31. Proposed policy options for the reduction of CRMs and plastics

Measure	Specification	Section
Limit the use of virgin CRMs and plastics	Information requirement to facilitate recycling (this could be information requirement regarding content of CRMs, disassembly requirements etc.)	4.5
	See policy option related to reuse.	6.2.3

6.2.3 Reuse

The next step in the waste hierarchy is reuse – meaning direct reuse of products or components. Direct reuse is when a product can be easily repaired or perhaps simply cleaned, thereby leaving the waste category, and returning to the market as a usable product or component thereby extending the lifetime of the product.

If a larger share of products is directly reused, less materials including CRMs will have to be mined and included in products. Reuse and refurbishment are recommended when the component is still energetically efficient in comparison with new products.

Extended lifetime by repair etc. could, however, lead to increased use of energy. This should be taken into account but is not dealt with in detail in this project. However, various stakeholders have indicated that the improvements in energy efficiency of new generations of servers has slowed down, meaning that the products can be used for longer time and upgraded rather than replaced, without compromising energy efficiency initiatives substantially. One thing that was brought up by stakeholders as standing in the way of upgrading servers rather than replacing them, is the lack of standardization between brands and generations, which greatly limits the possibility of upgrading products with new parts.

To extend the lifetime it is also important to increase the durability of the products, for instance by designing them to be easier to repair. In general servers and data storage products are durable and the actual lifetime is shorter than the technical lifetime. However, some studies indicate that the down time and failure rate increases by a notable amount over the course of the technical lifetime of the product.

It is relevant to see how relative obsolescence can be pushed closer towards the absolute obsolescence of the products.

The current ecodesign regulation for servers and data storage products does include requirements ensuring that joining, fastening or sealing techniques do not prevent the disassembly for repair or reuse.

According to the CEDaCI (WeLOOP, 2020) project the reuse, refurbishment and collection rates are higher in big datacenters (which have internal reuse mechanisms), than in smaller and private data centers. It might therefore be relevant to propose requirements supporting more reuse in smaller data centers.

The ecodesign regulation for smartphones and tablets (EU/2023/1670) could serve as an example for repair requirements for servers and data storage products even though the products are very different.

Various measures that could help improve reuse of the products are still too premature to implement within the ecodesign framework, but they could be implemented within public procurement or voluntary measures. This is for instance measures dealing with standardisation of components or modularity of components. Such measures are therefore only mentioned in section 7.3.

Table 32. Proposed policy options for the reuse of servers and data storage products

Measure	Specification	Section
Availability of spare parts	Specific listed spare parts shall be available for at least 8–10 years[63]. Should include all main elements in the server and data storage products. Spare part should among others include data storage devices (HDDs, SSDs, etc.), Motherboard, PCBs, RAM, CPUs, GPU, chassis/racks, fans, PSUs, integrated switch, capacitors, batteries, RAID controllers, and network interface cards.	4.4.1
Disassemblability	Fasteners shall be removable and the process for replacement shall be feasible with no tool, or with basic tools. The process for replacement shall be able to be carried out in a use environment and shall be possibly to be carried out by a generalist or expert (depending on the component). This should at least apply to the components in the spare part list.	4.4.3
Standardize design between brands and generations	Require that some specific parts of servers are standardized (for instance racks, sockets of CPUs, and connectors. across brands and generations.	4.4.4
Improve requirements on secure non-destructive data deletion	Require that a secure data sanitization functionality that deliberately, permanently, and irreversibly removes or destroy the data stored on a data storage device shall be made available for the deletion of data contained in all data storage devices of the product.	4.4.5
	Information requirement regarding the presence of the secure data sanitization functionality, its application and degree of security, and the supported data deletion standards.	4.4.5
	Require that the functionality for data sanitization can provide a certificate attesting that data are deleted from the data storage product with a high security level.	4.4.5

63. For smartphones the period for availability of spare parts is until at least 7 years after the date of end of placement on the market.

Improve the requirements on firmware updates	Require that software and firmware updates including security updates and updates to correct firmware issues should be available free of charge for at least 8–10 years after the date of end of placement on the market of the product	4.4.6
	Require that software updates do not make existing hardware and products obsolescent	4.4.6
	Require that essential firmware and software licenses are supported at least for a period corresponding to the technical lifetime of the product (8 to 10 years) and that frequent and necessary updates are provided during the period.	4.4.6
Prevent part pairing[64]	Prohibit the use of part pairing of serialised parts[65] (the appropriateness of this should be investigated further).	4.4.8
	In case the spare parts to be replaced are serialised parts, require that manufacturers provide non-discriminatory access for professional repairers to any software tools, firmware or similar auxiliary means needed to ensure the full functionality of those spare parts and of the device in which such spare parts are installed during and after the replacement[66]	4.4.8

64. Parts-pairing is a software serial identification system ensuring that all the components in a device are matched to the device. If a component is replaced (with an identical one) by a third-party repairer, the system will identify that component as "other" and will not function appropriately.
65. 'Serialised part' means a part which has a unique code that is paired to an individual unit of a device and whose replacement by a spare part requires the pairing of that spare part to the device by means of a software code to ensure full functionality of the spare part and the device.
66. This requirement is in line with requirement regarding part pairing of serialised parts in the ecodesign regulation for smartphones and tablets (EU) 2023/1670.

6.2.4 Recycle

Plastics and CRMs are the most problematic materials to be recycled in servers and data storage products. Furthermore, the number of different CRMs in servers and data storage products is high and the concentrations are low, which makes recycling and investments in new capacities less economical. In newer servers it is indicated in the ongoing ecodesign study, that only around 1% of newer servers consists of plastics (the rest is 68% metal and 31% electronics). A JRC study from 2015 listed the different plastics found in a typical server at the time (JRC, 2015). The list showed that the majority of plastics used were of a type that is not currently recyclable. Combining this, the indication is the same for plastics as for CRMs, the numbers are high, and the weight is low.

In order to improve the recycling of CRMs and plastics, the disassemblability could be improved. Increasing disassemblability means that it becomes easier and faster to take the products apart, thus improving the economy of recycling. As an example, the CEDaCI project found that with the current server designs and substantial amount of time was required to completely dismantle the PSU (WeLOOP, 2020). Just one PSU was found to include between 10 and 15 screws which took the researchers 6 minutes to fully dismantle. Standardizing which plastics are used, and to the extent possible requiring that they are of types that are recyclable, would further facilitate the recycling of plastics found in servers and data storage devices. This will, however, require alignment between the manufacturers of products, parts and components, and thus would involve many stakeholders. It will have to be determined if the reward outweighs the required efforts. Lastly, as evert CRM needs specific handling and treatment in order to be reclaimed it is a simple necessity for the recyclers and refiners to know which CRMs are present in the products and how much.

The proposed policy options are presented below.

Table 33. Proposed policy options for the recycling of servers and data storage products

Measure	Specification	Section
Design for recycling	Se requirement for Disassemblability above.	4.5.1
	Require that PCBs are produced in the same color, or in specific colors depending on their content	4.5.4
Reduce the number of different plastics used	Require that plastics should be of the types an established recycling infrastructure (ABS, PP, PA, PC, PC/ABS, HIPS, PE). If not possible the manufacturer should document, why other plastic types are necessary in the technical documentation.	4.5.2
	Prohibit the use of polymer blends and foams. If not possible the manufacturer should document, why these materials are necessary.	4.5.2
Information about content of CRMs in products and components	Require that manufacturer shall provide information about the content of critical raw materials in specific components (such as PCBs, HDDs and SSD, PSUs, CDUs and capacitors. Information should be supplied for all materials in the most recent EU list of critical raw materials, when the product is placed on the market.	4.5.1
	Require that the above-mentioned information should be available in a QR code placed close to name of the product and/or in the Digital Product Passport	4.4.7

We propose to update the current information requirements in regulation (EU) 2019/424, among others with an extension to inclusion of other CRMs. In addition, introduction of a digital product passport could improve the exchange of information and declaration of content of materials in products and components.

Inspiration for information requirement could be found in the regulation for smartphones and tablets. According to this regulation manufacturers shall provide information about the content of some specific CRMs in indicative weight ranges:

Indicative weight range of the following critical raw materials and environmentally relevant materials:

- cobalt in the battery (weight range: less than 10 g, between 10 g and 20 g, above 20 g)
- tantalum in capacitors (weight range: less than 0,01 g, between 0,01 g and 0,1 g, above 0,1 g)
- neodymium in loudspeakers, vibration motors, and other magnets (weight range: less than 0,2 g, between 0,2 g and 1 g, above 1 g).

It should be investigated if the information requirement could be set without the use of weight ranges (the market actor shall provide information about the content in the product or component of all CRMs on the EU CRM list). If weight ranges are used, it is important that the weight ranges make it possible to indicate small amounts because various CRMs are only present in very small quantities in the products/components. The standard "EN 45558:2019 General method to declare the use of critical raw materials in energy-related products" can be used in relation to this requirement.

Some requirements may need the development of verification and certification schemes to ensure compliance and reliable information. For example, ERMA (European Raw Material Alliance) has proposed an EU sustainability standard and certification scheme, to be developed by the European Commission with the support of the ISO/TC298 Rare Earth group, the leading standardisation initiative in rare earths worldwide today. This scheme will rely on traceability and independent auditing of standards.

6.3 Other policy options

6.3.1 Green Public Procurement.

Green public procurement criteria could be used as a supplement to ecodesign regulations, in cases where it is still too premature to implement ecodesign requirement or where the measure is more related to a service and therefore is more relevant for procurement contracts. There already exists green public procurement criteria for data centres, server rooms and cloud services, which include technical requirements for servers and data storage products (mainly energy efficiency requirements) and some requirements for end-of-life service.

Experiences have shown that only a few public authorities use the GPP criteria in their procurement process and that the criteria are too difficult to interpret and use (see more in section 3.2.1.1). Additional and better explained guidelines could potentially help both suppliers and procurers in their understanding and application of the GPP criteria.

Based on interviews with stakeholders we below propose several criteria that could be implemented in public procurement in addition to the existing ones. Some of the measures mentioned below are also mentioned in the section with ecodesign policy options, but they might be easier to implement in procurement criteria/contracts or in voluntary schemes.

Proposals for public procurement criteria:

- Include criteria regarding:
    - non-destructive and secure data deletion and provision of a certificate
    - reused products in procurement (for instance a minimum share of recycled components)
    - attempted reuse/reselling before recycling
- Require that:
    - CRMs come from mines with responsible mining (for instance IRMA's standard for responsible mining)
    - providers are classified as sustainable under the EU Taxonomy
    - suppliers are classified as sustainable under the EU Taxonomy
    - providers have not signed contracts requiring the destruction of servers, when taken out of service
    - IT consultants providing IT services has green skills
    - products bear and ecolabel (type 1 - third part certified)
    - some specific highly critical materials are not used in products or specific components
- Challenge the lengths of contracts and require that contracts take into account reuse and recycling
- Look into
    - The possibility of establishing a circular economy index to be used in public procurement.
    - Making a scoring/weighting system in the criteria to assist procurers

Input from stakeholders

"We experience that the GPP criteria are generally not used, as those responsible for the tender lack the necessary competencies to assess the importance of the individual requirements and also to determine what the additional cost of setting these requirements will be."

"Procurers do look to the GPP for inspiration, but it is difficult to apply the criteria and translate them to a local context. It would help to have the GPP geared more towards direct implementation in a procurement tender."

"It's important that the GPP focus on the measurement points that is subject to requirements within the EU. This could be information required under the EU taxonomy, code of conduct, or Digital Product Passport."

"If you can set minimum criteria as award criteria that give extra points for extending the lifetime of their products, it could help move the market. Here the procurers need help knowing what areas to prioritize and how much weight to assign to different factors."

6.3.2 EU Code of Conduct

The Joint Research Centre has created the European Code of Conduct for Data Centres (EU DC CoC)[67]. Its aim is to encourage and provide guidance to data centre operators and owners on cost-effective ways to reduce energy consumption.

The initiative sets voluntary standards for participating companies and focuses on key issues and agreed-upon solutions outlined in a Best Practices document. This document is updated annually to incorporate the latest technological advancements.

A similar initiative could be established focusing on circular economy best practices. Thus, we propose the following policy option:

- Creating of an EU Code of Conduct for Data Centre Circularity

This could among others include that servers should not be shredded unless data security reasons require it. It should be made sure that the exemption does not become a loophole.

67. The EU Code of Conduct for Data Centres – towards more innovative, sustainable and secure data centre facilities. The EU Code of Conduct for Data Centres – towards more innovative, sustainable and secure data centre facilities - European Commission (europa.eu)

6.3.3 Harmonization and improvements on data deletion standards

The assessed standard NIST 800-88r1 often recommend destructive data deletion methods, that do not render the servers and data storage devices reusable. Thus, it would be relevant to look into the possibility of making a harmonized European standard on data deletion where the current standards available are revised in order to address methods and recommendations that hinder circularity. The standards should furthermore ensure unrecoverable deletion of the data, in alignment with the proposed improvements of the current ecodesign regulation on secure non-destructive data deletion.

6.3.4 Update of design brief

As the designers and producers are mainly located in Asia, European stakeholders should update their design brief and specifications and include a mandate to minimise the use of CRMs in servers (WeLOOP, 2020).

6.3.5 Due diligence

The new Battery regulation establishes due diligence requirements on economic operators who place batteries on the market. It covers the supply chains of cobalt, natural graphite, lithium, nickel, and other chemical compounds. Economic Operators would also need to establish and operate a system of controls and transparency over supply chains and incorporate supply chain policies into agreements with suppliers (e.g. including risk management measures). These must be consistent with OECD Due Diligence Guidance for Responsible Supply Chains of Minerals for Conflict-Affected and High-Risk Areas (OECD, 2016). This type of requirement could be extended to ICT products for specific raw materials with high risk of illegal sourcing, or high environmental and social risks.

6.3.6 Basel Convention E-waste Amendments.

The Basel convention works to control transboundary movements of hazardous wastes and their disposals including e-waste, which is one of the fastest growing waste streams in the world. It could be considered to develop further mechanisms under this convention to prevent informal recycling of e-waste. It could for instance be increased reporting obligations to prevent illegal traffic of e-waste.

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