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## Circular economy: Definitions and concepts for material efficiency for information and communication technology

Recommendation ITU-T L.1022

ITU-T

International Telecommunication Union

ITU-T L-SERIES RECOMMENDATIONS

**ENVIRONMENT AND ICTS, CLIMATE CHANGE, E-WASTE, ENERGY EFFICIENCY; CONSTRUCTION, INSTALLATION AND PROTECTION OF CABLES AND OTHER ELEMENTS OF OUTSIDE PLANT**

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# Recommendation ITU-T L.1022

## Circular economy: Definitions and concepts for material efficiency for information and communication technology


### Summary

Recommendation ITU-T L.1022 contains a guide to the circular economy (CE) aspects, parameters, metrics and indicators for information and communication technology (ICT) based on current approaches, concepts and metrics of the CE as defined in existing standards, while considering their applicability for ICT.

In this Recommendation ICT is defined based on the definition given by the Organisation for Economic Co-operation and Development (OECD) (See [b-ISIC] in the Bibliography).

This Recommendation discusses the special considerations and challenges in a broader and more in-depth context for all ICT defining parameters, metrics and indicators with the intention to guide the vertical standardization of material efficiency for ICT.

The guidelines aim to examine the kinds of standards that are available and to assess their relevance for ICT product groups citing examples of interrelated relevance throughout the text of the Recommendation.



### History

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### Keywords

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FOREWORD

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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In this Recommendation, the expression "Administration" is used for conciseness to indicate both a telecommunication administration and a recognized operating agency.

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## Introduction

In order to facilitate a shift to a more sustainable economy, a circular economy (CE) has been proposed as one of the main ways forward. Improving the resource efficiency (RE) of products is important in order to promote a transition towards a more circular economy in the EU and beyond. This can be supported, for example, through a series of measures aiming to manufacture goods that are more durable, easier to repair, reuse or recycle. Improving certain material efficiency metrics of products might be important to reduce their environmental impact. Particularly, an improvement of the durability of goods can have the potential of bringing added value to the environment and to the economy by limiting the early replacement of goods and thus saving resources. However, the design of products needs to be assisted by appropriate assessment methods.

ITU-T has made preliminary descriptions of RE for ICT goods [b-ITU-T L-Sup.5] and [b-ITU-T L-Sup.28], which have been considered in the development of this Recommendation which focuses on the applicability of CE metrics for ICT.

# Recommendation ITU-T L.1022

## Circular economy: Definitions and concepts for material efficiency for information and communication technology

## 1 Scope

This Recommendation provides a guide to the aspects of circular economy (CE), parameters, metrics, indicators for ICT based on current approaches, concepts and metrics of the CE as defined in existing standards, while considering their applicability for ICT. It is necessary to distinguish between CE concepts for product design and maintenance and general concepts aiming at the corporate practices of ICT companies.

The scope of the Recommendation, in addition to the above context, includes the following aspects:

- reparability
- durability
- reusability
- recyclability
- recoverability
- refurbish ability
- remanufacture ability
- upgradeability.

The following parameters, indicators and metrics are related:

- recycled and renewable content
- use of critical raw materials
- ability to reuse parts/components/materials
- quality of recycling.

This Recommendation is a framework standard that covers aspects that will be elaborated in future Recommendations.

## 2 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T L.1021] Recommendation ITU-T L.1021 (2018), *Extended producer responsibility – Guidelines for sustainable e-waste management*.

## 3 Definitions

### 3.1 Terms defined elsewhere

This Recommendation uses the following terms defined elsewhere:

**3.1.1 bio-based plastic** [b-BioBag2]: Plastic that is made by plant material.

**3.1.2 biodegradable plastic** [b-BioBag1]: A plastic capable of undergoing biological, anaerobic or aerobic degradation leading to the production of $CO_2$, $H_2O$, methane, biomass, and mineral salts, depending on the environmental conditions of the process.

**3.1.3 component** [b-ETSI TR 103 679]: Part of a product that cannot be taken apart without destruction or impairment of its intended use.

**3.1.4 compostable plastic** [b-EN 13432]: Biodegradable/compostable plastic that completely decomposes in a composting setting in a specific time frame, leaving no harmful residues behind.

**3.1.5 corrective maintenance** [b-prEN 45554]: See Repair.

NOTE – An example is a fan filter exchange.

**3.1.6 critical raw material (CRM)** [b-EN 45558]: Materials which, according to a defined classification methodology, are economically important, and have a high-risk associated with their supply.

NOTE – For the purpose of this Recommendation, CRMs are the ones listed in Annex 1 of [b-COM CRM]. Future updates to this list will apply and replace former versions of this list.

**3.1.7 disassembly** [b-IEC 62452], [b-prEN 45554]: Process whereby a product is taken apart in such a way that it could subsequently be reassembled and made operational.

**3.1.8 durability** [b-prEN 45552]: Ability <of a part or a product> to function as required, under defined conditions of use, maintenance and repair, until a final limiting state is reached.

NOTE 1 – The degree to which maintenance and repair are within scope of durability will vary by product or product group.

NOTE 2 – The final limiting state has to be defined by the user of [b-prEN 45552].

**3.1.9 important change** [b-prEN 45553]: Modification which influences the safety, original performance, purpose or type of the product.

NOTE 1 – Refer to the EU Blue Guide [b-Blue] for conditions under which a product has to be considered as a new product when placing on the market after such changes.

NOTE 2 – The person who carries out the changes becomes then the manufacturer with the corresponding obligations.

**3.1.10 limiting event** [b-prEN 45552]: Event which results in a primary or secondary function no longer being delivered.

NOTE – Examples of limiting events are failure, wear-out failure or deviation of any analogue signal.

**3.1.11 limiting state** [b-prEN 45552]: Condition after one or more limiting event.

**3.1.12 maintenance** [b-pr45552]: Action carried out to retain a product in a condition where it is able to function as required.

NOTE – Examples of such actions include inspection, adjustments, cleaning, lubrication, testing, and replacement of worn-out parts. Such actions could be performed by users in accordance with instructions provided with the equipment (e.g., replacement or recharging of batteries); or the actions could be performed by service personnel in order to ensure that parts with a known time to failure are replaced in order to keep the product functioning.

**3.1.13 material** [b-EN 62474]: Substance or mixture of substances within a product or product part.

**3.1.14 oxo-degradable plastic** [b-BioBoxo]: Plastic that breaks into fragments in the presence of oxygen.

**3.1.15 part** [b-prEN 45552]: Hardware or software constituent of a product.

**3.1.16 product** [b-ETSI TR 103 679]: Goods or services.

**3.1.17 recoverability** [b-prEN 45555]: Ability of a waste product to be recovered.

**3.1.18 recoverability rate** [b-prEN 45555]: Ratio of the sum of recoverable products, product parts, materials mass to total waste product mass reprocessed.

**3.1.19 recovery** [b-EU WFD]: Any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy.

**3.1.20 recyclability** [b-prEN 45555], [b-IEC62635]: Ability of a product to be recycled at end-of-life.

**3.1.21 recycled material content** [b-prEN 45557]: Proportion, by mass, of secondary material in a product.

**3.1.22 recycling** [b-EU WFD]: Any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations.

**3.1.23 refurbish** [b-prEN 45553]: Returning by industrial process a used product to a satisfactory working condition without making any important changes to the product.

**3.1.24 reliability** [b-prEN 45552]: Probability that a product functions as required under given conditions, including maintenance, for a given duration without failure.

NOTE 1 – The intended function(s) and given conditions are described in the user instructions provided with the product.

NOTE 2 – Duration can be expressed in units appropriate to the part or product concerned, e.g., calendar time, operating cycles, distance run, etc., and the units should always be clearly stated.

**3.1.25 remanufacturing** [b-prEN 45553]: Industrial process which creates a product from used products or used parts where at least one important change is made to the product.

**3.1.26 repair** [b-prEN 45554]: Process of returning a faulty product to a condition where it can fulfil its intended use.

**3.1.27 reuse** [b-EU WFD]: Operation by which products or parts that are not waste are used for the same purpose for which they were conceived by another user.

NOTE – The transfer of ownership is an essential part of the concept of reuse.

**3.1.28 substance** [b-REACH]: Means a chemical element and its compounds in the natural state or obtained by any manufacturing process, including any additive necessary to preserve its stability and any impurity deriving from the process used, but excluding any solvent which may be separated without affecting the stability of the substance or changing its composition.

**3.1.29 substances of concern** [b-EUCOM32]: Hazardous to humans or the environment, present in products sold before they were restricted, have a long lifetime, are costly to detect or remove, create obstacles in particular for recycling.

**3.1.30 upgrade** [b-prEN 45554]: Process to enhance the functionality, performance, capacity or aesthetics of a product.

NOTE – Upgrade may involve changes to the software, firmware and/or hardware. IEC 62075:2012, definition 3.23, Note added in [b-prEN 45554].

## 3.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

**3.2.1 benefit rate**: Potential savings that can be achieved over status quo.

NOTE – Some examples include the following:

- "Potential environmental savings that can be achieved from recycling certain parts of the product over the environmental burdens of production of primary materials, manufacturing, use and disposal of the product" [b-ArdenteR].
- "Potential cost savings that can be achieved from reusing certain parts over the costs due to the production of primary materials, manufacturing, use and disposal of the product" [b-ArdenteR].

**3.2.2 preventive maintenance**: Preventive action carried out to retain a product in a condition where it is able to function as required. Adapted from [b-prEN 45552].

NOTE – e.g., cleaning.

**3.2.3 recyclability rate**: The ratio of the sum of recyclable products, product parts, materials mass to total waste product mass reprocessed.

**3.2.4 renewable material**: Natural material which can replace materials depleted by usage and consumption either through natural reproduction other reoccurring processes in a finite amount of time in a human time scale.

**3.2.5 reparability**: The ability of a product to be repaired.

**3.2.6 reused component**: A hardware constituent of a product that cannot be taken apart without destruction or impairment of its intended use, which is used again with or without alteration.

**3.2.7 single-use plastic product**: A product that is made wholly or partly from plastic and that is not conceived, designed or placed on the market to accomplish, within its lifespan, multiple trips or rotations by being returned to the producer for refill or reused for the same purpose for which it was conceived.

NOTE – Single-use plastic products include a diverse range of commonly used fast-moving consumer products that are discarded after having been used once for the purpose for which they were provided, are rarely recycled, and are prone to littering.

**3.2.8 single-use plastics**: Any disposable plastic items, i.e., packaging or a consumer product that are thrown away after one brief use, not intended for longevity, reuse or recycle.

**3.2.9 upgradeability**: The ability of a product to be upgraded.

## 4 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

AI Artificial Intelligence

CE Circular Economy

CRM Critical Raw Material

EPR Extended Producer Responsibility

FMEA Failure Mode and Effect Analysis

ICT Information and Communication Technology

IHS Integrated Heat Spreader

LCA Life Cycle Assessment

LCC Life Cycle Cost

LCI Life Cycle Inventory

ME Material Efficiency

MTBF Mean Time Between Failures

PSS Product Service System

RE Resource Efficiency

SUP Single Use Plastics

## 5 Conventions

None.

## 6 Introduction to circular economy concepts

Circular economy (CE) covers the full life cycle of both goods and business models.

Most business models are linear cradle-to-grave; that is, extracting, manufacturing, using and wasting. This usually turns 90% of the resources extracted from nature into waste [b-Thomas].

In general CE is about closing the loop between different life cycles through design and corporate actions/practices that enable recycling and reuse in order to use raw materials, goods and waste in a more efficient way and to increase energy performance. Thus CE is associated with strategies to minimize the input of primary materials and keep goods out of landfill and incineration. This is important as research has shown that the toxicity of waste mobile phones increased with technology innovation for phones produced from 2002 to 2013 [b-Chen]. CE deals with both environmental and economic aspects. In an ideal CE, all waste generated would be reused as raw material in production processes. Discarded goods represent a valuable source of materials.

NOTE – In order to be environmentally beneficial, CE strategies would need to be catered for the full life cycle of a given product category [b-Trusty].

Resource efficiency (RE) is sometimes used interchangeably with the CE concept. However, RE focuses more on the efficient use of resources and on minimizing the environmental impact of a good during its life cycle [b-Hamakawa]. An example of a generalized RE definition is dealing with the benefits obtained from the use of natural resources. Furthermore, materials efficiency (ME) is used in parallel with RE, or as a more precise concept dealing with raw materials only, excluding energy. In this Recommendation, RE is seen as a subcategory of CE and ME as a part of RE.

CE and RE aspects and parameters/metrics/indicators suitable for ICT are also discussed.

There are many examples of attempts to model different CE aspects of ICT [b-Hamakawa], [b-Talens], [b-Harivard], [b-Schischke], [b-Dimitrova], [b-Nissen], [b-Ardente], and [b-Andrae]. However, these efforts start from a bottom-up perspective and are potentially helpful in the production specific standardization of certain ICT applications. In case such standardization happens, it is intended to follow the guidelines of this Recommendation.

Previously, ITU-T [b-ITU-T L-Sup.28] attempted to provide an understanding of the scope and limitations of particular existing resource efficiency indicators in order to assist policy makers and the scientific community in the application and further development of indicators. This Recommendation builds on that information taking into account recent progress in other standards.

Through the design stage, it is possible to influence all the most important aspects, minimizing material usage and environmental impacts. Goods can be designed for increased lifespans, as well as to be repaired, upgraded, reused, refurbished, remanufactured and/or eventually recycled instead of being thrown away. However, in practice trade-offs have to be made with parameters such as safety aspects, reliability, phase out of specific substances (e.g., those dangerous to human health and the environment or which are detrimental in recycling processes) and cost. One important point of view is to avoid the use of hazardous materials and optimize the use of rare earth materials when possible.

This can lead to situations where recycling and reuse can be hampered by the presence of certain chemicals which were tolerated in the past, but are prohibited in current legislations.

In addition to reducing the materials, the focus is on energy usage during the whole life cycle of goods, which means improved efficiency in the production and use stages.

Table 1 shows a summary of CE aspects, the level of disassembly and the expected quality of the ICT good after CE related actions.

**Table 1 – CE aspects for ICT goods, level of disassembly and expected quality**

| CE aspect | Level of disassembly of ICT goods | Expected quality of ICT goods | Examples |
|---|---|---|---|
| Maintenance (preventive) | None | Working order | Replace fan filter |
| Maintenance (corrective) | ICT goods down to faulty part | Working order | Replace damaged mobile phone display |
| Upgrade | None if software | Working order | Software upgrades |
| Repair | ICT goods down to faulty part | Working order | Replace damaged mobile phone display |
| Reuse (direct) | None | "As-is" | Operators can directly reuse base stations in another location |
| Refurbish | Good or module | Specified level | Set-top-box gateway are refurbished by combining parts from different set-top-box gateway goods. Another example is used laptops: inspection for functionality, replacement of parts where necessary. |
| Remanufacture | Part | 'Like-new part' | Set-top-box gateways are remanufactured in several ways by upgrading the Wi-Fi module to a *better performance* standard. |
| Recycle | Recyclable streams | – | Gold recycling |
| Recover | Non-recyclable parts/materials | – | Energy recovery from plastics |

## 7 Circular-economy-related legislation and standards

A number of specific policy measures and regulations have already been established that are intended to support the transformation to the CE.

Within the CE area, there is ongoing work on e-waste in ITU-T which includes studies of circular economy metrics for ICT.

For example, the publication of [ITU-T L.1021] on EPR.

IEC has developed standards covering the reliability of goods [b-IEC 62380]. Moreover IEC released a standard for environmental conscious design of EEE [b-IEC 62430] where it is recommended, among many other things, to consider reducing material complexity in order to make material recycling easier.

The European Union and its Member States previously introduced extended producer responsibility legislation for various waste streams including WEEE, waste batteries and waste packaging.

EU Directive 2012/19/EU on waste electrical and electronic equipment [b-WEEE] introduced annual minimum collection rates requesting Member States to separately collect and treat WEEE at least at a ratio of 65% of the average weight of EEE placed on the market in the previous three years or alternatively 85% of the total WEEE volumes generated in the country. Choosing the latter rate would also require Member States to develop methods how to calculate and assess the total volumes of WEEE that are generated in the country.

[b-ETSI TR 103 476] on the circular economy in ICT was part of the work done under EU Mandate 543.

On a national level, British Standards prepared the BS 8001 standard for implementing circular economy in organizations [b-BS 8001].

Moreover, Austrian Standards has released a publicly available specification, ONR 192102 that aims to enable long-lived and repairable electronic goods [b-Austria].

Other existing standards are the European standard [b-EN50614], the British standard [b-PAS 141:2011], the German 63 standard [b-VDI 2343] and the Flemish standard entitled *Code of Good practice for re-use of (W) EEE* [b-Flem].

## 7.1 Emerging regulations and standards

### 7.1.1 EU Mandate 543

CEN-CENELEC published its first two standards in the first quarter of 2019, [b-EN 45558] and [b-EN 45559].

Overall, CEN-CENELEC targets to develop eight horizontal standards and two technical reports giving generic principles for addressing the material efficiency of ErPs [b-CEN-CLC]. The scope of these standards are explained below.

Currently CEN-CENELEC forecasts to vote on the documents in the second half of 2019, thus publications can be expected in 2020.

*prEN 45552 Durability:*

This document defines parameters and methods as a framework in order to assess the durability of ErP.

The prEN45552 standard refers to [b-IEC 61123] and [b-IEC 61124] for the durability "measurement".

*prEN 45553 Remanufacture and refurbish:*

This document proposes a general method to assess the ability of ErPs to be remanufactured on a generic level. Where a good specific standard for assessing the ability to remanufacture does not exist, this document can be used for such an assessment. The assessment of the ability of parts to be remanufactured is not considered in this document.

*prEN 45554 Repair, reuse, upgrade:*

This document provides generic methods to assess the following aspects:

- the ability to repair products;
- the ability to reuse products, or parts thereof;
- the ability to upgrade products.

It includes generic criteria and methods relevant for assessing the ability to access or remove certain parts from products for the purpose of repair, reuse or upgrading.

The criteria and methods in this document focus on the design of the product and related conditions when the product is placed on the market, taking into account knowledge of parts that are likely to fail, need replacing, or have reuse potential.

*prEN 45555: Recycle and recover:*

This document establishes general principles for:

- assessing the recyclability of energy-related products;
- assessing the recoverability of energy-related products.

This document also considers:

- the ability to access or remove certain components, assemblies, materials or substances from products to facilitate their extraction at the EoL for ease of treatment, recycling and other recovery operations;
- the recyclability of critical raw materials from energy-related products.

*prEN 45556: Reused components:*

This document deals with the assessment of the proportion of reused components in energy-related products on a generic level, which can be applied at any point in the life of the product. This document can be applied where no product-specific standard exists. Aspects such as performance, validation, verification and suitability of reused components are not in the scope of this document.

The reused part rate is declared by manufacturer based on evidence documentation. Reused component index can be calculated.

*prEN 45557: Recycled material content:*

This document provides a general method for assessing the proportion of secondary material in an energy-related product, its parts or material(s). This document is applicable as the framework to be used for defining the assessment of recycled material content in specific product groups. However, in absence of product specific standards it can be applied directly. This document does not apply to the assessment of reused components.

The recycled content is declared by the manufacturer based on evidence documentation.

*EN 45558: CRM content:*

The main intended use of this document is to provide a means for information on the use of CRMs to be exchanged across the supply chain and with other relevant stakeholders. Potential users of this document are any public, private or social enterprises involved in the production of ErP, such as manufacturers of energy-related products (including SMEs) and other organizations in the product supply chain. It is also relevant to European market surveillance and trade authorities as well as European policy makers. This document is horizontal in nature, and can be applied directly to any type of energy-related product.

This document proposes a standardized format for reporting the use of CRMs in energy-related products by applying the IEC 62474 [b-EN 62474] materials declaration standard. However, this document does not provide or determine any specific method or tool to collect CRM data. Process chemicals, emissions during product manufacturing and packaging are not in scope of this document.

The CRM content is declared by the manufacturer based on evidence documentation.

*EN 45559: Information related to material efficiency aspects:*

This document aims to set up a general method for the communication of material efficiency (ME) aspects of energy-related products (ErP). It is intended to be used as an input for the development of a communication strategy in horizontal, generic, product-specific, or product-group publications. This document relates to the standards in the range of "prEN 45552 – 7", and "EN45558 – 9" developed under the standardization request M/543 [b-M543]. While the other standards will provide methods to assess or measure specific ME topics, this document focuses on the communication of the various topic-related content. Legislation can require that ME information is provided to specific intended audience and is verifiable, accurate, relevant and not misleading. Therefore, this document requests that the intended audiences (end users, professionals or market surveillance authorities) are taken into account, as well as the means of communication and media for providing the ME information.

ETSI-EE might make an adjusted standard – based on CENELEC standards - for infrastructure goods (mainly mobile base stations, switches, routers and servers).

### 7.1.2 EU strategy for plastics in the circular economy

In December 2015, the Commission adopted an EU Action Plan for a circular economy [b-ECPlAP]. It identified plastics as a key priority and committed itself to prepare a strategy to address the challenges posed by plastics throughout the value chain and taking into account the entire life cycle.

The goal of the EU strategy is to ensure that all plastic packaging is recyclable by 2030.

### 7.1.3 EU action plan for the circular economy

Extended producer responsibility (EPR) schemes (which are an essential part of the EU's ambition to create a circular economy) may also encourage ICT good producers to design products that have a longer lifespan and which are easier to recycle [b-EU Action], [ITU-T L.1021].

The European Commission recently informed about [b-EU SEP] a methodology [b-Bovea] that allows the analysis of how an existing product design meets design guidelines required for the circular-economy perspective, and which guidelines would need to be incorporated to create a better circular-design product. The results, based on a case study of small electrical equipment, indicate that the most urgent priority is to incorporate circular-design guidelines related to extending lifespan and to product/components reuse, while there is a moderate need to include guidelines related to the use of simple removable connections or a modular product structure. This methodology [b-Bovea] could be considered to be applied to different ICT goods.

### 7.1.4 JRC initiatives

Independently from CEN/CENELEC standardization work, the European Commission is in the process of analysing and developing a scoring system to rate the ability to repair and, where relevant, upgrade products. [b-JRC score].

The EC will not only rely on CENELEC TC10 but also on the work of the EC with JRC to develop proposals for goods group specific requirements to be considered under the ErP Regulation for smartphones, laptops and washing machines. JRC has already published reports on the durability assessment of goods, the analysis and testing of washing machines [b-JRC 2018] and understanding lifetimes and failure modes of defective washing machines and dishwashers [b-JRC 2019]. In 2019, JRC plans to finalize two draft studies published in April 2018 on the analysis of material efficiency aspects of smartphones and on the assessment of the reparability and upgradability of TVs.

### 7.1.5 ISO

ISO14009 aims to provide guidelines to organizations for managing redesign and redevelopment of their products in a systematic manner using the framework of environmental management system (EMS) [b-ISO14009].

### 7.1.6 France

While the EU has an action plan focusing on certain products, France is introducing eparability labelling systems. France has launched a roadmap for the circular economy and they have the intention to develop a reparability index on all kinds of goods including the ICT sector.

The reparability labelling system will cover a range of goods including smartphones. These reparability labels are expected to be published by 1 January 2021. The current draft of the method includes six criteria for smartphones, which themselves include sub-criteria:

– **Criterion 1: availability of documentation with two sub-criteria**:
  - availability and duration of availability (in years)
  - user instructions, maintenance and product update information at the date of sale.
– **Criterion 2: accessibility, ease of disassembly and reassembly of unitary spare parts with 3 sub-criteria**:
  - ease of disassembly and reassembly
  - necessary tools
  - fasteners.
– **Criterion 3: availability of spare parts with 4 sub-criteria**:
  - undertaking for duration of availability of spare parts (in years) for key parts
  - undertaking for duration of availability of spare parts (in years) for other parts
  - undertaking for delivery time (in working days) for key parts
  - undertaking for delivery time (in working days) for other parts.
– **Criterion 4: price of spare parts** calculated according to a ratio between the price of broken/malfunctioning parts and the price of new product.
– **Criterion 5: software**
– **Criterion 6: diagnostic**

NOTE – The specified number of years, days and % will be decided by working groups established by the French authorities.

## 7.2 Voluntary certification schemes

### 7.2.1 EPEAT in the US

Labelling programmes in the US are non-mandatory (voluntary) certification schemes, but requirements might be included in the purchasing contracts.

### 7.2.2 SASF

The sustainability assessment framework (SASF) is not a standard but a tool by which a company can evaluate the sustainability performance of its products. The scoring involves several CE related questions on product level [b-SASF].

### 7.2.3 Modulated tariffs for e-waste treatment

Currently, simplistic mass-based tariffs are common for financing the handling of e-waste, including ICT e-waste. However, differentiated fees for e-waste treatment can be expected in the coming years depending on product characteristics such as recyclability [b-EU WFD].

In 2018, the European Union amended its waste framework Directive to minimum requirements for extended producer responsibility schemes. One of the requirements is to modulate the financial contributions paid by the producer, where possible, for individual products or groups of similar products. The modulated fees shall take into account the durability, reparability, reusability and recyclability and the presence of hazardous substances. However, the fees shall not exceed the actual costs that are necessary to provide the waste management services in a cost-efficient way. The EU Member States have to transpose these requirements into national legislation by mid-2020, but the principle is already implemented in most countries.

It is a common practice in the WEEE management sector to charge different prices for product categories that go into separate treatment processes (e.g., monitors and other ICT products).

The ICT and CE industry in cooperation with WRAP has developed a logo to differentiate TVs and monitors at the treatment site depending on whether or not the backlights contain mercury [b-DIGITALEUROPE]. With this knowledge, modulated fees could be applied as mercury containing backlighting requires additional treatment steps and incur higher costs.

However, most fee structures are still mass-based and do not reflect the actual recyclability of a product or product group. There is still need to develop relevant criteria limited to the targets of proper waste management and which are clearly defined to avoid ambiguity with other intentions or contradiction with other legislations [b-ERP].

## 8 Circular economy business models

Business models are important for the success of the CE. This Recommendation will show some examples but the main aim is to focus on the applicability of existing CE metrics for ICT. The use of these business models do not immediately imply that the model is circular, but they improve the circularity compared to other business models depending on their design.

New forms of business models drive the success of the CE. When companies transition from a product sales model to an as-a-service model, products remain in the possession of the manufacturer. Emphasis is placed on taking back the equipment at EoL. Product design is maximized for reoccurring value and the hardware life cycle and lifetime value is extended.

The OECD published a paper in 2019, evaluating five *Business Models for the Circular Economy* [b-OECD]. The report covers circular supply models, resource recovery models, product life extension models, sharing models and product service system models. The OECD estimates that such business models currently have a market share of 5 to 10%.

The philosophy of the circular supply model is that product materials are used for production of new product (cradle to cradle). Therefore, manufacturers need to design their products as well as adapt their processes with respect to this aim.

The resource recovery model is based on three main activities to produce secondary raw materials from waste streams, that is, the collection, sorting and secondary production.

The product lifetime extension model simply tries to keep products in the economy for a longer time and potentially reduce the extraction of new resources. This can be achieved by increasing the durability of goods, reuse and repair activities and remanufacturing.

Examples of product lifetime extension models include:

- sharing models which increase the usage of under-utilized consumer assets and therefore reduce the overall number of products that are required;
- user or result-oriented product service system (PSS) models where services rather than products are marketed, improve incentives for green product design and more efficient product use as products remain in the possession of the manufacturer. As emphasis is made on product service and reverse logistics, more sparing use of natural resources is promoted and lifetime is extended.

However, product lifetime extension models always come with trade-offs. For example, energy savings and environmental impact reductions might not be achieved if older energy inefficient goods are used instead of newer more energy efficient goods. [b-ITU-T L.1410] can be used to find the balance points.

Also the economical savings made by such models might be used instead for products or activities with a higher environmental impact.

## 9 Circular economy aspects and parameters affecting the environmental impact in different life-cycle stages

The different aspects of the CE could be divided into different areas such as those proposed in this clause. There are different ways to carry out this subdivision into areas and they are to some extent overlapping. Subdivision can be done using, e.g., life-cycle stages, design stages, aspect sorting by name, or by expected quality. Here the CE aspects are sorted according to the first life-cycle stage where the environmental impacts are assumed to take place.

It has to be differentiated between the environmental impacts ICT products cause during production (including material sourcing), its use stage and the treatment after the use stage. Different ICT products (e.g., mobile and stationary) might have different life-cycle stage focal points.

Impacts not directly related to the product, but caused by organizational decisions which can lead to a reduction of the environmental impact, are covered in clause 10.

The key question dealt with in clauses 9.1 to 9.4 is related to what extent different metrics are applicable to ICT.

### 9.1 Raw material acquisition stage

#### 9.1.1 Recycled content

The recycled content indicator/metric as defined by ISO [b-ISO 14021] can be applied to ICT goods. However, reliable data might be difficult to collect due to long supply chains. Nonetheless, according to certain RC standards the manufacturer has to get written proof from upstream tiers that the materials used are secondary to the degree claimed.

When looking at recycled content, one should be aware of the issues with substances of concern as discussed in clause 9.2.5.

Specifically for metals, each material requires a different solution. For some, like rare earth elements, recycled material is not widely available. So simply understanding the barriers to recovery requires significant exploration. For other materials, such as tin, recycled material markets are more robust.

#### 9.1.2 Renewable content

Renewable materials might be included in the RC calculations.

The use of bamboo is becoming increasingly popular to make casings for computers and peripherals. It has the advantages of being a sustainable and quickly renewable resource [b-Kaur].

Renewable materials are not inherently sustainable, and must be correctly managed to ensure continued supply and avoid adverse impacts on humans or the environment.

#### 9.1.3 Proportion of reused parts

The applicability of reused part standards is seemingly very high as the information can be controlled by the manufacturer. Certain reused part standards do not consider the reliability of the reused components.

The quality of reused parts is very important. It is highly useful for the second-hand market if the quality of the parts, which can be removed from the used ICT goods or overproduced ICT goods, is "as good as new". The use of counterfeit parts, instead of original reused parts, is a problem for the reliability of the second-hand product. These parts can have the effect that the device is working poorly or cause electric shocks or fires.

It is proven that laptops can be remanufactured successfully partly using reused parts. Defunct parts of laptops are replaced with functioning parts from others, and a new battery is added [b-Transform].

Pini et al. [b-Pini] studied the variations in environmental performance of the life cycles between new and reused EEE in Italy, including laptops. The scenarios feature preparation for reuse (repair and refurbish) using either new or reused replacement components. The results show that using new replacement components (for laptops) could lead to a worse environmental performance than the baseline (new product).

André et al. [b-André] studied the environmental performance of using second-hand laptops facilitated by commercial reuse operations instead of using new ones. The new finding, apart from the finding that a use extension lowers environmental impacts, is that reuse companies steer non-reusable laptops into state-of-the-art recycling.

### 9.1.4 Use of critical raw materials

Estimating CRM contents is relevant for ICT goods.

CRMs selected by the EU can be found in [b-EUcrm]. Other jurisdictions might have other CRMs.

CRMs may be substituted where possible.

For smartphones the material amounts have been estimated for about 30 different metals including CRMs and rare-earth elements [b-L.ER]. Figure 1 shows the amounts of some common metals used in smartphones.

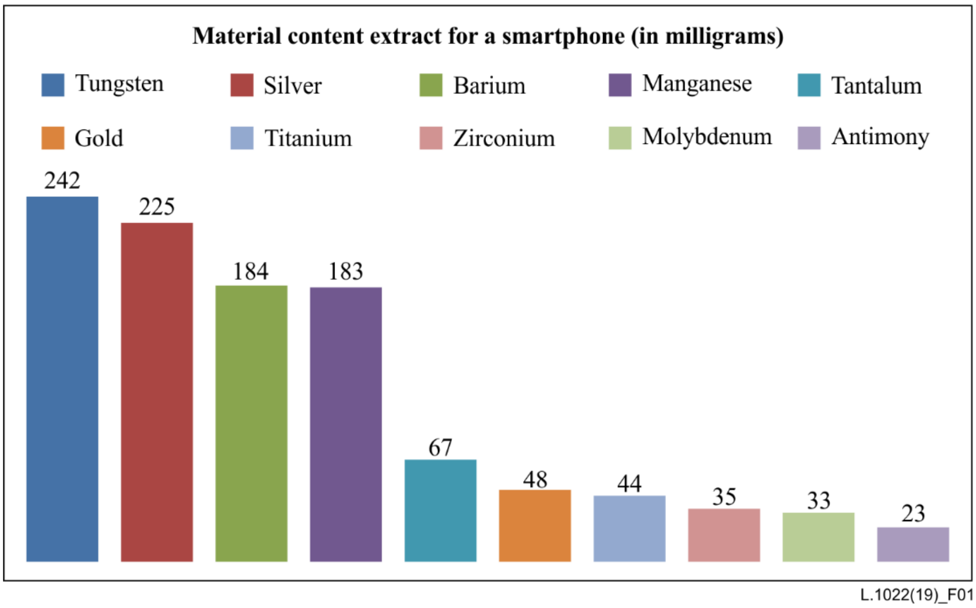


**Figure 1 – Extract of material content for a smartphone**

Based on expert comments on Figure 1, the barium and manganese absolute content in smartphones might be significantly higher while the content of tantalum, titanium, molybdenum and antimony might be significantly lower.

Recycling of CRMs are enhanced by:

1) identifying the locations of the CRMs in the different sections of the ICT goods;
2) finding the different possible recycling paths for each material (with steel, copper or aluminium);
3) gathering the sections which could be recycled together;
4) suggesting a design for the ICT goods which optimizes the recovery of CRMs.

### 9.1.5 Materials of concern: Single-use plastics

In recent years, SUP has become one of the most discussed sustainability issues. Retailers are starting to ban SUP and as a result the use is rapidly dwindling. [b-ITU-T L.1015] requires that *"The manufacturer shall indicate if a strategy to eliminate single-use plastic packaging is adopted."*

ICT infrastructure products are not considered to be SUP products based on the extended period of use time, typically ten years, and multiple usage events during this use time.

Some plastic packaging, which is protecting the products during storage and transportation, currently may be SUP. Such packaging could be avoided, e.g., by replacement, reuse, recycling, or recovery.

The so-called oxo-plastics or oxo-degradable plastics are a type of SUP that are problematic from a CE perspective. They are conventional plastics which include additives to accelerate the fragmentation of the material into very small pieces, triggered by UV radiation or heat exposure. Due to these additives, the plastic will fragment over time into plastic particles, and finally microplastics. Full biodegradation process has not been documented for oxo-degradable plastics but rather that oxo-degradable plastic is not suited for long-term use, recycling or composting, and therefore not suitable for a circular economy [b-DG ENV], [b-bioplastics] and [b-Selke].

In order to biodegrade, typical biodegradable plastics [b-bioBag1] will need a high temperature environment for an extended period of time. Complicating things further, biodegradable plastics should be separated from traditional plastics waste in order to ensure high-quality plastic products. Plastic recyclers prefer that bio-based plastics [b-bioBag2] have their own collection scheme. Biodegradable plastics might biodegrade slower in landfills due to a lack of oxygen. Moreover, no product, including biodegradable plastics, has been approved as marine biodegradable [b-PlasticsR]. The European Standard EN 13432 [b-EN 13432] defines the characteristics that a compostable material must have.

Telecommunication operators are requiring the elimination of SUP by 2020.

## 9.2 Use stage

### 9.2.1 Durability

The reliability part of durability is relevant for ICT goods.

Durability might be the most important aspect seen from an environmental impact perspective for those ICT goods having a relatively large share of the life-cycle impacts caused by the manufacturing [b-ITU-T L.1015], [b-Andrae]. Increasing the lifespan of phones and improving collection after use will reduce pressures on non-renewable resources and close 'metal flow loops' [b-Sinha].

Reliability refers to a faultless period before the first failure. Durability on the other hand refers to a longer period which could involve repair and refurbish. Durability includes the ability of a product to be repaired.

Durable design, especially of mobile ICT goods, includes the provision of software upgrades, patches and compatibility. Availability of such upgrades is important to extend the lifetime of the product.

To ensure the availability of such upgrades, it is important that manufacturers provide sufficient customer service and support solutions. Another important factor is the development of a sufficient local infrastructure to enable the provision of maintenance services to the product users.

There is always an upper limit of lifetime extension, beyond which the effects become net negative [b-Grobe].

*Including Drop resilience*

Drop testing is typically conducted on products that are held in the hand during use. There are several standards available which describe drop test parameters. See, for example, [b-IEC 60068-2-31].

NOTE – [b-IEC 60068-2] is a collection of methods for environmental testing of electronic equipment in general.

Durability testing for mobile ICT shall consist of both testing the components on their own and as a product.

*Availability of customer service/support*

The availability of proper instructions how to use an ICT product can increase their durability as users will be enabled to use the product properly and fix issues that otherwise might lead to disposal. The support can consist of proper instruction manuals delivered together with product or online, FAQs, support hotlines or websites or other means to support the user in properly using the product.

For ICT infrastructure goods a maintenance service can help improve the durability.

*Environmental and cost benefit rates*

Environmental and cost benefit rates are generally useful for finding the maximum return on investment for a certain CE strategy [b-Huysman], [b-ArdenteR] and [b-ArdenteD].

However, the complications which arise when trying to define environmental benefit rate metrics for ICT concern mainly the precision of the underlying life cycle assessment (LCA) or life cycle cost (LCC) analysis. Nonetheless, with strict frameworks such as the product environmental footprint guide [b-PEF] and [b-ITU-T L.1410] the precision will be less of a problem.

Appendix I of [b-ITU-T L.1015] presented three streamlined LCAs for smartphones by which the durability benefit rate can be calculated.

The environmental cost for these LCAs were explored by Andrae [b-Andrae] concluding that, for a very specific smartphone case, the durability benefit rate at low collection rates is ≈75%[1] for longevity and ≈11%[2] for refurbish.

Ardente et al. developed a method for assessing, from a life-cycle perspective, the potential environmental benefits of remanufacturing energy-related products [b-Ardente]. A specific enterprise server was chosen as example.

### 9.2.2 Energy efficiency

Use stage energy consumption is the biggest driver for the overall environmental impact for some of the ICT products, e.g., ICT infrastructure goods. For these products, energy efficiency is a very important product design criterion to minimize the harmful impact on the environment. Careful balancing is then needed to maximize both the material efficiency and energy efficiency of such products.

### 9.2.3 Reparability

High reparability normally requires a smart design for disassembly. CENELEC [b-prEN 45554] (working document version) regards disassembly as a condition to do the next step, making it a subcomponent of reparability. However, the ability to disassemble as such is not an end goal. Repair is also facilitated by the modular design of products.

In order to assess a product's reparability, a prioritization of parts may take place because not all parts will be equally prone to be repaired.

Therefore, not all parts need to be assessed, but only those that are more likely to fail during the expected lifetime of the product. These parts are called priority parts and is a central concept in [b-prEN 45554].

Product-related criteria included in [b-prEN 45554] are:

- disassembly sequence and depth;
- fasteners used as well as tools;
- working environment and skill level required for a given repair.

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[1] 1-189/747.

[2] 1-665/747.

[b-prEN 45554] also suggests to consider support-related criteria when assessing a product's reparability and organization parameters which facilitate the replacement of priority parts.

Support-related criteria include:

- availability of information to consumers;
- repair flows;
- availability of spare parts, repair infrastructure and return models;
- repair instructions, exploded views available for authorized repair personnel.

For mobile ICT goods, most common repair actions usually concern screens, batteries and charging ports.

For ICT infrastructure equipment, it is less obvious to identify the most common repair actions or parts of the equipment that break down most frequently.

While conceptional that reparability is a part of durability, there are trade-offs between reparability and reliability in the design of portable ICT goods such as smartphones. Many manufacturers prioritize design for reliability (e.g., water resistance, robustness) even though this could make it more difficult for common users to repair the product, for instance due to embedded batteries and use of adhesives instead of screws. It has also been reported that innovative adhesives such as pull tabs could make the repair of smartphones easier for professionals.

The repair of ICT infrastructure equipment such as radio base stations, core routers, large networking equipment or data centre servers is done in an entirely different way than for ICT consumer goods.

As ICT infrastructure goods are very costly and highly complex, they cannot be repaired by a local repair shop or non-dedicated, non-contracted repairers.

These products very often make up a critical, highly available network infrastructure, thus no downtime can be permitted. To tackle this, service providers, financial institutions or data centre operators close service contracts where rapid support from the manufacturer is provided on software and hardware problems. In most cases, a product is immediately replaced by another when it breaks down. After the network is operational again, the failed product is sent back for analysis to a test facility in order to assess if and how it can be repaired. The product repair is done by dedicated specialized personnel which are trained by the manufacturer. Because the repairer is working under contract for the manufacturer, a close cooperation is guaranteed between both parties, often reoccurring issues and improvement suggestions are being fed-back to the engineering department of the manufacturer. Once repaired, the product is reintroduced to the market as spare parts again.

Having these products repaired by a local independent repairer without contract and without close cooperation with the manufacturer is not advised because of issues with safety (high voltage/current), IPR and technical difficulties to repair.

#### 9.2.4 Upgradeability

In order to assess a product's upgradeability, a prioritization of parts may take place because not all parts will be equally prone to be upgraded. The evaluation of parts for upgrade is expected to focus mainly, but not exclusively, on parts subject to rapid technological changes or changes in use profiles over the use phase of the product. [b-prEN 45554] suggests to consider product as well as support-related criteria when assessing a product's upgradeability. In cases were upgradability can only be achieved by replacing physical parts, product-related criteria may include the same product level criteria as for product reparability. However, specific attention should be given to the role of software and firmware.

Upgradeability of the product can be assessed in terms of manufacturer support based on the availability of parts for upgrade (rather than spare parts).

The upgradeability is also determined by the availability of supporting information and software and firmware support.

*Software upgrade of ICT products*

Software upgrades are commonly used for ICT products to increase and enhance their performance. Software upgrades improve the usable lifetime of ICT products. The interface for providing software upgrade is normally available in the ICT products and no disassembly is required for this.

### 9.2.5 Maintenance

Maintenance is commonly done in the ICT industry, especially for larger ICT infrastructure goods and software to increase the performance and lifespan of the goods. Maintenance can also be done remotely.

Corrective maintenance is typically done as repair.

Preventive maintenance is typically done to prevent total collapse of the ICT product. The maintenance includes periodic cleaning, inspection, etc.

## 9.3 End-of-life stage

Collection of products at end of life is inevitable to achieve a circular economy and the participation of all actors is needed. In extended producer responsibility or product stewardship programmes, it is necessary that authorities, producers, distributors and consumers work together to achieve a high quality and volume of collected waste.

Where no mandatory programmes exist, it is key to provide incentives to users to return products to a system where they can be reused, refurbished or recycled. Such programmes need to be easy to access and visible to the product user. Therefore efforts have to be taken to raise awareness for these voluntary programmes.

### 9.3.1 Reusability

To assess and increase the ability to reuse products, a range of criteria has to be considered. Reuse can apply to either a whole product or to parts of it. The ability to reuse a product is interconnected to its durability, the ability to repair it and the ability to upgrade it.

Whereas the ability to reuse parts of it is also interconnected to the ability to disassembly it to harvest the reusable parts.

In some product (groups) and this is especially important for mobile ICT goods, the ability to reuse them is determined by the ability to transfer and permanently delete (personal) data from it.

Ease of data erasure is important, especially for mobile ICT to encourage users to hand used products over to another user.

On this topic, there is occasionally a trade-off between the security of users' personal information, protected by a personal code allowing complete wipe-out, and the willingness of refurbishing companies to lock up older but well-functioning products, perform complete wipe-out and refurbish for a new life.

### 9.3.2 Recyclability

Crucial for high recyclability rates is ease of disassembly into recyclable streams (unless contradicting safety requirements).

[b-prEN 45555] can be used to estimate the recyclability.

The actual recyclability rate is always related to the available technology.

### 9.3.3 Reused components

It might be important to be able to reclaim components for reuse. Manufacturers shall strive to reuse components/parts/materials at the end-of-life stage.

[b-prEN 45556] provides four calculation methods for assessing the proportion of reused components in an energy-related product based on the mass and the number of reused components.

### 9.3.4 Remanufacture ability/refurbish ability

[b-prEN 45553] identifies seven general process steps which are considered to be crucial for the remanufacturing and refurbishment. Product-specific standards can be developed based on these steps. The steps are:

– inspection

– disassembly

– cleaning

– reprocessing

– reassembly

– testing

– storage.

The ability to disassemble is important for the ability to remanufacture.

### 9.3.5 Substances of concern

Occasionally there is a conflict between waste, chemicals and products. Laws might change which prevents recycling. New products cannot be placed on the market when using recycled components that include banned substances.

Examples are Cd in batteries and PVC cables [b-Friege].

The incineration of plastics usually emit hazardous substances but might help avoid $CO_2$ emissions by replacing electric power production. The recycling of plastic usually helps avoid $CO_2$ emissions but might keep harmful substances in the loop.

It should be analysed which substances, used in the ICT supply chains, are regulated in which parts of the world, and how that affects the recyclability and reusability.

Recycling and reuse can be hampered by the presence of certain chemicals. Some chemicals can simply constitute technical barriers preventing recycling. Even a benign substance, which for example has a strong smell, could in some cases prevent use of the recycled material. Other chemicals are hazardous to humans or the environment. A growing number of these are being identified and becoming subject to restrictions or prohibitions. These chemicals may be present in products sold before the restrictions applied, some of which have a long lifetime, and therefore prohibited chemicals can sometimes be found in recycling streams. Such substances can be costly to detect or remove, creating obstacles in particular for small recyclers. All these different types of chemicals are known as 'substances of concern' for the purpose of this Recommendation [b-EUCOM32].

## 10 Circular economy on an organizational level

Decisions taken at an organizational level have an impact on the circularity of ICT products beyond their design. For example, striving to improve the quality of recycling can lead to better material quality and a larger share of recycled content in future products, not only for the manufacturer, but also for the whole ICT industry.

Companies can organize their reverse logistics in several ways to improve CE, such as:

- provide product return pickup and transport at no cost for any customer worldwide upon request;
- establish alternative commercial models that promote product return, including, purchase trade-in, banked credit, leasing, and product-as-a-service;
- offer comprehensive warranty, replacement, service and repair for all products to extend useful product lifetime and minimize obsolescence;
- repurpose returned product, subsystems, components and commodities, including closed-loop return to new product manufacturing.

Two metrics that have been used on corporate level are:

1) reuse rate of returned products;
2) landfill share of globally handled scrapped materials [b-Huawei].

### 10.1 Reduction and reuse of production scrap

Waste generated during the manufacturing process should be reduced, reused, recycled, composted, or when necessary converted to energy according to the waste hierarchy. The final target should be a zero waste to landfill policy. If production scrap cannot be avoided, it shall be reused where possible or otherwise utilized for maximum environmental benefit.

### 10.2 Operating with renewal energy

Besides reducing the total energy use and increasing the efficiency of ICT products, the operation of manufacturing and other facilities with renewable energy is an important step to achieve circular economy at an organizational level. This can be achieved through direct use of renewable energy by building own energy infrastructure or purchasing renewable energy from suppliers or by procuring renewable energy credits.

### 10.3 Transportation

The transportation of products, supplies and employees is contributing a fair share to emissions of greenhouse gases and nitrogen oxides. This can be reduced by shifting to renewable fuels, enabling telecommuting and videoconferencing, supporting the use of public transport or instalment of company commuting programmes.

### 10.4 Reduction of water usage

Water is used in different processes in the ICT industry, e.g., for cooling, sanitation, landscaping or during production.

In general, it should be the target to reduce water usage, but besides that there are alternatives such as the reduction of freshwater use by using recycled water and harvesting rainwater.

Special emphasis should be placed on facilities in water stressed regions and suppliers of components that are identified to have a high water usage.

### 10.5 IoT enabled circularity

Enhanced material recovery and reuse could be facilitated by advanced sorting, robotic disassembly, and digital tracing. Moreover, 3D printing will reduce the need for large manufacturing and might reduce waste and VR will reduce maintenance time and keep products in use longer. Additionally, blockchain can help transform the life cycle inventory (LCI) and traceability in the materials handling. Also, dark factories can save electricity used by lighting and air conditioning [b-Huawei].

### 10.6 Studies examining monitoring and control services with sensors and ICT infrastructure focused on waste management

Lelah et al. investigated a machine-to-machine enhanced product service system for the collection of waste glass, in which the collection routes were planned on the basis of real-time data on collection containers' degree of fill [b-Lelah].

Bonvoisin et al. made an LCA of a municipal waste collection system based on a city-scale wireless sensor network [b-Bonvoisin].

### 10.7 Take-back models reverse return logistics

Closed-loop efforts can:

- provide product return pickup and transport at no cost for any customer worldwide upon request;
- establish alternative commercial models that promote product return, including, purchase trade-in, banked credit, leasing and product-as-a-service;
- offer comprehensive warranty, replacement, service and repair for all products to extend useful product lifetime and minimize obsolescence;
- repurpose returned product, subsystems, components and commodities, including, closed-loop return to new product manufacturing.
- establish a dedicated circular economy performance indicator tracking appropriate progress.

### 10.8 AI enabled circularity

Artificial intelligence (AI) can play an important role in the shift from a linear to a circular economy because AI allows us to deal effectively with complexity and make sense of abundant data.

AI can enhance and enable circular economy innovation across industries [b-EllenAICE] in three main ways:

1. Design circular products, components, and materials. AI can enhance and accelerate the development of new products, components, and materials fit for a circular economy through iterative machine-learning-assisted design processes that allow for rapid prototyping and testing.
2. Operate circular business models. AI can magnify the competitive strength of circular economy business models, such as product-as-a-service and leasing. By combining real-time and historical data from products and users, AI can help increase product circulation and asset utilization through pricing and demand prediction, predictive maintenance, and smart inventory management.
3. Optimize circular infrastructure. AI can help build and improve the reverse logistics infrastructure required to 'close the loop' on products and materials by improving the processes to sort and disassemble products, remanufacture components and recycle materials.

### 10.9 Wider system considerations

Several cases exist in which ICT goods are repurposed to be used as something other than the original product. A recent lifetime extension approach includes repurposing notebook computers to thin client computers [b-Coughlan]. Another is the repurposing of a smartphone into an in-car parking meter or a portable solar charger [b-Zink]. It has also been proposed to repurpose electric vehicle Li-ion batteries for energy storage in a second-use application such as buildings [b-Bobba].

### 10.10 Circular economy in new network equipment acquisition process

One telecommunication operator has reported their example case of how to enquire about topics such as reparability, recyclability or upgradability when purchasing new equipment (b-CARE).

Circularity evaluation methods have been developed these last years (e.g., circular economy toolkit [b-Tool] or material circular indicator [b-Ellen]) but they are ill-suited for a telecommunication operator. Indeed, some of them are based on questions requesting very precise knowledge on the equipment architecture, with questions such as "Is there a complete bill of materials and substances for the product?" Others do not provide the level of granularity required (failure rate is defined with levels as "Product failures rarely occur" or "Product failures are frequent").

Therefore, the main goal of the method developed for the example case at hand is to use the same key criteria (durability, reparability, etc.) as in the CEN/CENELEC JTC 10 documents but with tailored questions for each type of equipment. The first trials covered six criteria:

– **Durabilit**y, with questions about the three most critical failure modes at equipment level according to FMEA and MTBF assessment at equipment level;
– **Reparability**, with, for example, a question regarding the type of fasteners used on electronic boards. Heatsinks fastened with acrylic thermal conductive adhesive which might damage the board or the integrated circuit's integrated heat spreader (IHS) during disassembly process);
– **Upgradability**, with for example a question regarding the ability to upgrade the equipment critical components (e.g., CPU, HDD/SSD and RAM for a server);
– **Refurbish ability**, with for example a question regarding time required to swap field-serviceable components;
– **Recycled content**, with for example a question regarding the post-consumer recycled material intentionally used for large metal parts (e.g., heatsinks or cabinet);
– **Critical raw materials (CRM) content**, with for example a question regarding the manufacturer's ability to provide information on CRM content (the 2017 EU Critical Raw Materials list is used as a reference [b-EU]).

For each question covered in the different criteria, several levels of performance were defined. For instance, fasteners can be categorized as reusable, non-reusable but which can be removed without any damage or problematic residue on the electronic board or non-removable.
For each criterion (e.g., reparability) a weighted importance is applied.

## 11 Reporting

[b-EN 45559] provides a common method for the provision of information related to the material efficiency aspects of ErP.

The content and the way of providing information related to material efficiency depends on several aspects and can diverge according to the intended target audience and sensitivity of the data.

[b-EN 45559] mentions several topics related to material efficiency:

• durability
• ability to remanufacture
• ability to repair, reuse and upgrade
• recyclability and recoverability
• proportion of reused components
• proportion of recycled content
• use of critical raw material.

However, information could also be provided on other topics, such as the use of conflict minerals according to guidelines provided by the OECD [b-OECDcon] or the use of certified paper products. Conflict minerals reporting is related to using only minerals that do not directly or indirectly finance armed conflict or benefit armed groups. Conflict minerals are understood to be gold, coltan (columbite-tantalite), cassiterite, wolframite, tantalum, tin and tungsten.

The use of paper is widespread in the ICT industry for packaging and providing information to users (instruction manuals, warranty documents, etc.). Using recycled paper content and sourcing virgin fibres only from sustainably managed forests or controlled wood sources is an important step to improve the circularity of paper products.

The reported content can have a qualitative or a quantitative nature depending on the type of information and intended audience.

The intended audience can be divided into:

- end users (professional and/or private persons);
- professionals (in product-related services such as retail, repair, maintenance, recycler);
- market surveillance authorities.

Depending on the sensitivity of the data, the disclosure of information might be limited to a restricted audience or made available to the public. The manufacturer shall decide which data is considered to be confidential, except when provision is mandated by the legislator.

The means of communication shall be chosen according to the intended user, the type and amount of information to be provided and the needed duration of availability.

Information could, for example, be provided on or with the product or its packaging, online, or at the point of sale.

## 12 Insights and conclusions

The following insights and conclusions can be drawn in this Recommendation:

- The material efficiency field is characterized by initiatives by several actors beyond M543.
- A vast number of companies have already implemented smart circularity solutions and business models, as well as having quantified the benefits.
- Designing ICT products for circularity always includes weighing different, sometimes contradicting targets such as durability, robustness and ability to repair and recycle goods. The ability to repair is important for the circularity of products, but due to the complexity of ICT products, it can be necessary that the repair is conducted by professionals authorized and trained by the manufacturer. Software and firmware are integral parts of ICT goods and need to be taken into account when designing and maintaining them. Another important factor is the availability of proper information and support by the manufacturer for the customer using the goods.
- For large and complex ICT infrastructure equipment, it is challenging to identify most common repair actions or parts of the equipment that break down most frequently.
- For large and complex ICT infrastructure equipment, it does not make sense to do local repair by non-professionals. Nevertheless, fibre optic cables may be repaired by non-professionals.
- For gateways, leasing business models works very well.
- Recycled content of CRM in ICT goods cannot be quantified easily.
- It is important to consider the circularity application while balancing between the environmental and business model perspectives.

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