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Definition of approaches, concepts and metrics

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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Environmental Engineering (EE).

Modal verbs terminology

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Introduction

In order to facilitate a shift to a more sustainable economy, Circular Economy (CE) has been proposed as one of the main ways forward. In this context, CE combined with Information and Telecommunication Technologies (ICT) could enable decoupling of economic growth and environmental impact [i.1]. Due to the seemingly scattered understanding of the topic of CE, and its main aspect Resource Efficiency (RE), it will be necessary to summarize, and then standardize, the manner in which CE and RE is quantified.

In 2015, the European Commission issued Mandate 543 (M/543), Standardization Request with regard to ecodesign requirements on material efficiency aspects for energy-related products [i.2] requesting European standardization organizations to develop needed standards. ETSI TC-EE accepted this mandate for ICT infrastructure goods. The present document is intended to provide input for standardization related to the Mandate 543.

The present document aims to provide an overview of the most important existing aspects, parameters, indicators, metrics, results, and business models used for estimating the resource efficiency and CE characteristics of ICT infrastructure goods as input for further standardization.

The present document is intended to provide an aid for all users of CE and RE concepts within the ICT infrastructure sphere.

ITU-T SG5 (Q13/5) has made preliminary descriptions of RE for ICT goods [i.3], which have been considered in the development of the present document which focuses more broadly on CE aspects for ICT infrastructure goods. Furthermore, the Methodology for Ecodesign of Energy-related Products (MEErP) report [i.4], as used in the framework of the Ecodesign Directive (2009/125/EC) [i.75], has been used as background information for materials efficiency aspects.

1 Scope

The present document investigates current approaches, concepts and metrics of CE and RE and their applicability for the ICT infrastructure goods. The present document:

1) introduces CE and RE,
2) describes CE as used in the ICT industry,
3) describes existing CE and RE metrics and examples of their use,
4) proposes next steps in CE and RE standardization.

The scope of the present document includes the following aspects: upgradability, reparability, removability, durability, reusability, recyclability, recoverability, refurbishability, manufacturability. The following additional parameters, indicators and metrics are included: recycled content, use of critical raw materials, proportion of re-used parts.

The present document is revision of ETSI TR 103 476 (V1.1.1) [i.73]. It has the same technical content , but it clearly clarifies its relation to M/543 [i.2]. The first version [i.73] was prepared jointly by ETSI TC EE and ITU-T Study Group 5. It is published respectively by ITU and ETSI as Supplement ITU-T L.Suppl.28 [i.72] and the present document, which are equivalent in technical content.

The present document provides a guide to CE aspects, parameters, metrics, indicators for ICT infrastructure goods.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

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NOTE: Available at http://data.europa.eu/eli/dir/2011/65/oj

[i.75] 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.

NOTE: Available at http://www.buildup.eu/en/practices/publications/directive-2009125ec-european-parliament-and-council-21-october-2009

3 Definitions and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

aspect: field of CE

NOTE: Examples include removability, durability, recyclability, reparability.

assessment method: procedure for determining the value of a metric or indicator and validating it

NOTE: The method could include measurement and calculation.

indicator: quantifiable representation of a parameter

NOTE: Example includes Service Output per Material Input.

metric: measurable representation of a parameter or indicator

NOTE: Examples include mass of product, disassembly time, and re-used parts.

parameter: entity representing an aspect

NOTE: Examples include R_{cyc} and $R_{cov.}$

Recycled Content (RC): proportion, by mass, of recycled material in a product or packaging

NOTE: Only pre-consumer and post-consumer materials should be considered as recycled content [i.6].

pre-consumer material: material diverted from the waste stream during a manufacturing process

NOTE: Excluded is reutilization of materials such as rework, regrind or scrap generated in a process and capable of being reclaimed within the same process that generated it [i.6].

post-consumer material: material generated by households or by commercial, industrial and institutional facilities in their role as end-users of the product which can no longer be used for its intended purpose

NOTE: This includes returns of material from the distribution chain [i.6].

re-use: any operation by which component parts of end-of-life products are used for the same purpose for which they were conceived [i.5] and [i.70]

recycling: reprocessing in a production process of the waste materials for the original purpose or for other purposes, excluding processing as a means of generating energy [i.5] and [i.70]

recovery: reprocessing in a production process of the waste materials for the original purpose or for other purposes, together with processing as a means of generating energy [i.5]

refurbishment: processing hardware and/or software of an ICT good, a plug-in unit or system module of a used ICT good for reuse through e.g. testing, cleaning and repair

NOTE: Refurbished ICT goods could be re-used by the owner or resold.

remanufacturing: process in which one or more part(s) are reworked to compose a new part/good

NOTE: More commonly used in mechanical engineering where mechanical part/product is reworked to correspond a new part/product, e.g. car engine.

repair: restore to working order

3.2 Abbreviations

For the purposes of the present document, the following abbreviations apply:

ADSL	Asymmetric Digital Subscriber Line
B2B	Business-to-Business
B2C	Business-to-Customer
Btu	British thermal unit
C2C	Cradle to Cradle
CAPEX	Capital Expenses
CE	Circular Economy
CFC	ChloroFluoroCarbons
ECD	Environmentally Conscious Design
EDE	Electronic Disposal Effectiveness
EEE	Electrical and Electronic Equipment
EOL	End Of Life
EoLT	End of Life Treatment
ERP	Energy Related Product
EU	European Union
GDP	Gross Domestic Product
GSM	Global System for Mobile Communications
HCFC	HydroChloroFluoroCarbons
IC	Integrated Circuit
ICT	Information and Communication Technology
IEC	International Electrotechnical Commission
LCA	Life Cycle Assessment
LCD	Liquid Crystal Display
LCI	Life Cycle Inventory
LTE	Long Term Evolution
MCI	Material Circularity Indicator
MR	Material Reutilization
OPEX	Operating Expenses
PAS	Planning Advisory Service
PCBA	Printed Circuit Board Assembly
RAN	Radio Access Network
RBUR	Reusability benefit rate
RBVR	Recovery benefit rate
RC	Recycled Content
R_{cov}	Recoverability rate
RCR	Recyclability rate of a Part
R_{cyc}	Recyclability rate
RE	Resource Efficiency
ROHS	Restriction of Hazardous Substances
RP	Resource Productivity
R_{reuse}	Reusability rate
RRR	Reusability/Recyclability/Recoverability rate of a part
RUR	Reusability rate of a Part
RVR	Recoverability rate of a Part
SASF	Sustainability Assessment Standard Framework
TM	Trade Mark
WCDMA	Wideband Code Division Multiple Access
WEEE	Waste Electrical and Electronic Equipment

4 Introduction of Circular Economy concepts

Circular Economy (CE) is a wide concept which covers both the full lifecycle of goods and business models. In general CE is about closing the loop between different life cycles through design that enable greater 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 keep goods out of landfill and incineration [i.7]. CE deals with both environmental and economic aspects. In an ideal CE, all waste generated would be reused as raw material in production processes.

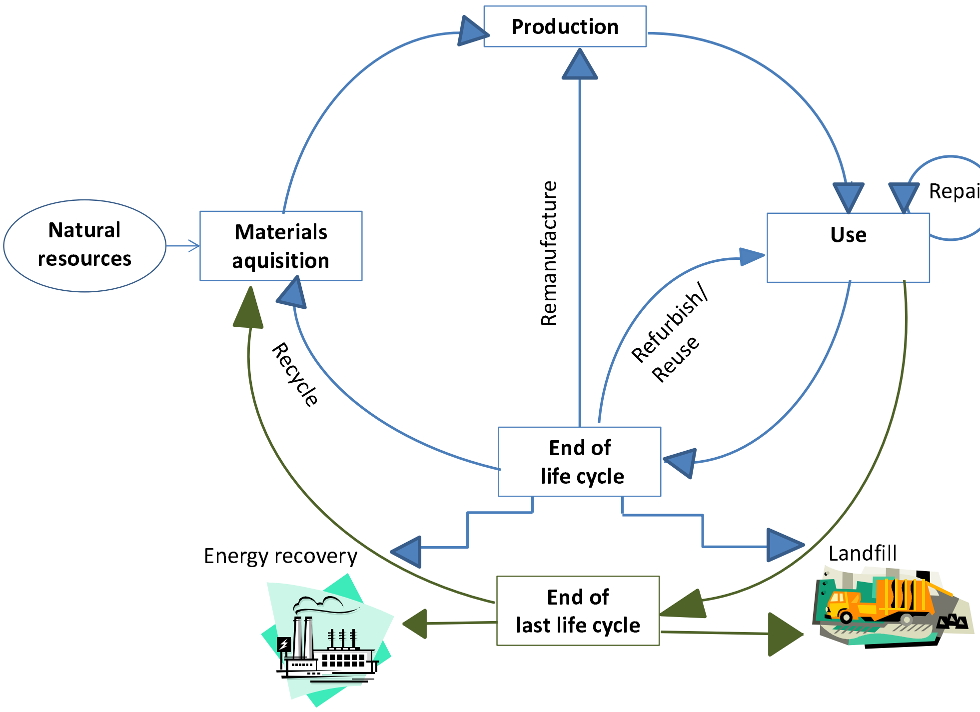
It is clear that discarded goods represent a valuable source of raw materials [i.8]. However, in practice trade-offs have to be made with parameters such as reliability and cost. The Resource efficiency (RE) is sometimes used interchangeably with the CE concept. However, RE focus more on efficient use of resources and on minimizing the environmental impact of a good during its life cycle. An example of a generalized Resource Efficiency (RE) definition is dealing with the benefit obtained from the use of natural resources [i.4]. Furthermore, materials efficiency is used in parallel with RE, or as a more precise concept dealing with raw materials only, excluding energy. In the present document, RE is seen as a sub-category of CE, and materials efficiency as a part of RE.

In the present document, CE and RE aspects and parameters/metrics/indicators are discussed.

Researchers have 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 [i.9].

As shown in figure 1, both for CE and for RE, the full life cycle of the good should be taken into account.

Through the design stage, it is possible to influence all the most important aspects; minimizing material usage and environmental impacts. Goods can be designed to be used longer, repaired, upgraded, refurbished, remanufactured and/or eventually recycled instead of being thrown away. One important point of view is to avoid use of hazardous and rare earth materials when possible [i.10]. 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.



NOTE: End of last life cycle means that the ICT infrastructure good can no more be circulated.

Figure 1: Interventions and other mechanisms that influence the flows in the material life cycle of ICT goods (modified from [i.11])

In addition to figure 1, figure 2 shows some relationships between various CE aspects which are described in more detail in clause 7.

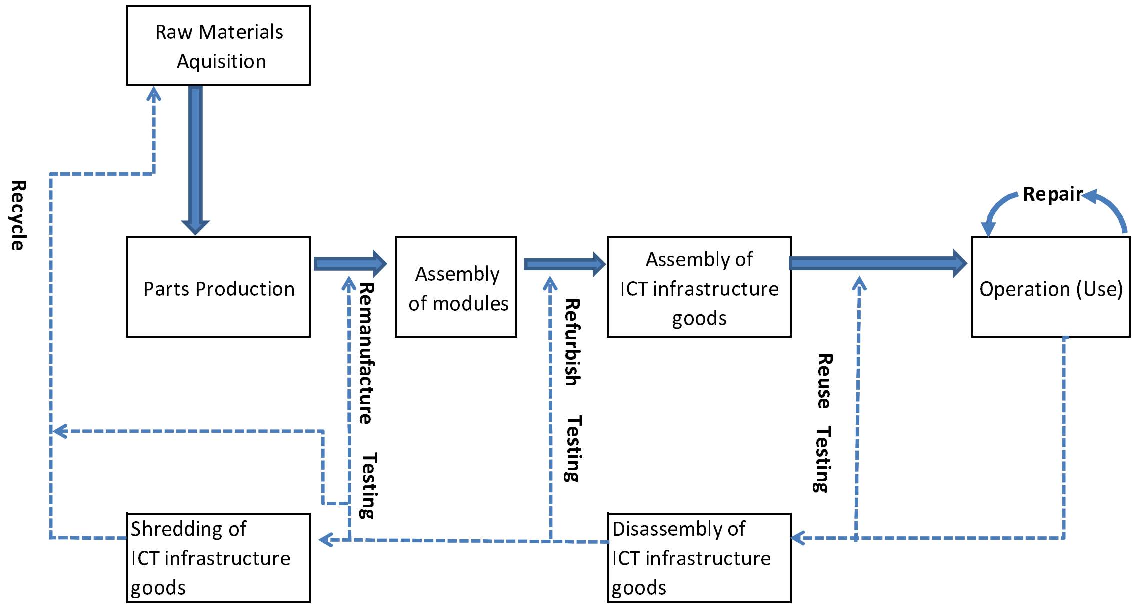


Figure 2: Relationships between different CE aspects (adapted from [i.12])

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

Table 1: CE aspects for ICT infrastructure goods, level of disassembly and expected quality (adapted from [i.12])

CE aspect	Level of disassembly of ICT infrastructure good	Expected quality of ICT infrastructure good	Examples
Maintenance	None	Working order	Replace fan filter.
Repair	ICT infrastructure Good down to faulty part	Working order	Repair blade servers.
Reuse (direct)	None	"As-is"	Operators reuse directly base stations in another location.
Refurbish	Good or module	Specified level	To make the good function according to a specified target level.
Remanufacture	Part	'Like-new part'	Examples could not be found for new parts in ICT infrastructure goods, due to e.g. reliability requirements for electronic parts.
Recycle	Recyclable materials	-	Gold recycling.
Recover	Non-recyclable parts/materials	-	Energy recovery from plastics.

5 Circular Economy related legislation and standards

A number of specific policy measures and regulations have already been established that intend to support the transformation to the CE. These regulations include WEEE, RoHS [i.74], and ErP Directives [i.75] from the EU. As an example, WEEE Directive [i.13] is encouraging design and production of EEE which take into full account and facilitate its repair, possible upgrading, reuse, disassembly and recycling. With the CE package published in November 2015, a more general framework for the CE has been created [i.10].

As an answer to Mandate 543 (M/543) [i.2], ETSI TC EE is collaborating with the joint technical committee founded by CEN/CENELEC, CEN-CLC TC10. ETSI TC EE will use the present document as input for that work.

Within the CE area, ITU-T SG5 (Q13/5) has ongoing work on e-waste. The tasks of Q13 include studies of rare metals information, e-waste quantities, e-waste management and best practises. As mentioned in the introduction of the present document, ITU-T SG5 (Q13/5) already completed initial work in the RE area [i.3].

On a national level, British Standards prepared PAS 141:2011 [i.15] on the preparation for reuse of used and waste electrical and electronic equipment (EEE), which provides guidance in the area [i.14]. PAS 141:2011 [i.15] set out the requirements to successfully manage the process of preparing used EEE and WEEE for reuse. PAS 141:2011 [i.15] describes the removability of external enclosures, PCBs, processors, data storage devices and batteries with common tools [i.15].

6 Circular Economy business models

Business models are important for the success of the CE [i.16]. CE business models address: circular supply chain (e.g. biomass resources), recovery & recycling (e.g. all waste is used for other uses), lifetime-extension of goods (e.g. reselling), sharing platforms (e.g. housing and transport), product-as-a-service (e.g. tyres-by-the-km, leasing of equipment such as radio base station) [i.17].

Business models in the context of ICT and the CE could refer both to ICT's own business cases, but also to how ICT enable other sectors to introduce CE business models. As an example, cloud services imply servitization of e.g. software, infrastructure, platforms. Furthermore, they also enable a servitization of other sectors [i.18].

For the success of the CE, the establishment of necessary business models is very important.

Further examples from ICT are presented in clause 9.

7 Circular Economy aspects and parameters affecting the environmental impact in different life cycle stages

7.0 Introduction

The different aspects of the CE could be divided into different areas such as proposed in this clause. There are different ways to do this sub-division into areas, and they are to some extent overlapping. Sub-division can be done using e.g. life cycle stages, design stages, or 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 take place. Some additional examples of aspects, parameters, indicators and metrics are listed in annex B. Those examples are considered of less relevance for ICT infrastructure goods.

7.1 Raw Material Acquisition stage

7.1.1 Recycled content

For ICT infrastructure network and parts of goods, European OPERA-Net 2 project studied resource efficiency [i.19] and identified recycled material content as an important indicator. The project also emphasized the need to consider versatile aspects beyond simple mass.

The recycled content indicator/metric as defined by ISO [i.6] can be applied to ICT infrastructure goods [i.20]. However, currently mainly secondary data is available.

The amount of recycled content (RC) is challenging to estimate for ICT infrastructure. Most parts are bought on a global market, involving long supply chains, and the origin of the material content is not easily trackable. For this reason the best assumption seems to be global average recycling data [i.21] and [i.22].

Table 2 shows the ISO definition as well as other examples of RC indicators/metrics found in literature.

Table 2: Indicators and metrics for the Recycled content parameter

Indicator/metrics	Reference	Comment
Proportion, by mass, of recycled material in a product or packaging. Only pre-consumer and post-consumer materials should be considered as recycled content.	[i.6]	
Ratio of cumulated mass of recycled material per part and mass of good.	[i.23]	
Plastics recycling traceability and assessment of conformity and recycled content.	[i.24]	
Mass of the good and its re-use percentages.	[i.25]	An example is "the weight of the recycled plastics per good combined with information on recycling percentages of the used plastics provided by materials suppliers".
Global average recycled content for metals was defined as the fraction of secondary metal in the total metal input to metal production.	[i.26]	An example is presented in annex A.
The average recycled content of steel was defined as the annual tonnage of steel scrap consumed divided by the tonnage of steel produced.	[i.27]	An example is presented in annex A.

In addition to recycled content (RC) indicators, there are indicators trying to estimate the environmental benefits of having a higher RC [i.23]. Additionally, cost is important to maximize the use of recycled materials and thereby the environmental benefits.

7.1.2 Use of Critical Raw Materials

Critical raw materials is a list of 20 materials (identified by the EU) combining a high economic importance to the EU with a high risk associated with their supply [i.28].

So far, no specific indicators, parameters or metrics are found for use of these materials for ICT infrastructure goods. For the recyclability of critical raw materials refer to clause 7.3.2.

7.1.3 Proportion of re-used parts

The proportion of re-used parts and sub-parts refers to the share of secondary parts of total parts of the ICT infrastructure good.

For ICT infrastructure goods, there are high requirements on quality which might put restrictions on reuse of parts. High-quality parts are required and there might be restrictions for secondary parts. However, some users may still be interested in reused parts due to cost advantages.

Moreover, as the innovation is fast in the ICT sector, reusing older parts might lower the energy efficiency of the ICT infrastructure goods. Reuse of mechanical parts (e.g. standardized whole racks) seems more likely than reuse of electronic parts.

Use of recycled materials seems a more promising way forward for the ICT infrastructure goods.

7.2 Use stage

7.2.1 Durability

Durability is about the ability of parts/modules/goods to maintain their functions and performances over their life cycle [i.4], i.e. extension of durability is about extending the technical lifetime.

For some categories of goods, maintained energy performance over time is a parameter that needs to be considered for durability. This parameter seems less valid for ICT infrastructure goods whose energy performance is not expected to worsen over time. It remains to identify the durability parameters that are the most relevant for ICT infrastructure goods.

Long durability is seen as a desired characteristic, however, striving for durability and longer lifetime might also have disadvantages such as use of more sophisticated materials, changes in sales opportunities and locking user into an old design with limited performance [i.29].

Durability implies the extension of operating lifetime. Often such an extension requires a trade-off with replacement of goods to minimize environmental impacts. As an example, for ICT networks, especially energy performance of the goods improves between generations and thus depends on the network modernization. New energy efficient technology provides environmental and OPEX benefits. One study regarding data centre rack servers suggests that, from a carbon footprint perspective, an aggressive modernization cycle makes sense if the power use decreases by at least 10 % generation over generation. [i.30]. Also from an economic perspective trade-offs are needed.

For example, one ICT infrastructure goods provider has estimated that, under certain conditions, the optimum modernization cycle for base stations was well below the typical commercial lifetime (5 years versus 10 years) when taking into account CAPEX and OPEX vs. improved energy efficiency [i.31]. Thus, the optimum modernization cycle from a total network life cycle energy perspective, is directly dependent on the technological progress in energy efficiency improvements of both operational and embodied stages [i.32].

Additionally, the durability of the good need to be considered in relation to the technical evolution. Currently the durability of the ICT infrastructure goods may well exceed the lifetime needed due to innovation.

Durability parameters or indicators/metrics suitable for ICT infrastructure goods have not been identified in the literature review.

7.2.2 Upgradability

A higher upgradeability reduces the need for replacement and increases the lifespan.

Software upgrades are commonly done for ICT infrastructure goods.

In terms of hardware, ICT infrastructure goods are generally designed in a modular way to ensure upgradability (e.g. empty slots for capacity expansion) . More specifically, ICT infrastructure goods are increasingly designed for replacement of key parts according to the technical evolution and capacity. This way the hardware (e.g. a sub-rack) is more efficiently used.

Upgradability parameters or indicators/metrics suitable for ICT infrastructure goods have not been identified in the literature review.

7.2.3 Removability

A high degree of removability is required for efficient repair, upgrade, and may also improve refurbishment and recycling efficiency. It could also extend the lifespan of the good by facilitating repair and maintenance.

Being very complex and highly integrated, components of PCBAs are often difficult to repair, so removability for repair/replacement/upgrade is on PCBA level, rather than on components (e.g. IC) level.

NOTE: Components and parts can both be used to describe items of which e.g. PCBAs consist. The LCA standards [i.21] and [i.22] use the term parts.

For recycling, it is assumed that especially parts made from or containing valuable materials (especially critical raw materials) are of interest. These parts are therefore a main target for removal [i.33], either through automatized or manual processes. The removability for recycling need not necessarily be high in modern highly automatized recycling processes. However, a certain degree of manual removability might impact the quality of the recycled materials (and thereby the value of the materials). Some design tools have used virtual reality interfaces to simulate assembly/disassembly operations during the initial stage of design [i.34].

Removability or removal efficiency can partly be measured by the time it takes to remove a certain part with a certain tool from an ICT infrastructure good [i.35]. Other metrics/indicators (e.g. quality-based) need probably to complement the time based metrics.

No definition was identified for removability. However, disassembly (a more common term) was e.g. defined as "*the process of systematic removal of desirable constituent parts from an assembly while ensuring that there is no impairment of the parts due to the process*" [i.35]. The two concepts are closely related.

Removability parameters or indicators/metrics suitable for ICT infrastructure goods have not been identified in the literature review.

7.2.4 Reparability

ICT infrastructure goods are usually associated with considerable investments. Consequently repair is a self-evident activity within ICT infrastructure operation and maintenance.

The repair is facilitated by the modular design of products and appropriate removability.

Repair flows are thus already established. However, reparability parameters or indicators/metrics suitable for ICT infrastructure goods have not been identified in the literature review.

7.3 End-of-Life stage

7.3.0 Introduction

Any End-of-Life (EoL) indicator value is based on future uncertain conditions. As an example, the future balance between recycling and reuse may change due to changed quantities of valuable materials in ICT infrastructure goods. This illustrates the difficulty to estimate the future End-of-Life Treatment (EoLT) impacts.

According to IEC TR 62635 [i.36], recyclability rates of complex electronic goods can be calculated for different recycling scenarios using today´s recycling technologies as estimates for unknown future conditions.

Figure 3 shows how ISO 22628 [i.5] defines the relationships between different parameters and indicators/metrics for different EoLT scenarios.

Also [i.4] MEErP referred to ISO 22628 [i.5] for these definitions. Both are in line with IEC TR 62635 [i.36] with respect to recyclability and recoverability rate definitions.

The present document follows the same categorization and definition. As an example, recyclability rate includes reuse and recycling.

<table>
<tr><th>Re-use
(ICT infrastructure goods)</th><th>Recycling (Materials)</th><th>Energy recovery
(Materials)</th><th>Undefined residue
(Materials)</th></tr>
<tr><td colspan="2">Recyclability rate</td><td></td><td></td></tr>
<tr><td colspan="3">Recoverability rate</td><td></td></tr>
<tr><td colspan="4">Mass of ICT infrastructure good</td></tr>
</table>

Figure 3: Scope for some different CE parameters and indicators/metrics in EoL (adopted from [i.5])

NOTE: As shown in clause 3.1, also Waste Framework Directive [i.70] defined the parameters and indicators mentioned in figure 3 in a similar way.

Mass of ICT infrastructure good is relevant for all parameters and indicators/metrics in figure 3. Recyclability rate, recoverability rate, and reusability rate are all based on mass and need to be complemented with other relevant characteristics to cover resource efficiency adequately.

7.3.1 Reusability

Reuse is generally seen as a preferable EoLT option. However, the ICT sector evolves so quickly that reuse is not always recommendable, e.g. introduction of more energy efficient goods may be delayed due to reuse (lifetime extension). On the other hand, the reuse of ICT infrastructure goods might result in less environmental impacts compared to the replacement so the balance between reuse and modernization needs to be carefully considered and may differ between goods.

Table 3 shows examples of reusability rate indicators and metrics found in literature.

Table 3: Indicators and metrics for the reusability rate indicator/parameter

Indicator/metrics	Reference	Comment
Percentage in mass of the part/good that is potentially reusable	[i.4]	

Equation (1) shows an example of how the reusability rate (R_{reuse}) parameter could be calculated from mass [i.23].

$$R_{reuse} = \frac{\sum_{i=1}^{P} m_i \times X_{RUR,i}}{m} \times 100 [\%] \quad (1)$$

$X_{RUR,i}$ Rate of the i[th] part of the ICT infrastructure good that is potentially reusable
m_i mass of i[th] part of the ICT infrastructure good
m mass of the ICT infrastructure good

In addition to the reusability rate (R_{reuse}) indicators, there are indicators trying to estimate the environmental benefits of having a higher reusability (see annex B for an example). The cost benefits could probably also be estimated.

7.3.2 Recyclability

Due to its functional and unique mix of materials each good provides specific opportunities for recyclability optimization [i.37].

Table 4 shows examples of recyclability rate indicators and metrics found in literature.

Table 4: Indicators and metrics for the Recyclability rate indicator/parameter

Indicator/metrics	Reference	Comment
Percentage by mass (mass fraction in percent) of the component/product potentially able to be recycled, reused or both.	[i.5]	
Sum of recyclable mass of each part, divided by the mass of the good.	[i.36]	
Percentage in mass of the part/good that is potentially recyclable.	[i.4]	
The share of materials from a good that are expected to enter the recycling stream.	[i.38]	

Equation (2) shows an example of how the recyclability rate (R_{cyc}) parameter could be calculated from mass [i.23].

$$R_{cyc} = \frac{\sum_{i=1}^{P} m_i \times X_{RCR,i}}{m} \times 100 [\%] \quad (2)$$

$X_{RCR,i}$ Rate of the i[th] part of the ICT infrastructure good that is potentially recyclable
m_i mass of i[th] part of the ICT infrastructure good
m mass of the ICT infrastructure good

In addition to the recyclability rate (R_{cyc}) indicators, there are indicators trying to estimate the environmental benefits of having a higher recyclability. The cost benefits could probably also be estimated.

Moreover, Mangold [i.38] concluded that present mass-based recyclability metrics by IEC TR 62635 [i.36] and ISO 22628 [i.5] are insufficient to the goal of measuring the eco-environmental impact of recycling of goods as cost drivers are missing.

Annex A provides some further observations on recycling and e-waste.

7.3.3 Recoverability

Recovery covers both materials recovery and energy recovery. Materials recovery includes both reuse and recycling. Compared to reuse and recycling, energy recovery provides lower environmental benefits. ISO 14021 [i.6] sees recovered materials as "material that would otherwise been disposed of as waste or used for energy recovery but has instead been collected and recovered (reclaimed) as a material input, in lieu of new primary material, for a recycling or a manufacturing process".

Table 5 shows examples of recoverability rate indicators and metrics found in literature.

Table 5: Indicators and metrics for the Recoverability rate indicator/parameter

Indicator/metrics	Reference	Comment
Percentage by mass (mass fraction in percent) of the component/product potentially able to be recovered, reused, recycled or any combination	[i.5]	
Sum of recoverable mass of each part, divided by the mass of the good	[i.36]	
Percentage in mass of the part/good that is potentially energy-recoverable by incineration, or recyclable	[i.4]	

Equation (3) shows an example of how the recoverability rate (R_{cov}) parameter could be calculated from mass [i.23].

$$R_{\text{cov}} = \frac{\sum_{i=1}^{P} m_i \times X_{RVR,i}}{m} \times 100[\%] \quad (3)$$

$X_{RVR,i}$	Rate of the i^{th} part of the ICT infrastructure good that is potentially recoverable
m_i	mass of i^{th} part of the ICT infrastructure good
m	mass of the ICT infrastructure good

In addition to the recoverability rate (R_{cov}) indicators, there are indicators trying to estimate the environmental benefits of having a higher recoverability (see annex B for an example). The cost benefits could probably also be estimated.

7.3.4 Refurbishability

Refurbishing is a process used, when needed, to prepare a good or module for reuse. Modules and plug-in units can be refurbished to a specified quality level thus extending the lifetime of used ICT infrastructure goods or parts of them. As shown in figure 2 refurbishing is usually performed on whole modules rather than smaller parts.

The quality of the good/module/plug-in unit at end-of-life will decide if a relatively minor or more extensive refurbishment is needed. If the target good is in fine condition, a relatively minor refurbishing cost would be incurred e.g. cleaning. In contrast, a part in worse condition will incur higher refurbishing costs such as repair, replacement, etc. Sometimes refurbishment might not be worthwhile and the good/module/plug-in unit will be recycled. One method proposed in literature for calculating the cost of refurbishment is presented in the annex D of [i.33].

Refurbishability parameters or indicators/metrics suitable for ICT infrastructure goods have not been identified in the literature review.

7.3.5 Remanufactureability

As shown in figure 2 and table 1, remanufacturing is usually performed on good/part level. Remanufacturing activities are likely to contain inspection, test, disassembly, rework, cleaning, reassembly, and re-inspection [i.12].

Remanufacturing primarily addresses goods/parts that do not meet the quality specifications. A remanufactured good should have the same or better quality as a newly manufactured good. One method proposed in literature for calculating the cost of remanufacturing is presented in the annex D of [i.33].

Remanufacturing of complete ICT infrastructure goods to become like new is not seen realistic due to very high quality and reliability requirements, as well as the very fast technical development of ICT. Likewise, remanufacturing of PCBAs is not seen as a viable option. The best option for remanufacturing for ICT infrastructure goods may be for simple mechanical parts.

8 Assessment methods and parameters

So far no detailed published and generally accepted methods have been identified to be applicable to ICT infrastructure goods. However, IEC in a TR outlined calculation flow for determining recyclability and recoverability rates [i.36].

For some parameters, the LCA methodology [i.21] and [i.22] could potentially provide a starting point when developing methods for quantifying the CE. This view is also supported by some researchers concluding that a better integration of RE with the life-cycle impact methodology, either at micro-scale or macro-scale, is necessary [i.9]. Still, multiple life cycles and avoided losses have room for improvement in current LCA methodologies [i.39].

More details regarding LCA in the context of CE are given in annex C.

9 Examples of actions taken by the ICT industry

Although standardized methods and metrics are so far missing, the ICT industry has started to take actions which aims towards CE. On sector level, the ITU-T project CONNECT2020 aims at reducing the volume of e-waste generated by Scope 1 and 2 of the ICT Sector (defined as telco operators and suppliers to telco operators) between 2015 and 2020 by 50 %, and the greenhouse gas emissions per subscription by 30 % [i.40]. Fulfilling such targets will likely require new CE inspired business models.

Also individual companies have started to take actions as table 6 shows.

Table 6: Industry examples aiming towards CE

Aspect or area	Example	Comment
Recycled content	Purchase requirements	ICT operators have adopted purchase requirements oriented towards a higher share of recycled materials within suppliers' products, accessories and packaging materials.
Reusability, Recycled content	Packaging	Transportation cabinet/box designed for reuse and/or package made of recycled materials.
Upgradability, Reusability	Multi-standard Radio access network (RAN) products	Multi-standard radio base stations are designed with a consolidated set of hardware modules allowing operators to use a single set of equipment, while supporting multiple mobile communications standards (GSM, WCDMA, LTE).
Upgradability, Reusability, Recyclability, Refurbishability	Product-as-a-service	An operator can buy a specific network element service instead of physical network elements from an ICT infrastructure goods manufacturer. The ownership of the physical network element remains within the manufacturer who delivers the network element to be used at operator's site (e.g. base station). Life-cycle management of the good is handled by the manufacturer by upgrading, repairing, refurbishing, reusing, recycling, etc. as needed.
Reparability, Recyclability, Removability	Disassembly reqDisassembly Requirements	Disassembly operations have been optimized (by requirement setting on the suppliers) in order to make maintenance and repair activities easier and allow for a more effective end-of-life management.
Reparability, Removability	Design for easy dismantling	Avoid screws and electrosoldering but instead use snap-in plastics for smaller ICT infrastructure goods such as ADSL modems and other CPEs.
Reusability	Packaging and logistics	System for leasing of packaging by cooperation between ICT infrastructure goods supplier, packaging supplier, and customer.
Reusability	Reuse parts and resources	Networks reusing copper lines for data transport.
Reusability	Testing before dismantling	By testing the whole ICT infrastructure good instead of direct dismantling, substantial improvement of reuse rate could be achieved (see annex E).
Reusability, Refurbishability	Guidelines at ICT operators	ICT operators are adopting certain guidelines oriented towards higher reusability of suppliers goods, accessories and packaging materials. This includes testing, refurbishment and finally reuse.

Aspect or area	Example	Comment
Recyclability	Automatized recycling processes for larger ICT goods	Highly automatized recycling processes (at recycling site) increase the recycling potential without demand for high removability.
Recyclability	Reduce number of materials	Same kind of plastics better than many different types
Reduce/avoid	Packaging design	Appropriately-sized packaging.
Reduce/avoid	Reduction of materials for improved RE	Reduction of mass results in less raw material, storage space and transport capacity needed.
Reduce/avoid	Dematerialization/Virtualization of set-top-box	Hard disc removed, storage in the cloud, smaller space and less energy used at the customer premises.

10 Reporting

So far no reporting formats for CE aspects have been identified for ICT infrastructure goods.

11 Insights and conclusions

Several useful aspects, parameters, indicators and metrics have been proposed in literature and are studied here from an ICT infrastructure goods perspective. The present document reveals that the current understanding of CE aspects, parameters, indicators and metrics is still a bit scattered.

However, it is clear that the CE quantification cannot be standardized for ICT infrastructure goods through one single aspect (e.g. recyclability) but should include several aspects, parameters, indicators and metrics. Carefully selected aspects, parameters, indicators and metrics together can give better estimation of the CE of a good during its full lifetime. Different perspectives should be considered like mass, environmental impact, and economical value.

12 Suggestions for future standardization activities

When needed, suitable aspects, parameters, indicators and metrics should be selected for ICT infrastructure goods. It is likely that future standardization of CE will involve both generic and ICT specific activities. For generic activities, cooperation between different SDOs is an option.

Annex A: Observations regarding CE

A.0 Introduction

The present annex collects examples and observations from literature regarding CE.

A.1 Recycling & e-waste

Liebmann (2015) tried to build a data set for EoLT of ICT infrastructure goods to be used as input for LCA studies. Due to the lack of homogeneous data, it was not possible to come up with a solid model. However, a best effort estimate proposes a global end-of-life treatment scenario for e-waste as follows:

- 19 % is recycled under formal conditions;
- 64 % is recycled using informal methods;and
- the remaining 17 % is discarded in landfills [i.41].

Dretsch (2015) argued that by 2017 Africa might generate more e-waste than EU [i.42].

Cheung et al. (2015) found that B2B and B2C companies claimed that the EOL stage accounts for below 7 % of the total economic life cycle cost of their goods [i.33].

Within the ICT sector, recyclability has been reported for laptops [i.43] and [i.38]. The variation is large for laptops > 96 % [i.43] and 36,8 % for 15" LCD Laptop Computers [i.38]. The reasons for this variation are not clear and could be caused by different modelling approaches as well as differences in design of the good. The above difference could be explained by that O'Conell et al. [i.43] used a pure mass-based approach whereas Mangold might have used a combined mass-, value- and design-based approach [i.38]. This illustrates the need for carefully and unambiguously defined calculation methods.

One example of an estimation of the recycling potential of critical metals was presented in 2016 [i.44].

A.2 Recycled content example for metals

Here follow an example about the difficulties of estimating the average for global RC, in this case for steel. According to World Steel Association, the global raw primary steel production in 2011 was around 1,1 billion tonnes and 109 million tonnes ferrous scrap were consumed, i.e. recycled content according to [i.26] = {109 / (109 + 1 100)} = 9 % [i.45]. Recently, World Steel Association [i.46] reported that in 2014 the EU produced 169 301 thousand tonnes of crude steel and imported 31 926 thousand tonnes steel scrap, i.e. recycled content 18,8 %. Globally, 95 283 thousand tonnes of steel scrap were imported and 1 670 145 thousand tonnes crude steel were produced, i.e. recycled content 5,7 %. Actually, these values do not represent the global use of ferrous scrap. The values only refer to the imported/exported amounts and therefore exclude the internal use of recycled steel in each country. The crude steel production from scrap in 2013 was 452 Mt on a total production of crude steel equal to 1 186 Mt [i.46].

The correct estimation for global RC = 30 % for steel can be derived considering the steel production by process [i.45] and [i.46]. In 2013, 72 % of the steel was produced in a basic oxygen furnace; 27,5 % in an electric arc furnace while the remaining 0,5 % in an open hearth furnace. The basic oxygen furnace and the open hearth furnace produce primary steel (from iron ore) while the electric arc furnace produces secondary steel from scrap. Consequently, it is necessary to consider which process can be used for secondary production.

A.3 Design process

IEC (2009) wrote a technical report on Environmentally Conscious Design (ECD) IEC 62430 [i.47]. Still, the integration of eco-design into development processes for goods is scattered. In the IEC report, the manufacturers are instead encouraged to show how they have considered eco-design [i.47].

Researchers are interested in how to integrate CE metrics into the product development process. One proposed method is based on eco-metrics and LCA [i.46]. Several of the eco-metrics are or could be CE related depending on the circumstances. A number of LCA tools exist which support the LCA integration in eco-design [i.48]. Such tools could likely to a certain degree be used for eco-design of ICT infrastructure goods too.

Annex B: Additional examples of aspects, parameters, indicators and metrics

B.0 Introduction

The present annex collects additional examples of aspects, parameters, indicators and metrics proposed in literature. The terminology is in accordance with the source reference and has not been harmonized with the present document.

NOTE: The aspects, parameters, indicators and metrics listed in this appendix are further examples which seem less relevant for ICT infrastructure goods.

B.1 Resource productivity

A number of generalized indicators for resource productivity (RP) have been proposed in literature as shown in table B.1. These examples only give limited guidance for ICT infrastructure goods CE evaluation.

Table B.1: RP indicators

Indicator	Reference	Comment
Service Output per material input	[i.49]	Service level
GDP per domestic material consumption	[i.4]	National level
GDP per metric ton material usage	[i.50]	Global level
GDP per Btu energy	[i.50]	Global level
GDP per m^3 water use	[i.50]	Global level
GDP per Raw Material Consumption	[i.51]	National level

B.2 Electronics Disposal Efficiency

The Green Grid® proposed to measure E-waste effectiveness using the Electronics Disposal Efficiency (EDE) metric [i.52]. It was defined as the share of mass of responsibly disposed e-waste of total mass disposed e-waste. The 100 % mark is the best practice where all old equipment for disposal is sent to a certified vendor for disposal to comply with electronic recycling standards. Responsibly disposed e-waste considers recycling and reuse as well.

B.3 Material Reutilization

One author proposed that one of the most important indices for the Cradle-to-cradle CM (C2C) method is Material Reutilization (MR) [i.53]. The MR score is used by a voluntary C2C system [i.54]. MR considers fractions of recyclable, renewable and compostable materials [i.54]. The larger the percentage of a good and/or its parts that remain in a technical and/or biological metabolism, the better the score for MR.

B.4 Material Circularity Indicator

A Material Circularity Indicator (MCI) has been proposed [i.55] to [i.58] according to equation (B.1) from [i.57]. Equation (B.1) is one example from one source and is not widely supported by the scientific community. The equation does not provide a transparent and easily understandable or comparable outcome.

$$MCI_P = 1 - \frac{V + W}{2M + \frac{W_F - W_c}{2}} \times F(X) \qquad \text{(B.1)}$$

where:

MCI_P =	Material Circularity Indicator for a good
V =	fraction of feedstock from virgin sources
W =	unrecoverable waste calculated from the waste going to landfill
M =	mass of good
W_F =	waste generated to produce any recycled content used as feedstock
W_C =	average of waste generated in the recycling process
$F(X)$ =	how the lifespan and intensity of the good compares with the industry average

B.5 RRR benefit rates

Reusability Benefit Rate (RBUR) and Recoverability Benefit Rate (RBVR) [i.23] are examples of environmental indicators which probably will be difficult to measure and implement for ICT infrastructure goods due to their complexity. These indicators are not widely used.

B.6 Value-based circularity indicator for recycled content

One paper presented a Value-based Circularity Indicator to keep track of the value of recycled contents [i.59].

It defined Circularity as the value of recycled materials divided by the value of total materials. A fully circular good gets a value of 1 whereas a fully linear good gets a value of 0 [i.59]. Looking at the definition it is clear that the Circularity indicator is more narrow than CE and seems to be limited to the recycling area.

The paper also argued that generally the Circularity in contrast to RE has not been improved historically, and it suffers from lack of agreed definitions. However it claims that the degree of circularity should be measured [i.59].

B.7 Reusability

Larsen et al. [i.14] has proposed that the best (most relevant) criteria for reusability in order to accept reuse of WEEE is absence of hazardous substances; absence of CFC and HCFC gases; and energy requirements in the use phase.

B.8 Company sustainability assessment model using CE indicators

Global e-Sustainability Initiative (GeSI) defined criteria for CE on company level in a Sustainability Assessment Standard Framework (SASF) [i.60]. SASF CE related criteria help companies to evaluate whether their whole good and service delivery is going in the right directions as far as resource conservation and many other sustainability areas are considered. Examples of criteria types are longevity of good, recyclability and waste management.

Annex C: Use of LCA in the context of CE

The need has been raised for concepts or eco-design tools to be combined with LCA to answer the question of how to strategize and take actions based on LCA results [i.61] and [i.62].

LCA studies show that recycling come with a good potential. Van Eygen et al. (2016) used LCA and concluded that recycling of desktops and laptops in Belgium saves between 80 % and 87 % of the natural resources compared to landfill [i.63]. Although these numbers only represent the conditions of the specific study, LCA would probably show recycling advantages also for ICT infrastructure goods.

Baxter et al. (2016) concluded for recycling of various types of WEEE in Norway that the net environmental benefit from recovering materials and energy exceeds the negative consequences of irresponsible disposal [i.64]. Similar conclusions were drawn before by Huysman et al. (2015) [i.7].

When using LCA for assessing the environmental impact of remanufacturing, several approaches have been proposed [i.65] and [i.66]. These approaches can take into account one or more life cycles or be limited in scope to include one or more unit processes such as manufacturing vs. remanufacturing and recycling.

A study by Nakatani (2014) concludes in the context of LCIs of open-loop recycling that in market-based consequential LCA the environmental consequences of recycling are largely dependent on the estimation of price elasticity which in turn is challenging to estimate correctly [i.67].

Annex D: Equation examples

D.1 Cost of refurbishment

One approach for calculating the cost of refurbishment is in accordance with equation (D.1) [i.68]:

$$C_{refurbish} = \sum_{i=1}^{k} \left\{ C_{good} \times e^{-\lambda t} + C_{failure} \times \left(1 - e^{-\lambda t}\right) \right\} + f \times L \times \left(T_d + T_a\right) \qquad \text{(D.1)}$$

where:

$C_{refurbish}$ = refurbishment cost

C_{good} = cost of reconditioning a used part when it is recoverable

$C_{failure}$ = cost of reconditioning a used part when it has failed

k = number of target Parts

λ = degradation rate, failure/hour [i.71]

t = service time of a product, hours

f = disassembly factor, number of disassemblies to disassemble/total number of assemblies

L = labour rate, e.g. euro/hour

T_d = time to completely disassemble a product

T_a = time to completely assemble a product

D.2 Cost of remanufacturing

One approach for calculating the cost of remanufacturing is in accordance with equation (D.2) [i.33]:

$$C_{rm} = ((T_d + T_a)) \times L \times f + \left(P_f \times C_f\right) + \left(\left(P_{pd} + P_f \times P_{pe} - P_{pd} \times P_f \times P_{pe}\right) \times C_p\right) \qquad \text{(D.2)}$$

where:

C_{rm} = remanufacturing cost

C_p = cost of part failure

C_f = cost of fastener failure

P_f = probability of fastener failure in disassembly and assembly

P_{pd} = probability of part failure in disassembly and assembly

P_{pe} = probability of part failure in fastener-method extraction

Annex E: Reuse example

An example of a procedure for returned servers is shown in figure E.1. In the past, the whole ICT infrastructure good was first disassembled and sub-parts such as hard discs could only be re-used separately. This method lead to a relatively high share of scrap going to recycling instead of reuse. When testing of the whole ICT infrastructure good was introduced as an initial step, a higher share of reuse was experienced.

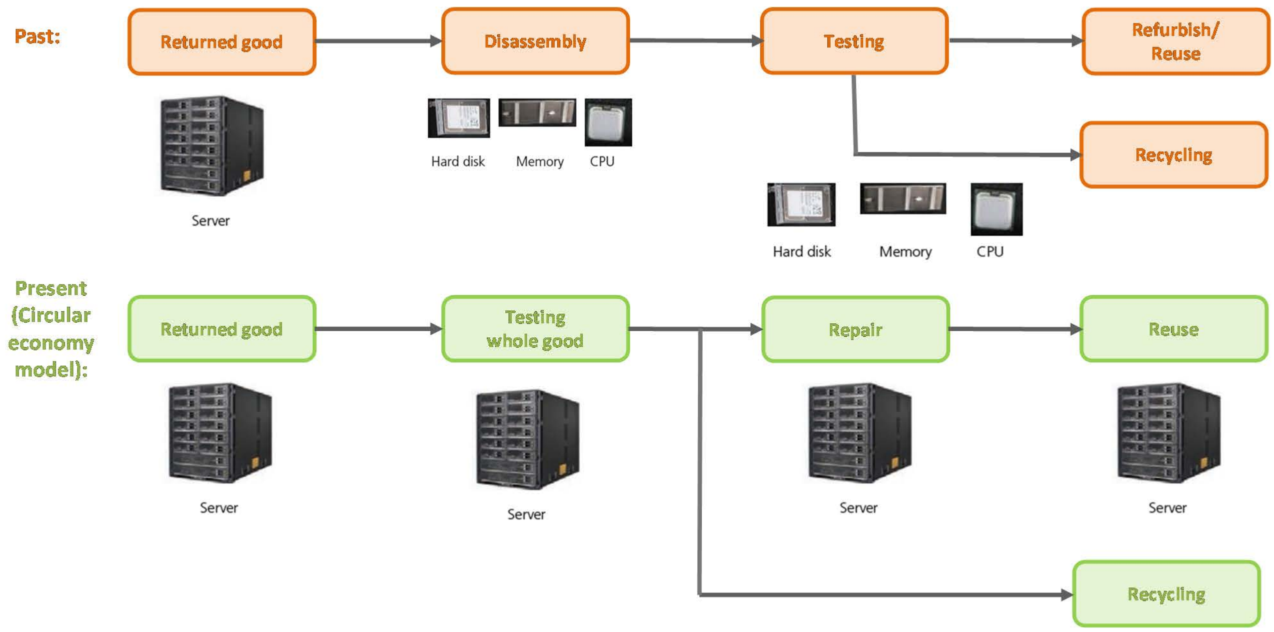


Figure E.1: Example of a reuse/refurbishment of servers (modified from [i.69])

History

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