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TECHNICAL SPECIFICATION

colour inside

Guidance on material circulation considerations in environmentally conscious design

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Guidance on material circulation considerations in environmentally conscious design

INTERNATIONAL
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COMMISSION

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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GUIDANCE ON MATERIAL CIRCULATION CONSIDERATIONS IN ENVIRONMENTALLY CONSCIOUS DESIGN

FOREWORD

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The text of this Technical Specification is based on the following documents:

Draft	Report on voting
111/759/DTS	111/772/RVDTS

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Specification is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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INTRODUCTION

The circular economy can be described as a systemic approach to the design of processes, products (including services) and business models, that tackles global challenges like climate change, resource depletion, biodiversity loss, waste, and pollution. It is based on the principles driven by design: eliminate waste and pollution, decreasing the use of resources, circulate products and materials (at their highest value), and regenerate nature. As such it focuses on managing resources more effectively and increasingly closing material flows. Changing from the traditional linear economy to a circular economy represents a paradigm shift in the way that society and natural capital are interrelated.

Different geographies have already introduced or are expected to introduce soon, the concept of circular economy into their legal systems. Standards can assist the effective adoption of legislation. It is important that the international community speed up addressing this topic, for example, CEN and CENELEC are already doing this in Europe on the assessment of the different aspects of material efficiency such as durability, ability to repair, reuse and upgrade, recyclability and recoverability, proportion of reused components, proportion of recycled content, and the ability of a product to be remanufactured.

Current IEC standards deal with functional approaches and dependability topics. Both can support material circularity optimization during the design phase across the different life cycle stages. Material circularity for a product can be supported by a systematic design approach taking all life stages of the product into consideration.

The design for material circularity means a design contributing to circular economy. This covers several interrelated efficiencies such as material efficiency, energy efficiency, and environmental footprint efficiency. Safety and health as functional priorities are covered by other standards.

Whereas ISO 14009 provides guidance and requirements for management systems to support incorporating material circulation in design and development, this document focuses on integrating the material circularity aspects in the design and development processes.

The design for material circularity supports innovation and technology managers, product designers and engineers by analysing the consequences of their ideas and decisions to the different life cycle stages of a product. Facilitating circulation of materials by closing the flow will assist organizations in fulfilling the objectives of circular economy, which is increasingly becoming an important objective in many parts of the world.

Environmentally conscious design (ECD) is the overarching concept applying life cycle thinking (LCT), which includes material circularity. This document, focusing on material circularity, aims at minimizing material losses and closing the material flow of the product's entire life.

This document is intended to become a horizontal document in a future edition, for example, if it becomes an International Standard.

GUIDANCE ON MATERIAL CIRCULATION CONSIDERATIONS IN ENVIRONMENTALLY CONSCIOUS DESIGN

1 Scope

This document describes principles and provides guidance on how to embed material circularity aspects into the design and development of products.

This includes making efficient use of materials and closing material flows in design and production, extending the lifetime of products through increased durability and enabling parts and materials to be reused or recycled at end-of-life.

- Closing the material flows includes the use of recycled content and reused parts.
- Durability extensions include such measures as to improve reliability and maintenance, enable and facilitate repair, provide updates and upgrades, refurbish and reuse.
- Improvements in material recyclability, parts reuse, and remanufacturing are possible through measures such as design for disassembly, separability of materials, choice of materials, traceability of materials, and durability of parts.

This document builds on the jointly published (ISO and IEC) document, IEC 62430:2019 for requirements for environmentally conscious design (ECD) processes, and it supplements ECD by adding more specific guidance on the aspects of material circularity and material efficiency.

This document only deals with material circularity of products. Economic, social and energy aspects are excluded from the scope of this document.

This document is applicable to all electrotechnical products including goods and services.

2 Normative references

There are no normative references in this document.

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- IEC Electropedia: available at https://www.electropedia.org/
- ISO Online browsing platform: available at https://www.iso.org/obp

3.1.1
circular economy
economic system that uses a systemic approach to the sustainable development by optimizing the use of natural resources, aiming to eliminate losses and emissions, circulate products and materials at their highest value for as long as possible

Note 1 to entry: Circular economy is driven by design aiming at enhancing value by increasing the satisfaction of the needs and expectations of users, in relation to the resources used.

Note 2 to entry: Circular economy supports natural systems regeneration.

Note 3 to entry: A concept diagram of a circular economy is given in Figure 1.

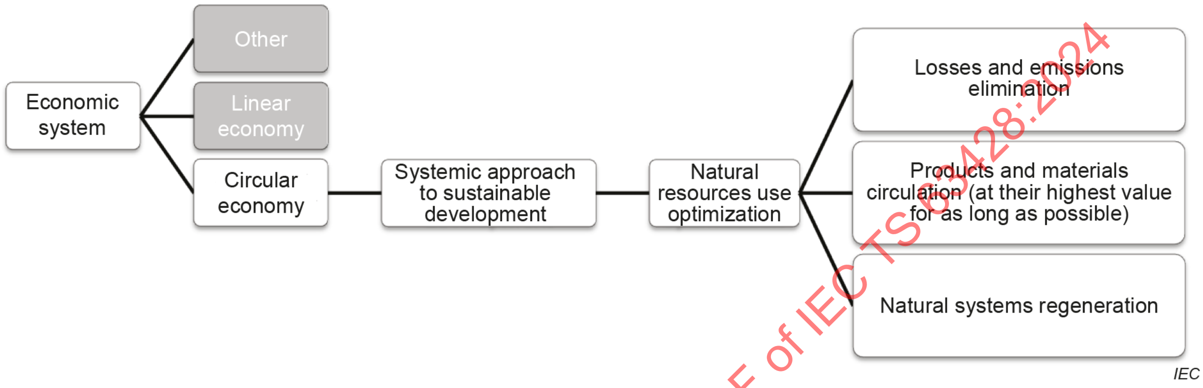

Figure 1 – Concept diagram of a circular economy

Note 4 to entry: This terminological entry is based on IEC 60050-193:—.

3.1.2
corrective maintenance
maintenance carried out after fault detection to effect restoration

Note 1 to entry: Corrective maintenance of software invariably involves some modification.

[SOURCE: IEC 60050-192:2015, 192-06-06]

3.1.3
critical raw material
CRM
materials which, according to a defined classification methodology, are economically important, and have a high risk associated with their supply

[SOURCE: EN 45558:2019, 3.1.1, modified – The note has been deleted.]

3.1.4
durability
<of a part or a product> ability to function as required, under specified conditions of use, maintenance and repair, until the end-of-life is reached

Note 1 to entry: The criteria for transition from non-functional state to end-of-life should be specified. The criteria is based on predictable aspects (e.g. technical aspects) so that the durability can be estimated.

Note 2 to entry: Durability can be expressed in units appropriate to the part or product concerned, e.g. calendar time, operating cycles, distance run, etc.

Note 3 to entry: This terminological entry is based on IEC 60050-193:—.

3.1.5
environmentally conscious design
ECD
systematic approach which considers environmental aspects in the design and development with the aim to reduce adverse environmental impacts throughout the life cycle of a product

Note 1 to entry: Other terminology used worldwide with the same meaning includes ecodesign, design for environment (DFE), green design and environmentally sustainable design.

[SOURCE: IEC 62430:2019, 3.1.1]

3.1.6
functional analysis
systematic investigation of the functions of a real or planned system

[SOURCE: ISO/IEC/IEEE 24765:2017, 3.1685, modified – The second definition was deleted.]

3.1.7
maintenance
process to retain a product, or restore it to, a state in which it can perform as intended

[SOURCE: IEC 60050-192:2015, 192-06-01, modified –"combination of all technical and management actions intended" has been replaced with "process", "item" has been replaced with "product", "required" has been replaced with "intended", and the Note to entry has been deleted.]

3.1.8
material
(physical) matter composed by one or more substances

[SOURCE: IEC/ISO 82474-1:—, 3.1.7]

3.1.9
material circularity
capability for product, parts, and the materials they are composed of to be kept in value retention loops

Note 1 to entry: Value retention loops refer to the capability of products and parts to have their life maintained or extended through multiple uses and materials to be recovered at end-of-life.

Note 2 to entry: This terminological entry is based on IEC 60050-193:—.

3.1.10
material efficiency
degree to which a system or product performs its designated functions with effective use of materials

Note 1 to entry: An effective use of materials can be achieved through balancing material use, product durability, and recovery.

3.1.11
product
good, service or combination hereof

Note 1 to entry: This terminological entry is based on IEC 60050-193:—.

3.1.12
refurbishing
reconditioning
industrial process to return a used product or part to its original or predetermined design

Note 1 to entry: Original design include form, functionality, performance and safety aspects.

Note 2 to entry: Upgrade could take place simultaneously with refurbishment. The refurbished product remains within the limits of the original specifications.

Note 3 to entry: The identity of the product or part shall be maintained (e.g. serial or type number).

Note 4 to entry: This terminological entry is based on IEC 60050-193:—.

3.1.13
reliability
<of a product> ability to perform as required, without failure, for a given time interval, under given conditions

Note 1 to entry: The time interval duration can be expressed in units appropriate to the item concerned, e.g. calendar time, operating cycles, distance run, etc., and the units should always be clearly stated.

Note 2 to entry: Given conditions include aspects that affect reliability, such as: mode of operation, stress levels, environmental conditions, and maintenance.

[SOURCE: IEC 60050-192:2015, 192-01-24, modified – The domain, "<of an item>" has been replaced with "<of a product>" and Note 3 to entry has been deleted.]

3.1.14
remanufacturing
industrial process to create a product by combining different parts from used products and including, where necessary, new parts

Note 1 to entry: Remanufacturing also occurs when at least one change is made which influences the safety or original performance of an existing product.

Note 2 to entry: The product shall be given a new identity (for example serial or type number) .

Note 3 to entry: This terminological entry is based on IEC 60050-193:—.

3.1.15
repair
direct action taken to effect restoration

Note 1 to entry: Repair includes fault localization (IEV 192-06-19), fault diagnosis (IEV 192-06-20), fault correction (IEV 192-06-21), and function checkout (IEV 192-06-22).

[SOURCE: IEC 60050-192:2015, 192-06-14]

3.1.16
reuse
operation by which a product or part having reached the end-of-use is used again

Note 1 to entry: Reused for another purpose is called repurpose.

Note 2 to entry: This terminological entry is based on IEC 60050-193:—.

3.1.17
update
maintenance of software

Note 1 to entry: Update of software includes fixes and security patches.

Note 2 to entry: Software includes applications, operation systems or firmware.

Note 3 to entry: This terminological entry is based on IEC 60050-193:—.

3.1.18
upgrade
process to enhance the functionality, aesthetics, or performance of a product

Note 1 to entry: An upgrade to a product can involve changes to its software, firmware or hardware (e.g. adding memory).

Note 2 to entry: This terminological entry is based on IEC 60050-193:—.

3.2 Abbreviated terms

CRM critical raw materials

ECD environmental conscious design

LCA life cycle assessment

EoL end-of-life

4 Principles of material circularity

4.1 Relationship between material circularity and environmentally conscious design

Circular economy approaches focus on the efficiency of the material flow with the aim of maintaining a circular flow of materials, by retaining value and reducing use of raw materials and eliminating waste. This concept promotes resource efficiency through closed-loop material flows throughout the product life cycle.

Environmentally conscious design (ECD), on the other hand, is a systematic approach aimed at minimizing the adverse environmental impacts of a product across its whole life cycle. ECD considers all the environmental impacts of a product from the earliest stage of design. This avoids uncoordinated product planning, for example decreasing use of materials in a product can lead to a decrease of durability, which on balance can have a negative impact on the environment. ECD systematically addresses the aspects of material efficiency and material circularity, with the focus on life cycle impacts.

Both concepts contribute to a sustainable development and promotes innovation and cross sector collaboration. Also, both concepts require a systematic approach to the design and development process to meet the targets of reduced environmental impact and increased material circularity. However, integration of material efficiency with ECD is necessary to guarantee that environmental impacts and trade-offs are carefully considered beyond just the promotion of the material efficiency only.

4.2 Material circularity principles

The linear "take-make-use-dispose" economic model is reaching its limits, and initiatives to develop alternative economic models are emerging. Circular economy promises an industrial system that is restorative and regenerative by design. As part of the circular economy, the material efficiency can be described through the three principles of narrowing, slowing down, and closing resource flows in order to increase the efficiency on the use of materials and other resources:

a) Narrowing resource flows: aimed at using fewer materials or other resources per product. It is an approach aiming to optimize use of materials associated with the product and production processes by using less materials to deliver the same function to the user or by applying strategies such as intensifying the use of products (e.g. by sharing products) or replacing products with services.

b) Slowing resource flows: through the design of long-life goods and product-life extension (e.g. services to extend a product's life, for instance through maintenance, repair, and refurbishing), the useful life of products is extended, resulting in a slowdown of the flow of materials by reducing the need to replace products.

c) Closing resource flows: through the use of recycled, reused, and renewable content, the flow between post-use and production is closed, resulting in a circular flow of materials. Remanufacturing and repurposing are common strategies to close the material flows by creating new products from already used ones. The durability (longevity) of the parts is key. Recycling is a common strategy involving actual "closure" of the material flows. It asks for strategies that contribute to making products and parts more easily recyclable. The selection of material that can be easily separated and the recycling technology are keys to guarantee the quality of recycled content, so that the material can be used for the same or similar purpose without being downgraded.

Although material circularity encompasses mostly slowing or closing the material flows, narrowing the flow of materials is also an important subset of material efficiency; therefore, this document focuses on strategies that contribute to the overall optimization (i.e. reduction) of use of additional materials to the circular flows.

Another guiding principle is the material efficiency hierarchy as shown in Figure 2, which can be used for prioritization when considering different strategies for material efficiency, in particular during product design. Here choices can be made on strategies when designing, using and discarding both consumer and professional products. Highest in this hierarchy are strategies associated with longer product life while using less resources: design products that use less material and are able to inherently last longer before they fail. The objective of design products should be to use less materials based on virgin materials, but incorporate recycled materials, to contribute to the circular economy and lower carbon footprint.

Figure 2 – Material efficiency hierarchy

Next in the hierarchy are design strategies that enable the reuse of products and extend the product life with repair, update, upgrade, and refurbishment. Reuse and repair are preferred over refurbishing. This is because the lower you go in this hierarchy, the more value can be lost or, in other words, the more resources are necessary to accomplish the intended functionality. For example, refurbishing is typically a more complex process than repair as it can require extra resources for its execution.

Lowest in the material efficiency hierarchy that still supports circularity is recycling. Although for many people, circular economy – closing the materials flows – equals recycling, it most often results in significant losses in value compared to the other material efficiency strategies. Recycling most often involves loss of material, lower quality material (downcycling) and can be energy intensive. Recycling is, therefore, to be applied only when all the other strategies are no longer possible. As most products eventually will reach their end-of-life, recyclability of products towards the pure materials is to always be considered during product design. The focus is on materials and design choices that allow for recycling at the highest possible quality and value.

If after their use, products are incinerated or discarded into landfill, there is a significant loss of value associated with that product. As such, we can attribute very low efficiency in the use of such product and its materials are literally "lost" for the economy. Such strategies belong to a linear economy and, where possible, should be avoided. Therefore, the last preferred strategy is energy recovery from the materials that cannot be otherwise recovered. Landfill should be avoided where possible.

It has to be noted that the hierarchy shown in Figure 2 should be considered in the context of the product type and the product sector, and should be put in perspective with other aspects that are also important for the organization. For example, the reuse of products containing certain (hazardous) substances can have low priority for an organization due to safety or compliance issues. Likewise, consuming less material to design a product can impact its durability. Therefore, it is necessary for organizations to consider the different strategies of this figure and analyse the trade-offs with other aspects that are relevant when defining their own material circularity strategy.

The material efficiency hierarchy of Figure 2 can be considered during all the life cycle stages of the product. This can be done by different approaches to improving durability (extended lifetimes) such as increasing reliability, and designing for maintenance, reuse, repair, upgrade, refurbishment, and ultimately recycling.

4.3 Functional analysis considerations on material circularity

When applying material circularity considerations as part of ECD, circularity strategies will be an integral part of the design process, business management and into the value chain management of an organization. Circularity is to be considered like any other design aspects, such as physical and economic requirements, aesthetics, usefulness, identity and meaning. In this case, the functional analysis of the product will include materials efficiency and material circularity considerations, meaning that material circularity is a functional aspect of the product to consider together with other functional aspects. Integrating material circularity in the functional analysis can successfully contribute to enhancing the value of products and as such support mitigating design challenges. Three indicative examples are given as the following:

- Aiming for increased recyclability can increase the value of the product at end-of-life and it can involve simplification of the product architecture and a reduction in use of materials, which in turn will contribute to lowering costs.
- Designing products prepared for predictive maintenance by adding smart controls and reducing downtime of the product and the total cost of ownership.
- Designing products for easy repair of the parts most likely to fail can increase the lifetime of the product and thereby also make the product more attractive as a long-time investment.

In practice, there will often be complexities when balancing the different functional requirements against each other, which can require to be explored further in the analysis.

With the focus on increasing the material circularity of the product at end-of-life and introducing material circularity considerations as part of ECD, the designers will have to ask questions that help them improve the environmental performance of such a design. Typical questions that can be asked as part of the functional analysis are:

- How to increase the recyclability rate of the product?
- How to introduce and validate the use of materials (including recycled content) that are easily separated from each other at the end-of-life to improve reuse of parts and recyclability?
- How to use durable and robust parts and materials to increase overall durability of the product and to support reuse, remanufacturing and repurposing?
- How to avoid or reduce the combination of material properties reducing the need and the number of additives in a material, for example reducing the use of substances such as brominated flame retardants, anti-dripping agents, or plasticizers that can reduce the recyclability of the materials at end-of-life (EoL)?

  NOTE 1 Examples of main classifications of material properties are: mechanical, thermal, electrical, environmental, porosity, workability, fire reaction.

  NOTE 2 Sometimes it is not possible to reduce such additives, in particular if there is a negative influence on the safety or performance of the product that cannot be, otherwise, prevented.
- How to design the product in a way that supports easy cleaning and maintenance with easy access to exposed as well as inner parts and choosing materials that minimize the need for environmental harmful cleaning agents?
- How to design products to support easy repair including easy disassembly and easy access to those parts most likely to be changed and how to apply the use of standard parts and modular design to facilitate availability of spare parts?
- How to carry out simple life cycle thinking at the concept phase of the product design – avoiding the situation whereby improvements in one area are undone by bigger losses in another area?
- How to obtain the material declaration (extent of hazardous materials, percentage of flame retardant, percentage of CRM, etc.)?
- How to provide information and documentation to the users that can support maintenance, repair, upgrade, reuse, remanufacture, and recycling actions?

An important outcome of the functional analysis is, therefore, a product design specification which will encompass the circularity design strategies, their respective contributions and impacts along the life cycle phases, and the respective trade-offs, if any, for the minimization of the environmental footprint.

5 Guidance for integrating material circularity aspects during design and development

5.1 General

When applying material circularity considerations during the ECD process, optimization of the product design in relation to the various life cycle phases should be considered. Each of those offers opportunities or pose risks for material circularity, which can be anticipated and planned for in the design and development process.

Table 1 presents different life-cycle phases for consideration at design and development and the corresponding recommendations applied to materials, parts, and products, aiming at realizing material circularity when conducting ECD. The actions should be in accordance with the design strategies and the material efficiency hierarchy in Clause 4.

Designers should be aware that some life-cycle phases can affect material circularity more than others. Therefore, life cycle assessment (LCA), in addition to other qualitative criteria (i.e. possibility to extend the product life cycle), should be applied as part of the ECD process to support that chosen solutions have the lowest possible environmental impact.

Table 1 – Material circularity considerations during ECD process

Life-cycle phases for consideration at design	Material circularity considerations	Recommendations
Value proposition creation	• Value creation propositions that include material circularity	• Identify stakeholders' requirements, expectations, and other aspects that can take material circularity into account, e.g. resource availability, including use of recycled, reused, and renewable content • Consider value propositions to meet identified requirements
Material selection	• Use less materials to achieve same functionality • Support extended durability • Use renewable materials coming from sustainably managed renewable sources • Reduce the use of critical raw materials • Use recycled materials (recycled material content) • Use recyclable materials, where recycling infrastructure is commonly available in the region where the product will be sold • Design for material recovery at EoL • Reuse already used parts	• Seek opportunities to reduce the amount of materials used, e.g. apply dematerialization • Select materials that contribute to the extension of the lifetime of the product • Replace virgin materials by reused parts or recycled material content • Decrease the number of different types of materials, and so improve recyclability of the product • Choose materials with the lowest environmental impact • Be aware of use of hazardous substances and CRMs; check for possible reductions or alternatives • Avoid hazardous substances • Avoid, when possible, laminated and composite materials as it is more difficult for them to be recycled
Manufacture	• Avoid scraps or rejects through effective product designs and manufacturing processes • Reuse or recycle, internally or externally, industrial scrap	• Rethink product design and manufacturing processes towards zero waste • Segregation or separation of streams of discarded materials for either internal or external use • Create business models for use of byproducts
Distribution and installation	• Optimize use of packaging material • Use recycled packaging material • Avoid product durability from being affected due to distribution and storage conditions	• Design to allow multiple use of packaging • Design packaging with less use of materials, e.g. reduce packaging volume, increase recycled or renewable content in packaging, or both, use mono packaging material, use recyclable packaging, consider possibility for reusable packaging and reverse logistics • Identify the environmental conditions in which the product will be transported and stored and design for robust transportation and storage

Life-cycle phases for consideration at design	Material circularity considerations	Recommendations
Use of product (Maintenance, repair, upgrade, reuse and refurbishing)	• Improve product durability and apply lifetime extension strategies: – Improve reliability – Improve ability to be dis- and re-assembled – Improve ability to be maintained or repaired, or both – Improve ability to be updated or upgraded – Design for reusability and ability to be refurbished – Design for lower cost of reuse • Optimize use of consumables	• Optimize product reliability • Improve the ability of a part or product to be maintained, repaired or refurbished by including designs for easy dis- and re-assembly • Match lifetime of parts with lifetime of product to the extent possible • Build maintenance or repair services • Anticipate potential updates or upgrades • Optimize use of consumables by e.g. developing technologies that consume less materials • Consider need for de-installation at a later stage (e.g. due to repair)
End-of-life (Remanufacture, repurpose, recycling, recovery and disposal)	• Improve ability to be remanufactured • Improve ability to recover parts for reuse • Improve recyclability	• Design product for easy replacement of the most vulnerable parts • Support remanufacturing through modular designs and use of standardized and compatible parts • Identify parts best suited for reuse and improve lifetime and reusability of parts • Improve ability for materials to be recovered at the end-of-life by e.g. promoting separability of materials, avoiding coatings and composite materials that reduce recyclability • Favour use of materials with existing recycling stream or that can be recycled without loss of value (downcycling) • Avoid materials that have an adverse impact on recycling, in particular hazardous substances • Avoid glue and favour latches, snaps, clips, bolts and screws as they can be used multiple times • Identify and consider use of non-recyclable contents or difficult supplies (e.g. CRMs)

5.2 Value proposition creation phase

At the value proposition of the product, stakeholders' requirements and expectations as well as market opportunities should be identified. This can include regulatory requirements (e.g. on recycled content), criteria from ecolabels or environmental schemes, customer requirements, market opportunities, and organization's internal sustainability and circularity objectives.

Consider which value proposition(s) will meet the identified requirements, for example durable products having a long lifetime or a highly recyclable product that will secure resource availability. The value proposition on material circularity will guide further considerations in the design and development process.

5.3 Material selection phase

The selection of materials can be done through a functional analysis describing the objectives in terms of material circularities.

It is important to apply LCA on the use of materials and to choose materials with the lowest environmental impacts considering the whole life cycle of the product.

When selecting materials, different considerations should be made:

- What are the opportunities to use less materials – either by a more lightweight design, or by using stronger materials that can fulfil the same function with less material use?
- Select materials that contribute to the extension of lifetime of the product, i.e. materials that do not deteriorate under the expected use case conditions, or materials that support the strength of the construction and the parts (thus avoiding breaks and fractures), or materials that enable easy maintenance of the product.
- Use of renewable material content can enable a regenerative flow, and so decrease the impact on the planet's resources. When mixed with non-renewable resources, these renewable materials can, however, prevent recycling and so have a negative effect on the environment. Taking into account the LCA of the production and, in particular, the disposal of these materials is necessary. Renewable materials should be allowed to return to nature, and so close the biological cycles in order to be the most effective; the use of scarce materials such as critical raw materials (CRM) should be considered very carefully at the product design. Where today certain product functions cannot be delivered without such materials, a search for reduction on the amounts or for alternatives (substitution) should take place.
- Use of recycled material in parts and products contributes to material circularity. When designing for use of recycled material content, organizations should take into account the following considerations:
  - the functional analysis should cover the properties (mechanical, electrical, thermal, chemical, environmental, etc.) and the necessary specifications and to balance the potential trade-offs if the recycled materials cannot meet the same requirements as virgin materials;
  - it is important to avoid contaminations or presence of hazardous substances that can prevent the recycled material to be used in products;
  - give preference to materials with full material composition known.
- All products will reach, sooner or later, their end-of-life (EoL). Therefore, being able to recycle their materials is key. Designing products to be recycled at EoL asks for special attention, for instance:
  - choose materials that can be easily recycled with no or minimal loss of value, taking into account existing and expected future material handling streams (such as waste management). This includes use of materials with no or limited additives, coatings, etc. as these can reduce the recyclability of the material or lead to downcycling. Such additives are commonly used to ensure certain characteristics, which are aimed at strength, flexibility, fire resistance, etc., but some of these can also reduce the recyclability of the materials considerably. In such cases, other materials with the same characteristics can be used or other design options that would reduce the need for using such materials can be considered;
  - avoid as far as possible mixed materials that cannot be separated, since this can also reduce the recyclability of the materials considerably;
  - reduce or avoid materials and substances that are hazardous or in other ways have a negative impact on the recycling of the materials;
  - limit the number of materials used so that enough quantity of each material is available for the recycling operations.

- Use of reused parts to repair or (re-)manufacture products, and so substitute the use of virgin materials, decreasing the impact on the already limited resources, is an important strategy to close the material flows.

5.4 Manufacture phase

Modification of product designs can allow for improvements of existing manufacturing processes of a product, its parts, or materials leading to the fulfilment of the aim to achieve zero waste at production. This can be achieved by either:

- effective product designs that can support avoiding scrap and rejects during manufacturing;
- effective manufacturing processes that are tweaked to limit scrap and rejects production (e.g. allow for visual or sound signals when the process is mis-performing);
- harmonizing the type of material used in similar production processes to enable utilization of materials discarded from one manufacturing process as input to manufacture new products in another process. This can be supported by making use of discarded materials as input for the manufacture of new products, which can be supported by segregation or separation of streams of discarded materials for either internal or external use;
- business models – creation of a business for by-products generated from the manufacturing process that are normally eliminated as waste to become valuable resources for other sectors (industrial symbiosis).

5.5 Distribution and installation phase

Often distribution and installation of products make use of packaging and transport material – which are often single use. A more conscious product circularity design will optimize the need, type and amount of virgin materials to produce packaging and transporting tools. For instance,

- by making packaging and transporting materials to last longer, allowing for multiple uses and considering reverse logistics for the packaging;
- by reducing the amount of material needed to produce packaging and transporting materials;
- by increasing recycled content in the packaging;
- by considering the use of recyclable materials for the packaging and, if possible, use mono packaging material to facilitate the separation for recycling.

Especially for online consumer sales, design the packaging in such a way that the product contained inside the packaging can be evaluated by the customer, and easily repackaged and returned to the retailer for re-sale, without damaging or polluting the product contained inside the packaging.

Design considerations should also be made to ensure that product durability will not be affected by distribution and installation (including transportation and storage) conditions. The product specification should identify the environmental conditions in which the product is transported and stored. This can be achieved by:

- effective logistics (local sourcing, avoiding damage of products, etc.);
- optimization of the storage conditions (e.g. ambient temperature);
- packaging and product that should have a design that is suited for transportation and robust to anticipated transportation and storage conditions.

5.6 Product use phase

5.6.1 Framework for product durability

From a material circularity perspective, the goal in optimizing designs of products for the use phase is to retain the value of a product as long as possible so that extraction of additional resources for new products is deferred.

The key consideration in assessing the useful lifetime of a product is represented by its durability. Durability takes into account all appropriate steps to maintain the product in a state where it performs as intended. This can include but is not limited to product reliability, maintenance, updates, upgrades, repair, and refurbishment.

As shown in Figure 3, the durability includes the use of the product by the initial users and reuse of the product by subsequent users, until a decision is taken to discard the product (EoL).

Figure 3 illustrates further the various states and actions that can be taken during the useful life of a product and its disposal at EoL. The functional state (normal use) is represented by the oval on the far left and EoL management is captured by the oval on the far right. The states in between represent actions that can be taken to extend the useful lifetime of the product. It is necessary for the product design to support these actions if the extended lifetime is to be realized. When a product is repurposed, it will enter a new functional state, which is different from the one of the original product. When a product is remanufactured, the product will enter a new lifetime. In the same way, parts can be reused both for a similar product but also for a different type of product.

If any, maintenance actions should be considered when assessing durability. The durability of the materials, the parts, and product can be different. To extend the lifespan, all aspects increasing the loops from the non-functional state to the functional state should be considered for the product, parts, and then materials, while ensuring the environmental footprint stays lower than that of the use of a new part or product.

NOTE The decision to maintain or repair a product can be complemented with a complete life cycle perspective (e.g. see if the energy consumption represents the greatest part of the environmental footprint of the product and therefore the decision to replace the old product with a new one with lower energy consumption can be the best option for the environment).

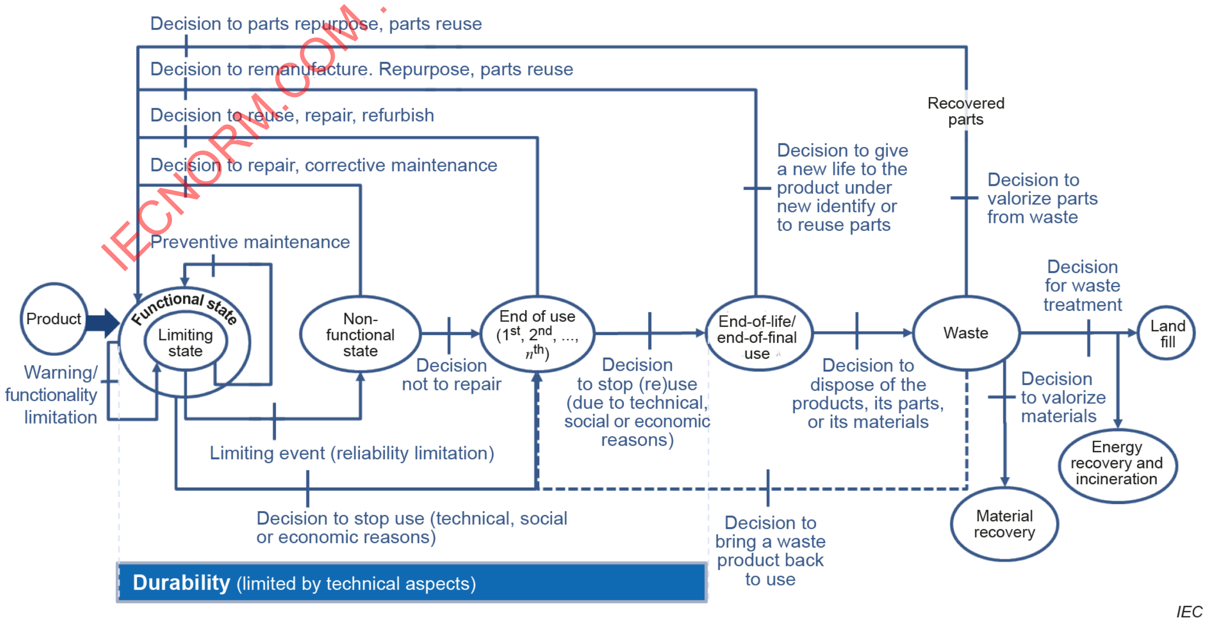

Figure 3 – Functional, non-functional and limiting states of a product

5.6.2 Product reliability

Reliability represents the assessment of a probability of duration from first use of a product or part to the first failure (and subsequent failures). Figure 3 shows that the first (and next) limiting events are expressed in terms of "reliability limitations" of the product.

The lifespan of materials and parts composing the product can be different, and so is its reliability. The product designer should, therefore, consider carrying out an assessment of the product or product group to determine the aspects which affect their reliability. This can include the identification of:

- product functionality and actual use conditions,
- choice of components and their potential failure modes,
- applicable regulatory requirements.

NOTE The components which are most likely to cause product failure at an early stage can be used as a basis for the repairability considerations (see 5.6.4).

Examples of standards that provide frameworks for reliability assessment that can be applied by the user of this document, are:

- EN 45552:2020, *General method for the assessment of the durability of energy-related products*;
- any product-specific standard relying on EN 45552:2020;
- IEC 62308:2006, *Equipment reliability – Reliability assessment methods*;
- the IEC 61960 series that describes the measurement of battery cycle life.

To summarize, reliability assessments provide a more in-depth understanding of the product helping the management of individual parts and materials through planned preventive and corrective maintenance (see Figure 3).

5.6.3 Ability of products to be dis- and re-assembled

Disassembly is the process whereby an item is taken apart in such a way that it can subsequently be reassembled and made operational. The disassembly can be used partially for circularity actions necessary before the product EoL.

The ability to disassemble and reassemble a product is important whenever it is necessary to access, remove or replace parts of a product. This is applicable for many of the design strategies to extend product lifetime, including maintenance, repair, upgrade and refurbishment, and potentially at EoL for remanufacturing or reuse of parts. For repair, it is important that parts can be cleanly removed (without damage) from the product.

The reusability and reversibility of fasteners and connectors are important. Specific aspects such as which fasteners and connectors are relevant (for example, the fasteners and connectors for repair) should be considered.

The disassembly depth is an important criterion in assessing the ability for maintenance, repair or upgrade. The deeper a part is located in the product (high disassembly depth), the more timely and costly it becomes to access that part.

If applicable, and when available, reference standards or other norms associated with assessing the disassembly characteristics of a product category should be considered. For generic information on disassembly and reassembly of a product, see EN 45554:2020.

5.6.4 Ability of products to be maintained

Although there are many types of maintenance (see the IEC 60300-3 series), it will often be known by its two main actions: monitoring the condition of a product and replacing worn-out parts, often in planned or pre-determined intervals. Appropriate maintenance can extend the lifetime of a product or part and improve environmental performance during the use phase.

Maintenance is made easier for products designed for easy disassembly and reassembly. For maintaining the functions of a product or part, execution time and part replacement availability should be determined prior to its putting on the market.

Information to users about maintenance needs will prevent decreased lifetime of the product. This can include availability of parts, or location (in the product) where maintenance is to be applied, intervals for maintenance, tools and methods, and other operational-related issues.

5.6.5 Product repairability

The product repairability is relevant to a broad range of products for which the useful lifetime of such a product can exceed the timeframe based only on its reliability. The need for a product to undergo repair depends on the likelihood of failures to occur and the ability to correct each of the potential failures.

Repair most often requires products to be designed to be disassembled and reassembled and spare parts need being available. Insight from functional and reliability or durability analysis will support designs for easy repair.

When the product failure is due to the failure of a part within the product, repair will involve identifying, removing and replacing such part. Therefore, the ability to remove and replace components or parts that are of highest risk of failure during the expected lifetime of the product (called priority parts – see EN 45554:2020) is a key contributor to the repairability of a product. The determination of a priority part is based on the failure likelihood or the need to replace or upgrade the part during the product lifetime. The results of the reliability assessment can help in identifying the priority parts. For some product categories, a standardized list of priority parts can be identified by a product group technical committee or industry association. These lists, when available, should be considered when designing a product to be easily reparable.

NOTE The identification of priority parts can also be used in assessing product upgradability.

One reference standard that is applicable to a broad range of products is EN 45554:2020, which provides useful criteria and recommendations on how to assess product repairability.

In addition to the above, the criteria relevant to product repairability that should be considered during the product design include:

- disassembly depth, disassembly time or number of disassembly steps;
- the type of fasteners and connectors that are required to be removed and replaced during the repair;
- fastener visibility and accessibility;
- tools that are required to conduct the repair;
- working environment that is required to conduct the repair;
- skills level necessary for the person executing the repair;
- availability of spare parts;
- interchangeability of parts, which facilitates removal and replacement of parts.

It should be taken into account, that different technologies or manufacturing processes can lead to products with different reliability as the different parts are likely to have each their distinct lifetime and risk of failure.

The design should also consider support-related aspects, which will determine whether users will let their products to be repaired in practice. Although they don't form the basis for the activities that can be influenced by designers, they are fundamental for the success of repair businesses. They are, for instance:

- availability of diagnosis support;
- delivery time of spare parts;
- type and availability of repair information;
- availability of repair services, particularly when repairs are complex or require a specific technical skill;
- product return options and cost.

Building service options around maintenance and repair can both contribute positively to stimulating and facilitating users to have their products repaired and so provide new business opportunities.

5.6.6 Ability of products to be updated and upgraded

A product design should anticipate potential updates and upgrades that can be necessary for the product's software or hardware, during the product's lifetime. The ability of products to be updated and upgraded represents the ability to replace software or parts that are subject to technical evolution that is faster than the lifetime of a product. The replacement parts or software can have a higher performance, and feature set or other capability.

The relevance of upgrading a product depends on whether or not it is necessary to evolve the functional capability of the product in order for the product to remain useful and desirable to the user over its potential lifetime. Product upgrade focuses often on aspects of the product that can lead to premature obsolescence of the product because it no longer meets users' needs.

Updates typically refer to (minor) modifications to the software of the product that help maintain its functionality (e.g. security software updates) whereas upgrades typically refer to enhancing the functionality, performance or capacity of a product.

An update or upgrade should not degrade or change other functionalities. Any deviation should be documented and communicated.

Parts subject to rapid technological changes or changes in use profiles over the use stage of the product should be identified as potential parts to be upgraded. When designing a part assumed to be "upgradable", criteria should be considered such as:

- typical upgrade features and frequency of upgrade,
- reasons justifying upgraded part and product,
- potential for upgrade during repair.

The need to perform a software update on a product is typically to preserve good functionality, for example maintenance and repair, or to extend its lifetime. Therefore, the ability for software updates is a criterion that should be considered when assessing the ability to maintain and repair the product.

Product designs should also consider innovative ways to upgrade the product to provide additional capability without replacing existing parts. This can provide upgradability while reducing the potential risks to impacting reliability.

Standards that can be relevant in assessing the ability to upgrade a product include EN 45554:2020.

5.6.7 Design products so that they can be reused or refurbished

The user of a product can decide to stop using the product for technical, social, or economic reasons other than the product's ability to continue functioning as expected. In Figure 3, this is represented by the arrow from the functional state (leftmost oval) to the end of use state (third oval from the left). To improve material circularity, the product and packaging should be designed to allow and appeal to additional users to reuse the product or packaging, or both.

The opportunity and ability for a product to be reused depends significantly on its durability (including reliability and ability to maintain, repair, update, upgrade and refurbish) so that the product continues to provide a useful (or upgraded) function to subsequent users.

Refurbishment (or reconditioning) is an industrial process (or combination of processes) applied during the expected service life of a product to restore a product to a condition of safety and performance according to the specification of the manufacturer. Refurbishment is likely to include activities such as repair, maintenance, replacement of worn parts, and update of software, and upgrade of hardware can take place simultaneously, all of which should be supported by the product design. The opportunity and ability for a product to be refurbished will also depend on criteria such as availability of (spare) parts and ability of dis- and re-assembly. Parts modularity and use of standardized components will increase the ability of a product to be refurbished.

Effective reverse logistics is key to enabling a supply of high-quality secondary resources to enable circular activities such as reuse and refurbishment. The design of products and packaging can support a reliable reverse supply chain by guaranteeing the quality of returned items, including traceability of individual products and components.

For products that require installation, especially large-scale products, the ability to demount the product from its installation can be particularly important.

If the product contains personal data or other personal characteristics, the ability to transfer and delete data and to provide a factory reset of the product is necessary.

The following reference standards can be useful to consider when designing products that are to be reused:

- EN 45554:2020, *General methods for the assessment of the ability to repair, reuse and upgrade energy-related products*;
- IEC 63333:2023, *General method for assessing the proportion of reused components in products*.

5.6.8 Other considerations

Reuse of returned products, especially for products that are sold online, is limited by the costs of testing the returned product and repackaging, in comparison with the costs of replacing with a newly manufactured product. To prevent vendors from destroying returned products, costs for enabling reuse should be lower than costs of replacement.

Product and packaging design can lower the costs of reuse, by enabling the consumer to open the packaging, inspect the product, close the packaging and return the product to the vendor in a way which allows the vendor to re-sell the product without replacing the packaging or having to test the product for damage or tampering.

When designing products, how to minimize the need for use of consumables during the use of the product should be considered.

5.7 End-of-life phase

5.7.1 General

Design strategies applicable to EoL include remanufacture or repurposing the product, facilitating parts to be reused, or the materials to be (easily) recycled. The design strategy should determine how to support remanufacture and determine target parts or materials which can be recovered for reuse, while other parts can be selected for recycle or energy recovery (see Figure 3).

The parts with relative long-life expectancy from EoL products can be used for new or remanufactured products or as spare parts for repair actions, even though the product (as a whole) has little value for reuse or remanufacturing itself.

5.7.2 Ability of products to be remanufactured and repurposed

Reaching EoL, a product can be remanufactured or repurposed for a new lifetime with original or modified functionalities. Remanufacture and repurpose are generally facilitated by appropriate product design choices. Remanufacture requires a set of different processes such as disassembly, inspection, reprocessing, change of parts, assembly (to the new product) and test, all of which should be supported by the product design. Also, reverse logistics is fundamental to enable remanufacture, so it is important to consider the entire business model during the design process.

In the design, it should be determined which parts are the most likely required to be replaced in the remanufacture process, for example because they are the most vulnerable to wear and tear or because they have reached their EoL. Based on that, the product structure should support easy access to, and ability for secure (without damage) disassembly of these parts. Furthermore, locating and assessing access points or fasteners should be made easy. Cleansing or other aesthetic restoring should also be possible, without damage to the materials (including aesthetics).

The durability of key parts strongly influences the ability to remanufacture a product and thus should be considered carefully during product design. The possibility for assessing remaining lifetime of parts can be important to support the decision process during remanufacture.

Use of modular designs and standardized components and parts increases the possibility to find and use replacement parts during remanufacture, also after the original product was put on the market. Compatibility considerations should also include software.

The availability of information about the design, the key parts and the dis- and re- assembly process is important to support efficient remanufacture operations.

To enhance material circularity, the use of reused, refurbished, or remanufactured parts can be applied during remanufacturing of products. Backward compatibility of parts between old and new models should be safeguarded to make this possible.

For repurposing of products or parts it is important to notice that when using a part for a different purpose than for it was initially conceived, the suitability (safety, performance, etc.) will require to be assessed by the repurposing organization.

The design, refurbishment and remanufacture processes can provide assurance on the quality and reliability of repurposed components. Documented evidence allows authorities to inspect manufacturers and the components they repurpose to prevent counterfeit or low-quality components from entering the market, especially for components which impact the safety of users.

Standards that can be relevant in assessing the ability to remanufacture a product include EN 45553:2020.