STANDARDIZATION ROADMAP
CIRCULAR ECONOMY

Supported by:

Federal Ministry
for the Environment, Nature Conservation,
Nuclear Safety and Consumer Protection

based on a decision of
the German Bundestag

PUBLISHED BY

DIN e. V.
Am DIN-Platz
Burggrafenstr. 6
10787 Berlin
Tel.: +49 30 2601-0
Email: presse@din.de
Website: www.din.de

DKE German Commission for Electrical, Electronic & Information Technologies
Merianstraße 28
63069 Offenbach am Main
Tel.: +49 69 6308-0
Email: dke@vde.com
Website: www.dke.de

VDI – The Association of German Engineers
VDI-Platz 1
40468 Düsseldorf
Tel.: +49 211 6214-0
Email: vdi@vdi.de
Website: www.vdi.de

Photo credit:
Cover: Andres – stock.adobe.com
Foreword:
Christoph Winterhalter – DIN
Michael Teigeler – DKE
Dieter Westerkamp – VDI
Greetings: Steffi Lemke – Bundesregierung/Steffen Kugler
Chapter entry pages: royyimzy (S. 7),
pickup (S. 29, 159, 177), Olena (S. 31),
Gina Sanders (S. 49), Harry Wedzinga (S. 65),
Victoria M (S. 93), Meaw_stocker (S. 107),
Le Do (S. 127), Dominique (S. 145)

In case of doubt, the German language original shall be considered authoritative.

January 2023

FOREWORD

Christoph Winterhalter
DIN Executive Board Chairman (CEO)
Source: DIN

Michael Teigeler
Chairman of the Board of Directors German Commission for Electrical, Electronic & Information Technologies of DIN and VDE (DKE)
Source: VPS Media

Dieter Westerkamp
Division Head VDI Technology and Society
Source: VDI

Dear Readers,

The fact is: If today's production and consumption patterns do not change, resource scarcity, environmental pollution, loss of biodiversity and increased climate change will be the consequences. The consumption of resources for our current prosperity will exceed the ecological carrying capacity limits in the foreseeable future. How we organize production and consumption in our economy in the 21st century will thus be both a major challenge and an opportunity for Germany!

For a sustainable society, the transformation of value creation – from a linear economy to a Circular Economy – is a necessary path to a livable and sustainable future for future generations as well. This is based on a consistently regenerative production, supply and trading chain that ideally does not require the use of any new raw materials. For a Circular Economy means that raw materials are used as long and as frequently as possible, and natural resources are used in a closed circle, without needing to use up new resources.

The question of how Germany can be transformed into a sustainable Circular Economy by 2030 has already been discussed by the Circular Economy Initiative Germany (CEID). It lists ten key areas for action, with "standardization" being among the most important areas. According to the CEID initiative, standards are needed for product design, recycling and recyclates, among other things, as well as data standards that enable the exchange of information and thus ensure transparent material flows. The current federal government's coalition agreement, "Dare more progress," states: "We are bundling existing raw materials policy strategies in a 'National Circular Economy Strategy'. On this basis, we are advocating uniform standards in the EU."

We are responding to this request with the German Standardization Roadmap Circular Economy presented here. In this Roadmap, we address the obstacles and challenges to transformation from a standardization perspective, and identify the standardization needs for seven crucial sectors of the German economy. Only by setting uniform standards and specifications worldwide can requirements for services, products and processes be defined in dialogue with all participants along the value chains. Products must be durable, reusable, recyclable and, if possible, repairable. As the German federal government's coalition agreement states: "Accelerating the development of quality standards for recyclates will create new high-value material cycles."

To sum up: Today's product is tomorrow's raw material. This also involves thinking in terms of new business models and developing them. For new business models to be applied in the Circular Economy, standards and specifications are needed as a basis because they provide industries that have not previously come into contact with each other with a common language. This results in better communication and an effective exchange of information among market actors, for example by laying down requirements for repairable and recyclable products, as well as an unambiguous classification of materials for manufacturers and recyclers.

We would especially like to thank the more than 500 authors who developed this Standardization Roadmap collaboratively and by consensus, thus making this project possible in the first place. With this way of working, we as standards organizations want to exemplify the principles of a Circular Economy: developing innovative approaches collaboratively and across existing silos.

We wish our readers an interesting read and look forward to active support in the implementation of this Standardization Roadmap. For the Roadmap does not mark the end, but rather the beginning of the implementation of the standardization needs, which is being consistently driven forward in particular by existing expert committees of DIN, DKE and VDI. Industry, civil society, science and politics are now invited to actively shape the rules of the Circular Economy together. We are convinced that standardized rules will support and, in part, enable the transformation toward a Circular Economy. Let’s take on this challenge together!

Your
Christoph Winterhalter, Michael Teigeler & Dieter Westerkamp

Christoph Winterhalter,
DIN Executive Board Chairman (CEO)

Michael Teigeler,
Chairman of the Board of Directors German Commission for Electrical, Electronic & Information Technologies of DIN and VDE (DKE)

Dieter Westerkamp,
Division Head VDI Technology and Society

GREETINGS

Steffi Lemke
Federal Minister for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection

Dear Readers,

the transformation from the linear to the Circular Economy is a major challenge. The aim is to close material cycles and thus save valuable resources. Many different measures are necessary for this: Resource-saving design at the beginning of the production process is one measure, as is the collection and recycling of products.

Standards and specifications play an important role here. They ensure comparability and reliability. They are important steering instruments and aids in everyday life: for government institutions, business enterprises, research institutes, and private individuals alike.

This is where the Standardization Roadmap Circular Economy comes in, for it provides a targeted impetus for implementation towards a Circular Economy. In doing so, it keeps a firm eye on environmental protection requirements.

This is entirely in line with the EU Commission's Circular Economy Action Plan (CEAP) which emphasizes the importance of European standardization in individual sectors such as plastics. The German government wants to advance the issue of standardization for a genuine Circular Economy in the EU and to define requirements for products throughout Europe – in dialogue with manufacturers.

At national level, the federal ministry for the environment will work with relevant stakeholders to develop a National Circular Economy Strategy. In doing so, we want to focus on the entire life cycle of products. At every point in the cycle, resources should be saved or products reprocessed so that they can be returned to the cycle.

With the Standardization Roadmap Circular Economy, important preliminary work has been done for this strategy.

The transformation to a true Circular Economy requires all players to take part, from manufacturers of products, materials and equipment to waste management companies. These players bring different interests and points of view and a wide range of know-how to the table. Value chains are to become value cycles.

This potential was used for the development of the Standardization Roadmap Circular Economy: The German Institute for Standardization (DIN), the DKE German Commission for Electrical, Electronic & Information Technologies (DKE), which is supported by VDE, and the Association of German Engineers (VDI) brought together all stakeholders to discuss and formulate challenges and needs. In this way, they actively are supporting the path to a true Circular Economy. Many thanks to all participants for their valuable contributions!

Your
Steffi Lemke

Steffi Lemke,
Federal Minister for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection

Summary

DIN, DKE and VDI worked for three-quarters of a year with more than 500 experts from industry, science, the public sector and civil society on the Standardization Roadmap Circular Economy. The aim of the Roadmap is to create a framework for action in standardization that promotes the transformation toward a Circular Economy and defines international framework conditions. This also supports a demand in the current federal government's coalition agreement, "Dare more progress," which states: "We are bundling existing raw materials policy strategies in a 'National Circular Economy Strategy'. On this basis, we are advocating uniform standards in the EU." [1]

The Circular Economy is of particular importance in achieving the targets of the Green Deal and the Climate Change Act of 2021. To achieve the ambitious climate protection targets, new and revised technical rules for the Circular Economy are needed [2]. The Standardization Roadmap Circular Economy will set the path for this, thus driving forward the green transformation of Germany and Europe. Standardization has a key role to play here, because closed-loop economies require an increased level of cooperation and communication among the stakeholders along the entire value chain. Standards and specifications define interfaces and ensure clear communication between the different stations in the cycle, thus making a smooth cycle possible in the first place.

The present Standardization Roadmap Circular Economy was developed in a broad participation process with interdisciplinary actors, and outlines the work and discussion results of the key topics. It provides a comprehensive overview of the status quo, requirements and challenges for the following seven main topics which are oriented towards the EU Commission's Circular Economy Action Plan:

- → Digitalization/Business Models/Management
- → Electrotechnology & ICT
- → Batteries
- → Packaging
- → Plastics
- → Textiles and
- → Construction & municipalities [4]

Based on extensive standards research (see Chapter 1.6.2), the current environment of Circular Economy standardization was analyzed for the seven key topics, which served as a basis for the work on these topics. With over 200 identified standardization needs (see Annex: Overview of standardization needs), the Roadmap demonstrates concrete potential.

In the course of the work, topics were identified that were introduced and discussed cross-sectionally in all key topics.

The five cross-cutting topics of sustainability assessment, life extension, end-of-waste, digital product passport (DPP), and recyclability were considered in more detail and across the board in a separate chapter. At the end of each of the five individual cross-cutting topics is an overview with references to the relevant standardization needs from the point of view of the key topics.

The Standardization Roadmap comes to the conclusion that the desired transformation towards the Circular Economy can be significantly supported by an early and comprehensive commitment of German stakeholders in national, but above all in European and international standardization. With the Roadmap, standardization activities can be guided and coordinated for the first time along the value chain in the key topics examined.

In addition, the Roadmap gives rise to important cross-sectoral and specific needs for standardization, which must now be implemented Interested experts are expressly invited to participate and contribute their knowledge in standardization.

1
Introduction to the Circular Economy

1.1 What is the Circular Economy?

Against the background of the already existing and growing shortage of resources and the dependence on petrochemical raw materials, increasing energy, material and resource efficiency is becoming more important. The timeliness of these issues is reflected in the fact that they have been included in several of the Sustainable Development Goals addressed by the United Nations [5]. The Circular Economy offers suitable solutions for this. In the European Union, this will be realized by the planned implementation of the Circular Economy Action Plan in legislation [4]. Raw materials, materials and products should be used as efficiently and effectively as possible to create a sustainable, low-carbon and resource-efficient economy [4]. This transformation involves moving from a linear to a circular and networked form of value creation. The overarching goal of the Circular Economy is the absolute reduction of resource consumption, which is to be achieved through various measures (resource-saving design, more efficient use of resources, product life extension, etc.) as well as the gradual transition to the use of renewable energies. In view of a growing shortage of raw materials, economic development and the scope of resource use are to be decoupled. More efficient use and recycling of resources promotes economic development and growth, which can create and sustain new jobs in the long run.

The Circular Economy is a rapidly developing area. Accordingly, there is not just one, but a number of definitions that are used in parallel Kirchherr et al. analyzed 114 different definitions in a paper [7]. At the international standardization level, ISO has defined the Circular Economy as follows: “Economy that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles.” [8]

The Ellen MacArthur Foundation has defined its understanding of Circular Economy broadly as follows: “[The Circular Economy is] a systems solution framework that tackles global challenges like climate change, biodiversity loss, waste, and pollution. It is based on three principles, driven by design: eliminate waste and pollution, circulate products and materials (at their highest value), and regenerate nature. It is underpinned by a transition to renewable energy and materials. Transitioning to a Circular Economy entails decoupling economic activity from the consumption of finite resources. This represents a systemic shift that builds long-term resilience, generates business and economic opportunities, and provides environmental and societal benefits.” [9]

It is likely that different definitions of “Circular Economy” will continue to be used in parallel in the future, as different definitions may also represent different application perspectives and user groups. Thus, the ISO definition is also currently still under discussion and it is to be expected that the announced framework standard ISO 59004 on the Circular Economy will contain a modified definition of the term [10]. This International Standard on the Circular Economy could lead to a generally accepted interpretation and thus reduce the diversity of definitions.

1.2 Why do we need a Circular Economy?

Production and consumption are characterized by the concept of linearity: The available resources are extracted from nature, transformed into products in multi-layered processes and then, after sometimes disproportionately short use, accumulate as waste. Plastics, for example, are made from crude oil, which has been produced over millions of years and from which polymers are elaborately manufactured – only to have a short service life in some cases. In Germany, at least, this waste is largely disposed of reliably and mostly in an environmentally friendly manner – for the direct threats to human health and the environment in this country we have found technical solutions in recent decades, such as regulated landfilling and thermal waste recycling – but this is not yet a true Circular Economy as described above.

The linear system was highly successful in the past, especially economically, and has brought us unprecedented prosperity, if one disregards the associated emissions. However, the system is increasingly clearly reaching its limits and has become a dead end for a variety of reasons:

→ From an ecological perspective, it is clear that the resource consumption associated with this model is far beyond any planetary limits for the long-term survival of humanity on Earth [11]. Whereas 2,5 billion people lived on Earth in 1950, only half a century later this figure has tripled to 7,84 billion. Accordingly, there has been and continues to be not only a considerable absolute increase in resource consumption, but also a per capita increase. According to a United Nations forecast, the world’s population will grow to around 10,4 billion by 2080, meaning that resource consumption will reach a level that will require innovative solutions [12]. By 2020, humanity as a whole will have consumed more than 100 billion tonnes of natural resources for the first time, and the use of resources such as biomass, ores, and minerals will have increased fivefold in just a few decades. According to estimates by the International Resource Panel, resource consumption is thus responsible for 50 % of all greenhouse gas emissions and over 90 % of global species losses. This means that the goal of climate neutrality called for by the German Federal Constitutional Court can only be achieved within the framework of a Circular Economy, cf. Figure 1. Current calculations show that the Circular Economy could enable one-third of the necessary emissions reductions from industry in Europe by 2050 if energy needs are met by renewable and zero-emission sources [13]. The energy transition is necessary, but must be considered together with a no less challenging resource transition in an overall strategy.

→ In addition, there is the economic necessity of the transformation to the Circular Economy: The economic symptom of a shortage of raw materials is a rise in prices, which can lead not only to purely economic conflicts but also to social conflicts and even military conflicts over strategically important sources of raw materials. Germany will only be able to secure its role as an economically strong nation, and especially as an industrial nation, if the transition to the Circular Economy is successful. With regard to most critical raw materials, Germany is now dependent on imports, which is increasingly proving to be a risk to the security of supply chains. Added to this is the realization by many companies that the comparatively simple linear production patterns can probably be established or copied more cheaply in other parts of the world in the future, but this is just a geographical shift of the problem. Against this backdrop, the Circular Economy represents a strategic opportunity to develop global innovation leadership that could safeguard competitiveness and thus millions of jobs in Germany, Europe and the world.

→ In addition, the Circular Economy is an effective concept for achieving climate protection goals. By reducing CO_2 emissions with the help of Circular Economy levers, a containment of global warming to 2 degrees can be achieved, as modelling for Germany shows in Figure 1. Thus, the reduction of resource consumption in a Circular Economy is one of several drivers for climate protection [14].

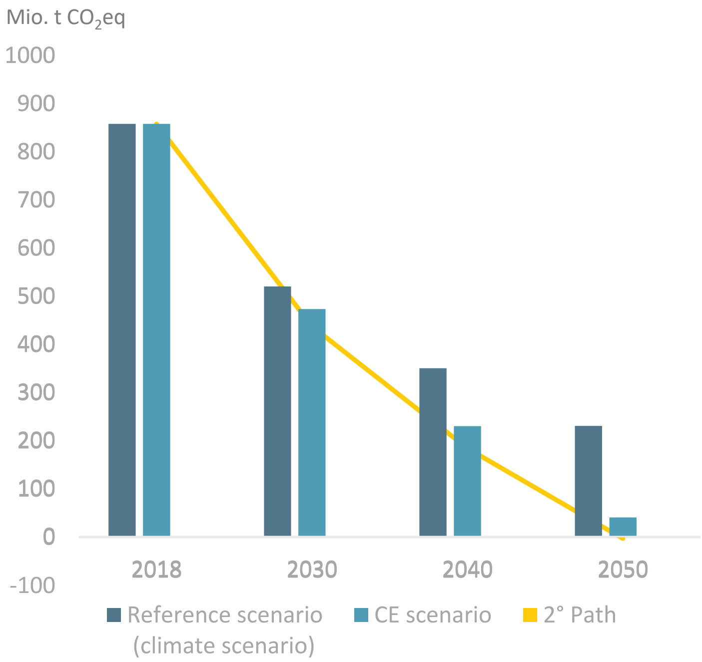


Figure 1: The Circular Economy and the 2° path for Germany (Source: Circular Economy Roadmap for Germany, 2011 [14])

The Circular Economy is not an end in itself, but a key lever both to address environmental challenges such as climate change and biodiversity loss, and to strengthen future competitiveness and resource independence through a necessary reduction in transport distances and dependence on imports. The goals set in both areas of sustainability will not be achievable without the transformation to the Circular Economy [14].

1.3 Trends in the Circular Economy

In view of this need for a Circular Economy outlined in 1.2, the progress achieved so far is not yet sufficient. The following Figure 2 shows the development of the share of recycled materials, the circular material use rate (CMR), in industry within Germany. According to the German government's plans, this rate is to be doubled by 2030 – however, this would require an annual increase of 1,1%, yet so far only 0,5% has been achieved since 2019.

Central topics of the current debates are the uncertainty of supply chains and the dependence on Russian imports for raw materials such as gas, nickel or palladium, which are central to future electromobility. Together with the European Union's self-sufficiency in critical raw materials, which has been declining significantly for years, and the sharp downward trend in Circular Economy patents, these are clear warning signals that although the Circular Economy is being discussed intensively, it is still far from being implemented quickly enough. The German government's Council of Experts on the Environment is therefore quite right to say that the task will be to move "from rhetoric to practice" in the Circular Economy [16].

At the same time, countries like the Netherlands show what has long been technically possible: The circular material use rate there is now 30,9%. In an analysis, the German Federal Environment Agency also comes to the conclusion that "the transformation towards a Circular Economy in Germany is still in an early development phase with little momentum" [17]. In particular, it is evident that significantly more money is still being spent on optimizing linear processes and products than on the transformation to circular value creation [18].

This would urgently require new business models aligned with the principles of the Circular Economy: The classic concepts of generating revenue by maximizing the sale of more and more new products inevitably lead to ever-increasing quantities of waste – no appeals for waste avoidance will help here if this would jeopardize the business basis of entire companies. What is needed, therefore, are circular business models that focus more on the use than on the sale of products or on the desired benefits, and thus contribute to an absolute reduction in resource consumption: Nobody buys packaging for packaging's sake, but essentially with the motivation of acquiring fresh or undamaged goods. Such approaches make it possible to provide the necessary impetus for truly circular product design, where, for example, a longer service life would in effect increase the profit of the manufacturing company.

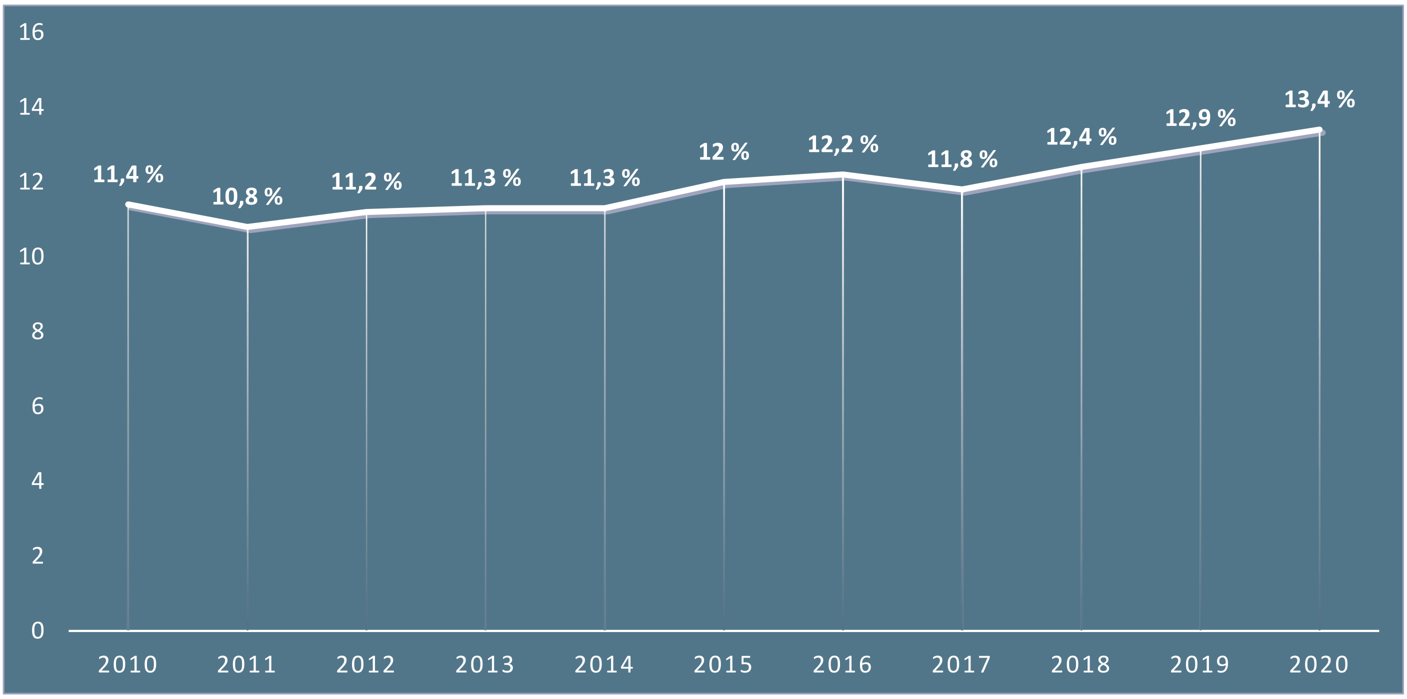


Figure 2: Development of the circular material use rate (CMR) in Germany, 2010–2020 (Source: Eurostat 2022 [15])

The transition from product to service orientation described in Figure 3 is extremely complex in its practical implementation. In the classic linear economy, revenue and profit are generated with the sale of ever new products; incentives for repairability or longevity are thus understandably limited. Circular value creation, on the other hand, relies more on the paid use of a product or service. In the sense of "using instead of owning", the company's profit increases with the extension of the product's useful life.

Such closed-loop thinking requires a massively increased level of cooperation and communication between stakeholders along the value chain: Investments in the recyclability of a product are worthless if that product is not collected and sent to the proper recycling structures following its use. This in turn then requires a product design that enables the integration of recycled materials. This increases the number of contributors with whom coordination must take place, as well as the number of decisions to be made internally [20]. The market potential of the Circular Economy is thus closely linked to increasing demands on the management of complexity and the radical transformation of entire value chains. Business models geared to short-term profit must thus be replaced step-by-step by models that ensure more long-term safeguarding of earnings and value creation.

> In view of the aforementioned background, standards and specifications can make a massive contribution to increasing the competitiveness

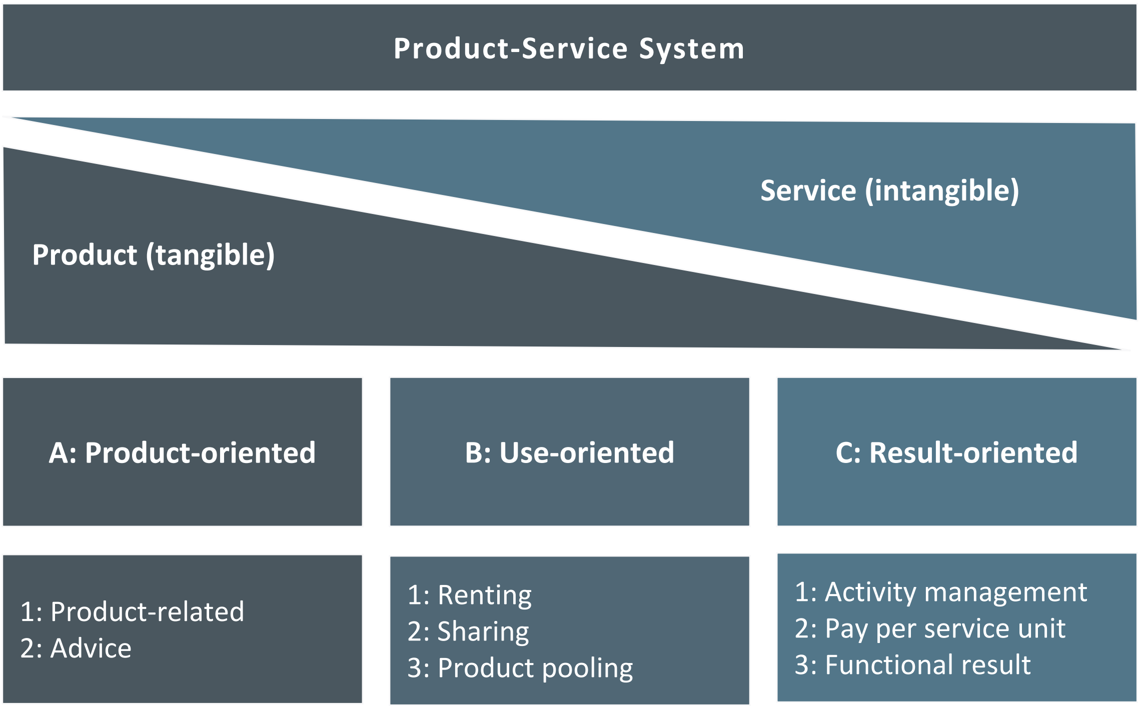


Figure 3: Transition from product orientation to services orientation (product as a service) (Source: Along the lines of Tucker (2004) [19])

1.4 National and European implementation of the Circular Economy

The topic of the Circular Economy is gaining increasing momentum in the political arena. The European Commission in particular has become a key driver in recent years and, with the Circular Economy Action Plan, has presented an extremely ambitious roadmap to transform the European Union in the direction of circular value creation [4]. The concrete quantified targets include not only halving the volume of residual waste by 2030, but also doubling the share of recycled materials in industry, creating 700,000 new jobs and increasing gross value added by 80 billion euros per year. In addition to environmental and climate policy, the focus is thus primarily on strengthening the competitiveness and innovative capacity of European industry.

These goals are to be developed through 35 key actions to be initiated by 2023, covering the following strategic areas of action along the entire value chain:

→ The development of policy frameworks for circular and sustainable products, including a right to repair and the extension of the Ecodesign Directive to include aspects of product circularity.
→ Concrete actions on selected value chains such as packaging, vehicles or buildings with specific requirements, e.g. on the share of recycled materials.
→ The adaptation of classic waste law instruments in the sense of a Circular Economy, for example the specification of quantified waste prevention targets in addition to the existing recycling quotas, or the adaptation of waste management plans.
→ Targeted support for cities and regions as key participants in the transformation to the Circular Economy, as well as global initiatives such as support for a global agreement on plastic.
→ Linking the Circular Economy with other megatrends such as climate neutrality or digitalization, for example in the development of digital product passports.

The European Commission has thus set a strategic framework, which must, however, subsequently be implemented through concrete legislative processes. One example of implementation is the draft regulation on the revision of the Ecodesign Directive published in March 2022 [21]. Among the reasons given for the very far-reaching revision of the Directive are the above-mentioned implementation of the European Green Deal and the Circular Economy Action Plan [4]. In summary, the motivation for implementing new product requirements in the Ecodesign Directive is explained by the fact that no overarching policy instrument has been found for the transition to a Circular Economy. This makes the regulatory framework on ecodesign one of the first central tools in the legal landscape – others will follow. The explanatory introduction to the draft regulation refers to an expansion of the scope to include (i) new product groups and (ii) new product requirements. Accordingly, the new scope is intended to cover as broad a range of products as possible and to go well beyond the predominantly regulated energy efficiency of energy-related products. Other product groups mentioned as examples are textiles and, in accompanying events on the revision of the Ecodesign Directive, also building materials, steel, etc. The aim is to take environmental impacts into account throughout the entire life cycle and to increase demand for sustainable products. Increased emphasis is being placed on durability, reusability, upgradeability and reparability – all core elements of a circular product design.

Unlike other EU member states, Germany does not yet have an overall strategy for the Circular Economy. In the past, numerous programmes and strategies have been developed for individual aspects of the Circular Economy, including the German Resource Efficiency Program III of the federal government, the waste prevention programme of the federal and state governments, the raw materials strategy or the national programme for sustainable consumption. However, the large number of these individual programmes has not yet produced a consistent picture of a Circular Economy in Germany that would actually guide the actions of industry, for example [22]. With regard to the necessary investments in research and development as well as in processes and products, there is a lack not only of clear priorities and targets, but also of market-based instruments that could establish the Circular Economy as a successful business model across the board (for example, the removal of environmentally harmful subsidies for the linear use of plastics) [17]. [Another bottleneck is unclear terminology, a lack of definitions and a lack of standards as a basis for communication in trade and politics [23].

Against this background, the coalition agreement of the new German government contains the announcement of the development of a “national Circular Economy strategy” which, among other things, is to bundle the various raw materials policy strategies [1]. The coalition agreement clearly states that the Circular Economy is to make significant contributions to climate protection. The reduction of primary raw material consumption is mentioned as an important goal. The substantive lead for this strategy lies in a newly established

“Transformation” department in the Federal Ministry for the Environment – the substantive claim could thus be much broader than the hazard prevention of waste law; a strategy formulated in this way would go beyond the claim of proactively shaping value chains in terms of climate and resource protection as well as others. Currently under discussion are key issues such as a recycling label, digital product passports, mandatory guarantee statements and the certification of recycling plants in combination with the export of waste.

The coalition agreement refers in several places to the relevance of standardization at national, European and global level.

Implementation of the Circular Economy in other countries

The Circular Economy in the Netherlands

The Netherlands is considered a global pioneer in the transformation to a Circular Economy; for example, the circular material use rate (the proportion of recycled materials in industry) is over 30 %, more than twice as high as in Germany. Also, as a country poor in raw materials, the Netherlands already developed a Circular Economy programme in 2016, for which an implementation programme defined through an intensive stakeholder process was also adopted in 2019; special focus was placed on the participation of all relevant stakeholder groups. Among other things, the specific goal of halving the use of abiotic primary raw materials by 2030 was defined there [24]. This extremely ambitious goal is to be achieved through a clear focus on individual value chains with transformation agendas worked out in detail (food/biomass, plastics, manufacturing, consumer goods, construction); linked here, for example, with the goal of completely avoiding the (net) outflow of critical raw materials from the Netherlands by 2030 and the development of corresponding financing programmes for the manufacturing industry [25].

The basis for the successes already achieved is, on the one hand, a very well-positioned innovation ecosystem, including research institutions such as Delft University of Technology, which developed interdisciplinary and application-oriented offerings on the topic of the Circular Economy at a very early stage. On the other hand, there is also a high level of social acceptance for the need for a Circular Economy, which has led to its implementation in national concepts such as the Green Deals [26], which enable the suspension of individual regulatory barriers at the regional level if this results in significant potential for the Circular Economy [27]. This has benefited industrial symbioses in particular, which often fail in Germany due to very small-scale regulations on waste shipments. Circular Economy processes at the local level, such as in Amsterdam, make the benefits of a Circular Economy very practical for the general population to experience.

The Circular Economy in France

France is strongly committed to the Circular Economy, but with a significantly different, more top-down approach than the Netherlands, for example. The “Law for the Fight against Waste and for the Circular Economy” [28] adopted in 2020 strongly targets regulatory requirements enforced by the French central government [29]. Single-use plastics are to be completely eliminated from the market by 2040; a 100 % recycling rate for plastics is to be achieved by 2025. In many areas, the law puts the onus on manufacturing companies, for example through a system of extended producer responsibility (EPR) for textiles. The various EPR systems are also expected to finance a fund in the future, which will then actively promote the formation of reuse networks. However, the disposal of still usable products will be prohibited; verifiable attempts at planned obsolescence of products will also be prosecuted. At the same time, there are requirements for retailers that, for example, unsold food must be handed over to appropriate initiatives. A mandatory repairability index for electronic products is intended to enable consumers to factor service life extensibility into their purchasing decisions.

The Circular Economy in China

In China, people began to look at Circular Economy issues as early as the late 1990s. The main reasons for the importance of this issue are the enormous population of over 1,4 billion, the country's limited resources, which must be used as efficiently as possible, and the serious negative impact on China's environment as a consequence of rapid economic development since the country opened up in the late 1970s.

In 2008, the Circular Economy Promotion Law was published, which defines the 3 R-strategies as the core of the Circular Economy, i.e. "reduce", "reuse" and "recycle". The main goal of this early phase of Circular Economy initiatives was to increase resource productivity and, in particular, energy efficiency as part of an expansive growth strategy. Later, additional goals such as increasing the circularity of industrial systems, especially in the context of industrial parks, were added with the aim of transforming them into circular eco-industrial parks.

Developments towards the Circular Economy in China are strongly driven by the state and are characterized by a top-down approach. Nevertheless, local agencies at the provincial, city, and county levels have the opportunity to experiment and find solutions appropriate to local conditions within the framework of national policy guidelines. Conversely, locally developed approaches can then be generalized in the form of demonstration projects and find further application in other parts of the country or at the national level. In contrast to the European approach of the Circular Economy with a focus on resource efficiency and waste management, pollution prevention has always been considered an essential part of the Circular Economy in China.

As part of the Circular Economy development, China has developed standards and indicator systems to measure the productivity of essential resources such as fossil fuels, metals, minerals, and biomass, as well as indicators on recycling rates and aspects of the recycling industry. China has standards for circular management and industrial park performance evaluation, among others. In addition, there are various standards, e.g. for "repair", "remanufacturing" and "recycling" for different product groups.

China joined ISO back in 1978, and has become increasingly involved in international standardization over the past decade. As of July 2022, the Standardization Administration of the People's Republic of China (SAC) was a member of 811 ISO committees, of which SAC provides the secretariat in 76 committees and actively participates in 723. If we look exclusively at committees in the fields of resources and materials, it is also evident here that standardization in these areas is of great importance to China. In the field of "Ores and Metals" SAC runs ten secretariats and actively participates in 52 committees, in the field of "Non-Metallic Materials" it runs eight secretariats and actively participates in another 34 committees. At China's suggestion, a number of new technical committees were also established in ISO between 2015 and 2022, such as the Technical Committees on rare earths in 2015, karst in 2018, and lithium in 2020 [30].

1.5 Standardization in the Circular Economy

1.5.1 Objectives and content of the Standardization Roadmap Circular Economy

The Standardization Roadmap Circular Economy forms the basis for a subsequent implementation programme, which is intended to initiate concrete standardization projects on the basis of the Roadmap and to initiate the rapid transferability of knowledge gained into German, European and International Standards and test criteria. Central topics include

→ standards for a design 4 circularity at material, product, process level,
→ quality standards for the scalable use of high-quality secondary raw materials, and
→ technical standards for the provision and exchange of digital data.

Standards and specifications play a central role in the transformation to a Circular Economy and a more sustainable economy, which is also reflected in the EU Commission's standardization strategy. This changeover to new circular business models requires innovations, which standardization must also take into account. In addition to the task of describing the state of the art and best practice examples, standardization also has the duty to create a framework for future technological developments. Harmonized rules promote the recognition of innovative technologies among governments, consumers, manufacturing companies and institutions, and create transparency and trust. A common language created through standardization based on technical facts makes it easier for new, innovative technologies to enter the market globally. Standardization must not under any circumstances create market barriers, but rather has the task of supporting and enabling the upscaling of new technologies.

The timing for integrating new, innovative technologies into standardization is crucial and must be precisely adjusted. Standardization projects can be started at any time, but the standardization process today is not very agile and thus standards cannot be adapted to technical developments at short notice. The development of new standards is also relatively long and complicated. The integration of new technologies into standards must therefore be planned and prepared at an early stage. A Standardization Roadmap with a coordinated strategy is therefore an important strategic tool for innovative technologies.

1.5.2 Role of standardization

Standardization has an essential role to play in the transformation: Standards create a uniform understanding of the Circular Economy. They help to break down existing barriers, most of which are technical. Figure 4 shows the general mode of action of standards and specifications as a catalyst for innovation and the transfer of knowledge for economic, social and environmental purposes. These standards and specifications can support transformation processes toward a Circular Economy.

In general, standards and specifications have the following functions [40]:

→ they codify knowledge that then becomes available to companies; regular updates of standards ensure that this knowledge is reviewed and updated as necessary;
→ they reduce product diversity and thus allow investments to be concentrated on successful products, which helps to expand the market;
→ they formulate basic requirements for the quality of products and services;
→ they define compatibility requirements, which enables connectivity of products to network products and their interchangeability;
→ they contribute to the continuity and incremental innovation of technical systems, thus safeguarding investments made and existing infrastructure.

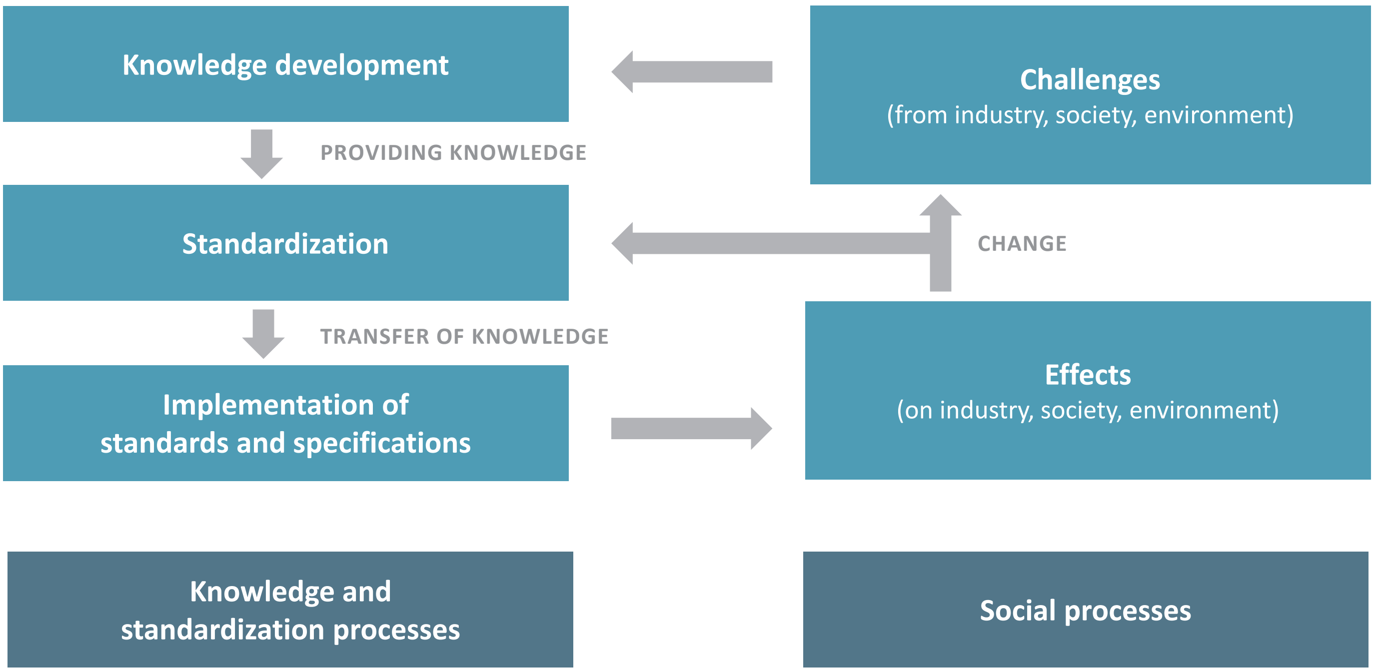


Figure 4: Effectiveness of standards and specifications (Source: DIN)

Standards and specifications also support the alignment of corporate strategies and the ability to achieve competitive advantages at an early stage. In addition, standardized test methods increase the comparability of products and services from different providers. If there are legal provisions, standardized test methods provide a basis for companies to demonstrate product conformity. This provides a basis for fair competition and appropriate market monitoring.

Taking into account standards and specifications, products and services can be made more recyclable from the ground up. At the same time, the expertise gathered in the standards enables the standardization bodies to make a well-founded entry into the aspects of the Circular Economy and to link up with the current state of development and knowledge from industry and science. Duplication of work and undesirable developments are avoided, and effective and efficient transformation is promoted, because “detours of thought save detours of action” [33].

1.5.3 National, European and international standardization environment

Standards and specifications are developed in various organizations at different levels (national, European, international) in self-administration by the stakeholders (e.g. science and research, industry, environmental protection, consumer protection and the public sector). At the beginning there is always a need of the stakeholders. Standards also play an important role as instruments for legislators to support and implement legal regulations and provisions.

In terms of full consensus-based standardization, ISO [34], IEC [35] and ITU [36] are the authoritative standardization organizations at international level. The corresponding standardization organizations at European level are CEN [37], CENELEC [38] and ETSI [39]. The respective national standards organizations are members of ISO, IEC, CEN and CENELEC (see Figure 5).

As technical rules, standards are the result of national, European or international standardization work and are developed by committees according to defined principles, procedures and rules of presentation. All interested parties, such as manufacturing companies, consumers, the trades, universities, research institutes, authorities, testing institutes, , associations etc., can participate in the work of the committees. Standards are developed by consensus. This means that experts come to agreement on the state of the art and on standards contents that take the interests of all stakeholders into consideration. Whenever possible, International Standards should be developed and applied in preference to European or national standards, since they ensure a common understanding among market participants worldwide and thus support the dismantling of trade barriers. All standardization docu-

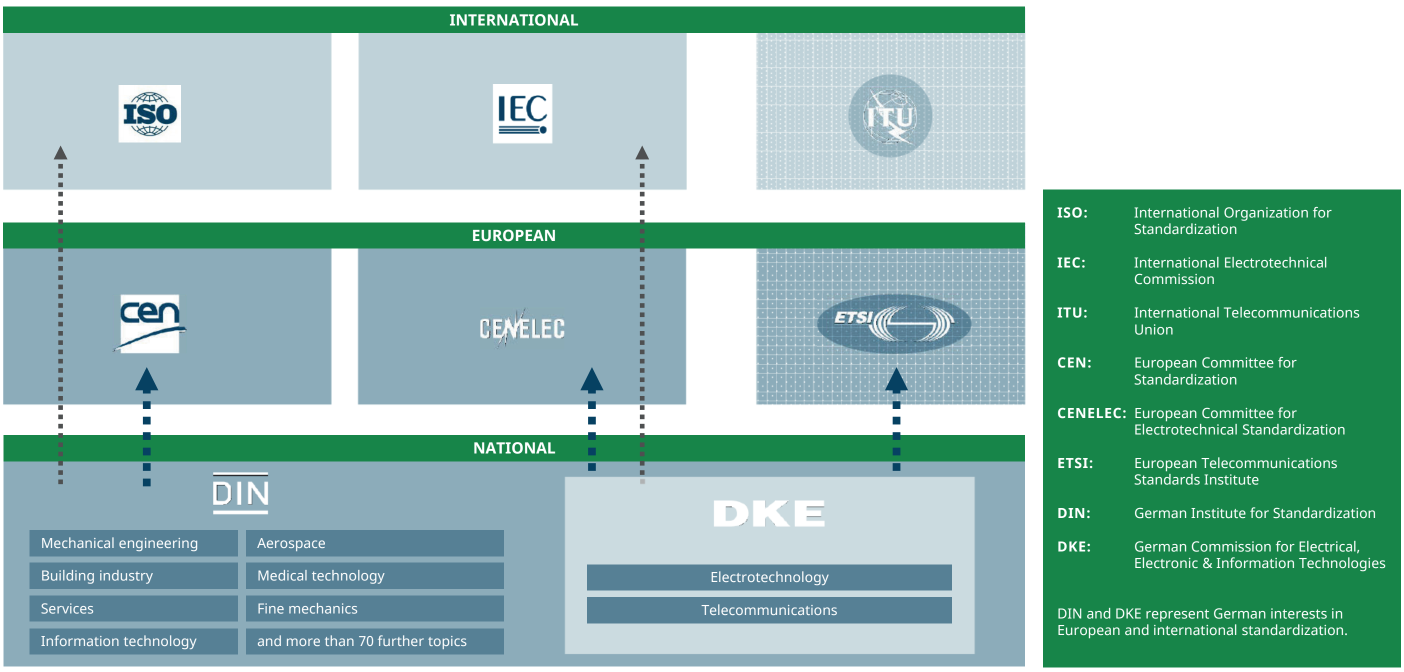


Figure 5: Organization chart of international standardization (Source: DIN)

ments of the national standards organizations (DIN/DKE), the European standards organizations (CEN/CENELEC/ETSI) and the international standards organizations (ISO/IEC/ITU) are referred to as "standards" in the context of this Roadmap.

The general term "specifications" refers to all other technical rules such as technical reports (TR), pre-standards, technical specifications (TS, DIN SPEC), consortial standards, application rules (AR), guidelines, expert recommendations, etc., for the preparation and publication of which the above-mentioned organizations as well as other organizations and technical rule setters may be responsible. For example, topics that have not yet fully arrived on the market or whose market does not yet exist are dealt with in consortial standards. Compliance with the principles of standardization work, such as full consensus and participation of all stakeholders, is not mandatory for specifications.

DIN, CEN and ISO

DIN, the German Institute for Standardization, is the independent platform for standardization in Germany and worldwide. DIN brings together around 36,000 experts from business and research, consumers and the public sector, who contribute their expertise to the development of standards and specifications. DIN thus provides the "round table" for experts and, as a privately organized service provider, assumes the project management for the development of technical rules.

The end result are standards and specifications that help to reduce trade barriers, save costs, ensure quality, and protect society and the environment. In addition, they contribute to safety and security, and promote understanding.

Since 1975, by agreement with the German federal government, DIN is acknowledged as the sole national standards body that represents German interests in European and international standardization.

Today, almost ninety percent of the standards work now carried out by DIN is European and international in nature. As a service provider, DIN organizes the entire process of non-electrotechnical standardization at national level and ensures German participation at European and international level via the relevant national bodies. Standards are developed by those who will later use them. The principles of DIN's standardization work, such as the participation of all stakeholders, openness and consensus, ensure confidence in the market and that standards are applied.

DIN promotes the marketability of innovative solutions through standardization in areas such as artificial intelligence (AI), climate change and the Circular Economy, often within the framework of research programmes. DIN SPECs (DIN Specifications) promote and accelerate knowledge and technology transfer, especially in areas with a high degree of innovation.

The standardization of the basic principles of the Circular Economy takes place at national level in the DIN Standards Committee Principles of Environmental Protection (NAGUS) in NA 172-00-14-01 AK "Circular Economy". This working group mirrors the activities of the international technical committee ISO/TC 323 "Circular Economy". The working groups of ISO/TC 323 deal with topics such as terminology, principles for implementation, business models, and frameworks for measuring circularity.

At European level, the CEN/CENELEC Strategic Advisory Body on Environment (SABE) is responsible for strategic environmental issues, and is concerned with the identification and coordination of ongoing activities and the identification of standardization needs. One focus of SABE is the exchange of information between the relevant stakeholders in environmental policy and standardization in Europe. SABE is in regular contact with the European Commission and has set itself the goal of addressing the issues of the Green Deal in particular. In this context, the Circular Economy Topic Group (CE-TG) was launched by SABE.

In addition, other European committees and national mirror committees focusing on specific product groups were established last year, such as the working groups CEN/TC 248/WG 39 "Circular Economy for textile products and the textile value chain" and CEN/TC 207/WG 10 "Requirements and methods for the circularity of furniture" (see also Chapter Standardization bodies in the context of the Circular Economy).

DKE, CENELEC and IEC

DKE, the German Commission for Electrical, Electronic & Information Technologies of VDE and DIN was founded in 1970 and works on the basis of the "Standards Agreement" of 1975 between the Federal Republic of Germany and DIN. DKE is an organ of DIN. In addition, the DKE is a division of the VDE Verband der Elektrotechnik Elektronik Informationstechnik e. V. (Association for Electrical, Electronic & Information Technologies) and is supported by the VDE.

In Germany, the DKE is responsible for standardization work in the field of electrical engineering, electronics and information technology at international, European and national level. As a competence centre for electrotechnical standardization, DKE represents the interests of German industry in European (CENELEC, ETSI) and international standards organizations (IEC).

DKE is a non-profit service organization promoting the safe and rational generation, distribution and use of electricity, serving the interests of the general public.

DKE's task is to develop and publish standards in the fields of electrical and electronic engineering and information technology. The results of the electrotechnical standardization work of the DKE are laid down in DIN Standards, which are included in DIN's body of German Standards and, if they contain safety-related specifications, at the same time as VDE provisions in the body of VDE regulations.

Standardization of electrical engineering fundamentals relating to the Circular Economy takes place at international level in IEC/TC 111 "Environmental standardization for electrical and electronic products and systems".

At European level, CLC/TC 111X "Environment" deals with Circular Economy topics.

Nationally, the activities of the above-mentioned committees are mirrored in DKE/K 191 "Environmental protection and sustainability for products in electrical engineering, electronics, information technology" (see also Chapter Standardization bodies in the context of the Circular Economy).

VDI
The Association of German Engineers (VDI), Europe's largest technical-scientific association with around 135,000 individual members, founded in 1856, is the third largest technical rule-setter in Germany. With its VDI guidelines, it creates generally recognized standards with assessment and evaluation criteria as well as methodological principles for almost all industries, and also provides concrete recommendations for action across national borders. In the 12 VDI "Fachgesellschaften" with their 46 "Fachbereichen" and about 600 committees, the topics range from architecture, construction technology, bionics, plastics technology, energy and environmental technology to reliability.

The body of VDI guidelines currently contains more than 2,200 valid documents. In VDI guidelines, the state of the art of current and future developments, and the state of the art of science, are usually described in two languages (German and English). The VDI expert network (over 12,000 experts) from science, industry and the public sector develops VDI guidelines on a voluntary and interdisciplinary basis. In doing so, the individual committees follow the internationally established standardization process. Through VDI guidelines, a consolidated national position is developed, if necessary as preparatory work for European/international standardization projects. Agreements between VDI and DIN exist for this purpose.

The VDI is involved, for example, with technology-relevant aspects such as the transformation of energy supply, climate protection, digitalization, and environmentally friendly and resource-efficient production. Recommendations and specifications are derived based on this work.

The topic of the Circular Economy is at home in many bodies of the VDI. This is because products of all kinds should be brought to their greatest use and value through innovative technologies and kept in circulation. Many of the 12,000 voluntary committee members active in the VDI from cross-sectional technologies such as materials technology and production engineering, and sector-oriented technologies such as construction engineering, energy technology and automotive engineering are therefore also closely involved in developing technical solutions for establishing circular value creation. The VDI considers this topic with stakeholders from different industries and from different perspectives in order to turn value chains into well-coordinated value networks. In addition to the publication of VDI guidelines, the VDI creates a broad transfer of knowledge through specialist conferences, congresses and workshops. And with its statements, status reports and roadmaps, the VDI provides information on current topics to all experts and interested parties from society, the media, industry and politics. The topic of the Circular Economy is at home at the VDI under the umbrella of the VDI-Gesellschaft Energie und Umwelt (VDI-GEU) (VDI Society Energy and the Environment). Complex topics such as the transformation of energy supply, climate protection as well as environmentally compatible and resource-efficient production are dealt with at VDI-GEU in the four specialist areas of Energy Technology, Environmental Technology, Operational Safety Management and Integral Energy and Environmental Topics as well as in 48 working bodies (see also Chapter Standardization bodies in the context of the Circular Economy).

1.5.4 DIN/DKE advisory board Circular Economy in DIN's Environmental Protection Helpdesk (EPH)

A wide range of committees at ISO, IEC, CEN, CENELEC, DIN, DKE and VDI are already dealing with the cross-cutting issue of the Circular Economy. However, the interest in standardization is often limited to one's own product group, so that the topic of the Circular Economy is only dealt with in part. At the same time, however, it is also clear that sector-specific interests of the respective bodies must fit into an overall context. And when many deal with the "same thing," duplication of effort is to be avoided, as are conflicting decisions, in other words: coordination, communication and cooperation are necessary! For this reason, the Expert Advisory Board 2 "DIN/DKE Expert Advisory Board Circular Economy" was founded within the DIN Environmental Protection Helpdesk (EPH) on January 20, 2021. It acts as a central point of contact for the pooling and dissemination of information on standardization activities relevant to the Circular Economy and performs the following tasks, among others:

→ coordinating the technical work within the relevant DIN and DKE bodies, as well as the current and future standardization projects at national level;

→ organizing the handling of European and international projects and the mirroring of CEN/CENELEC and ISO/IEC bodies at DIN and DKE – the decision-making freedom of DIN and DKE management bodies (e.g. advisory boards, technical advisory boards, steering committees) remains unaffected;

→ identifying new fields of work at national, European and international level;

→ making recommendations as to which body should take the lead in standardization activities or whether a new body should be established and which other DIN and/or DKE bodies should be involved;

→ working together with the relevant DIN and DKE bodies to avoid duplication or contradictory specifications in the standards to be developed;

→ making recommendations (including content) to the responsible DIN or DKE (working) committees on how to vote on national, European and international projects, with the final decision being made by the technically responsible committee;

→ developing, adopting and publishing an action plan, and periodically reviewing it for currency and updating it as necessary.

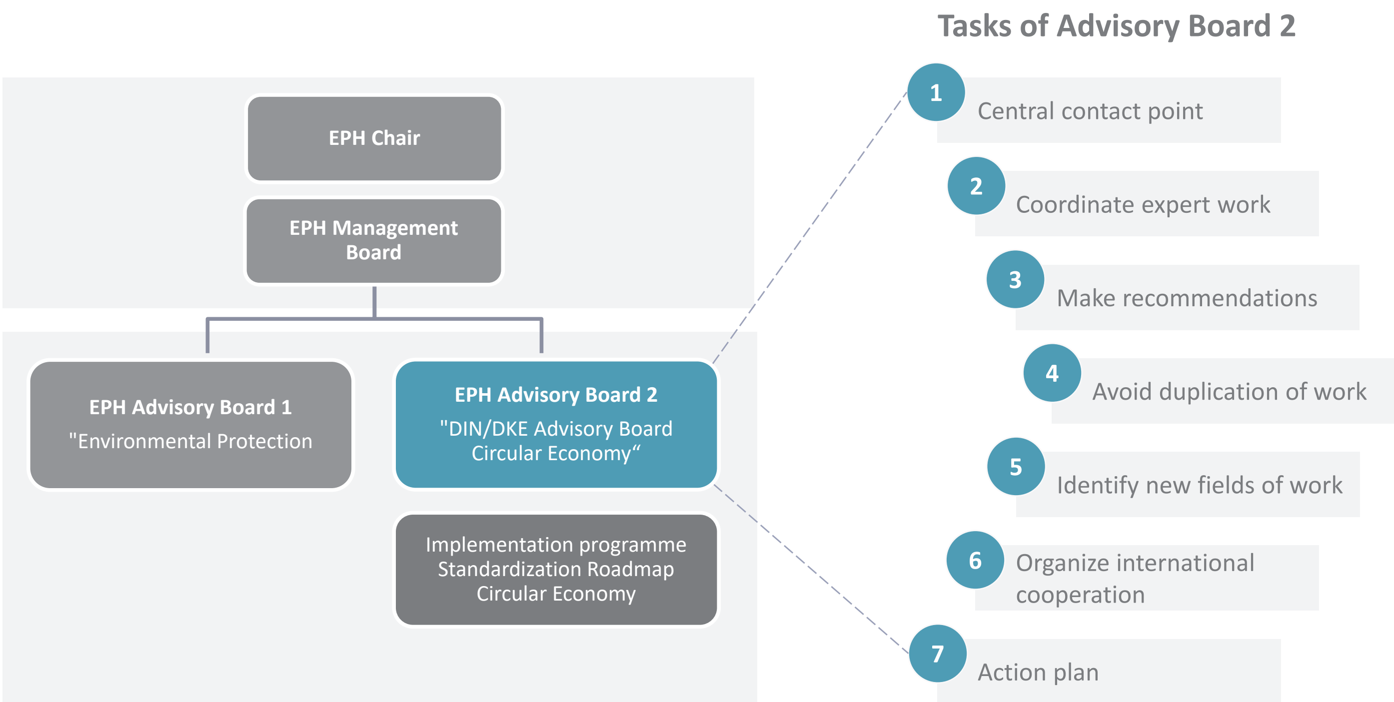


Figure 6: Tasks and organization of the DIN/DKE advisory board Circular Economy in DIN's Environmental Protection Helpdesk (EPH) (Source: DIN)

The DIN/DKE Expert Advisory Board Circular Economy in the EPH is composed of representatives of the DIN standards committees, DKE committees, the VDI, the Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV), the Federal Ministry for Economic Affairs and Climate Action (BMWK), the Federal Environment Agency (UBA), and other experts from the stakeholders (e.g. the public sector, industry, environmental and consumer associations, science). The Standardization Roadmap Circular Economy is a first project under the auspices of the DIN/DKE Circular Economy Expert Advisory Board in the EPH.

1.5.5 Standards for the Circular Economy: Five practical examples

The success of a good idea often depends on how long it takes to reach the market. With standards and specifications, companies and organizations – from start-ups and SMEs to large corporations or research institutions – set guidelines for orientation.

Requirements described in standards and specifications with regard to quality, interfaces and safety, for example, can thus accelerate product development and dissemination, i.e. the implementation of innovations, and provide security in the application of the products based on them. Especially in such a time-critical subject area as the Circular Economy, decisive steps can be taken that lead to trust in circular products and services.

By participating in international standardization, it is possible both to support technological developments and to attempt to give German innovations international recognition. Here we give examples of the great relevance of standards to the Circular Economy:

DIN SPEC 91446, Classification of recycled plastics by Data Quality Levels for use and (digital) trading [49]

There are clear deficits in the recycling of plastics – large quantities of the material do not make it into the recycling circuit, but end up in incineration or even in the world's oceans. This is because processing plastic waste into recyclates that can be used again in products of equal or higher value remains a challenge today. The material quality varies, and for a long time there was no uniform description of recyclates of all polymer types that were graded according to the depth of information – that makes compliance with quality requirements cumbersome and difficult to demonstrate.

Due to the inadequate data basis, companies producing recyclates usually have to enter into individual production and supply relationships with a customer.

DIN SPEC 91446 [49] changes this and removes barriers to industrial use. For the first time, it describes a common system for all market participants to classify plastic recyclates according to the amount of data with standardized material characterization. This allows material to be classified according to four different data quality levels. In addition, the DIN SPEC contains rules for terms that are not clearly defined (or are differently used) for input material, recycling processes and plastic recycled plastics as materials. The specification is intended to serve all stakeholders along the value chain as a common language for consistent communication and (digital) trade in recyclates.

VDI 2074, Recycling in the building services [51]

The guideline VDI 2074 provides guidance on creating cycles for the individual phases of the life cycle of buildings and facilities by identifying possible contributions for all those involved in planning, construction, use and modernization or dismantling. It pursues an integrated approach taking into account a comprehensive value-added concept and covers the manufacture of components, the planning and execution of construction measures and dismantling, as well as the collection and processing of end-of-life products. The guideline takes the recycling approach into account by giving preference to material recovery. Costs can be saved by avoiding handling and landfill costs with regional disposal companies.

VDI 2343 series, Recycling of electrical and electronic products [52]

Parts 1 to 7 of the VDI 2343 series of guidelines provide all concerned parties with recommendations for action on the recycling of electrical and electronic products. It specifies the terms used in waste electrical and electronic equipment (WEEE) recycling, describes the necessary planning and processes of logistics and the structures for the efficient collection of WEEE, the operation of collection points and/or transfer points as well as the transfer to treatment plants from an economic and ecological point of view. It provides instructions for the dismantling of WEEE and for the treatment of WEEE and takes into account provisions and influences such as the legal framework, requirements of manufacturing companies, sales markets for recovered material streams, and the type and depth of dismantling. In addition, the guideline provides concrete instructions and recommendations for the recycling of materials and energy from waste electrical and electronic equipment in line with the current legal situation, and shows that the stock of raw materials for the manufacture of products can be conserved by using natural resources sparingly and that additional resources can be saved if products are used repeatedly.

DIN EN 643, Paper and board – European list of standard grades of paper and board for recycling [6]

DIN EN 643 [6] provides guidance for the waste management industry, trade, the paper industry and other organizations in the waste paper sector. It provides support in the purchase and sale of paper for recycling and is, in particular, the basis for business between the supplier and the manufacturer of paper and board. Because DIN EN 643 specifies grades of paper for recycling, the raw material labelled according to the standard can be used in recycling without additional presorting. Manufacturing companies can rely on the purity of the standardized paper grade and produce appropriate paper grades on this basis. Customs authorities and tax officials also benefit from DIN EN 643: They need to distinguish between raw material and waste in the context of cross-border regulations and waste shipment control. DIN EN 643 defines “prohibited materials” and the limits for non-paper components, so that the paper for recycling can be clearly identified as a raw material.

Another advantage for buyers and sellers are the specified tolerance limits – this saves individual agreements between the two parties.

After problems with mineral oil residues arose in the use of recovered paper in the packaging sector, DIN SPEC 5010 specified sampling and measurement methods that can also be used to check the usability of packaging [48].

DIN VDE V 0510-100, Safety of lithium-ion batteries from electrically propelled road vehicles for use in stationary applications [50]

When EV batteries for road vehicles have reached 80 % of their original energy storage capacity, they are no longer considered suitable for this application by automotive manufacturers. However, the storage capacity is absolutely sufficient on a long-term basis for other stationary applications (2nd use/repurposing). This draft national prestandard provides basic safety requirements for this repurposing, e.g., in industry as temporary or auxiliary storage. The draft was published in 2021. Publication as a prestandard will take place in the next few months. This national prestandard will also be introduced at international level. The standard helps to take into account the widely differing requirements for batteries for electric vehicles (e.g. vehicle approval regulations) and the additional conformity requirements in the stationary sector. The document refers to industrial storages which are not accessible for laypersons.

1.6 Methodical approach of the Standardization Roadmap Circular Economy

1.6.1 Project structure

The participation of experts from all relevant areas is the essential basis for drawing up the Standardization Roadmap. The stakeholders to be involved include industry representatives from the relevant sectors, experts from the scientific community, representatives from politics and civil society, as well as representatives of already constituted groups concerned with the topic of the Circular Economy. In this context, the consideration of different perspectives and associated requirements is of great importance, so that both technical and non-technical aspects were equally incorporated into the development process of the Standardization Roadmap. The development of the Standardization Roadmap Circular Economy involved the overall coordination and orchestration of the relevant stakeholders and took place in seven working groups on the various key topics. The key topics are based on the Circular Economy Action Plan. Experienced experts have been recruited to head these topics:

The Roadmap was drawn up with the involvement of more than 1,300 experts from various sectors and with different backgrounds. Of these, more than 500 authors contributed their expertise to the seven working groups from diverse areas of society. The great number of interested and active authors as well as the diversity of persons and institutions cover a broad professional expertise. An overview is given in the Index of authors. It became apparent that the Standardization Roadmap Circular Economy project has met with great interest and has motivated many people to become involved in standardization. This provides the opportunity to recruit new experts for the future topics at DIN, DKE and VDI, who at the same time are to be introduced to the complex and multi-layered world of standardization. The new experts were informed about the instrument of "standardization" and its mechanisms of action in three large-scale training courses in March and April, which were very well received.

The governance structure of the Circular Eco-nomy standardization roadmap can be seen in Figure 7. The composition of the stakeholders, participants in the working groups (WGs) and breakdown of the authors is shown in the following Figure 8:

After an initial clustering of topics, the operational development shifted for the most part to sub-working groups, which are organized by product group or process. Together with the interested experts, the topic-specific heads recorded the concrete needs and identified interfaces to other WGs and sub-WGs together with the WG heads. The Working Groups Electrical Engineering & ICT and Batteries did not have any sub-working groups.

It should be noted that the process and needs assessment consisted of the existing knowledge of the collaborating experts. Thus, background research was not possible on the breadth of topics and was dependent on the knowledge level of the experts and their individual availability and participation in working meetings.

1.6.2 Standards research on the Circular Economy

In preparation for the working meetings, DIN, DKE and VDI conducted a broad-based research on existing standards and specifications on the Circular Economy. The entire body of national and international standards was scanned and evaluated for relevant Circular Economy standards. A total of 280 sets of rules with over 700,000 current references were researched, making this the most comprehensive standards database in the world:

The total result of 3,313 basic titles was manually checked for relevance by DIN, DKE and VDI and assigned to the seven working groups and superordinate topic areas. A total of 2,101 documents were deemed relevant after the qualitative review. These were reviewed by the experts in the working

DIGITALIZATION, BUSINESS MODELS, MANAGEMENT

HEAD
J. F. Aigner
(W.L. Gore & Associates)

Deputy HEAD
P. Bartel
(Circular Economy Solutions)

ELECTROTECHNOLOGY & ICT

HEAD
Dr. J. Giegerich
(Vorwerk)

Deputy HEAD
Dr. M. Schlegel
(BAM)

BATTERIES

HEAD
Dr. C. Rosenkranz
(Clarios)

PACKAGING

HEAD
Dr. H. Wilts
(Wuppertal Institut)

Deputy HEAD
Prof. Dr. A. Büttner
(Fraunhofer IVV)

Deputy HEAD
Prof. Dr. Langowski
(Fraunhofer IVV)

PLASTICS

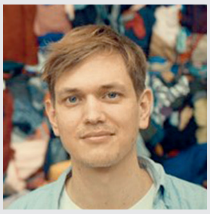
HEAD
Dr. H. Lehmann
(Remondis)

Deputy HEAD
Prof. Dr. H. J. Endres
(Institut für Kunststoff- und Kreislauftechnik)

TEXTILES

HEAD
Dr. E. Claßen
(Hohenstein Laboratories)

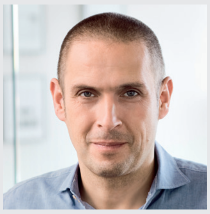
HEAD
N. Kösegi
(solutions for business)



Deputy HEAD
M. Malzacher
(circular.fashion)

CONSTRUCTION & MUNICIPALITIES

HEAD
Prof. A. Klinge (FHNW, ZRS Architekten Ing.)



HEAD
Prof. Dr. E. Klinge-Roswag
(TUB, ZRS Architekten Ing.)

Deputy HEAD
Prof. Dr. P. Jehle
(TU Dresden)

Figure 7: Heads of the key working groups of the Standardization Roadmap Circular Economy (Source: DIN)

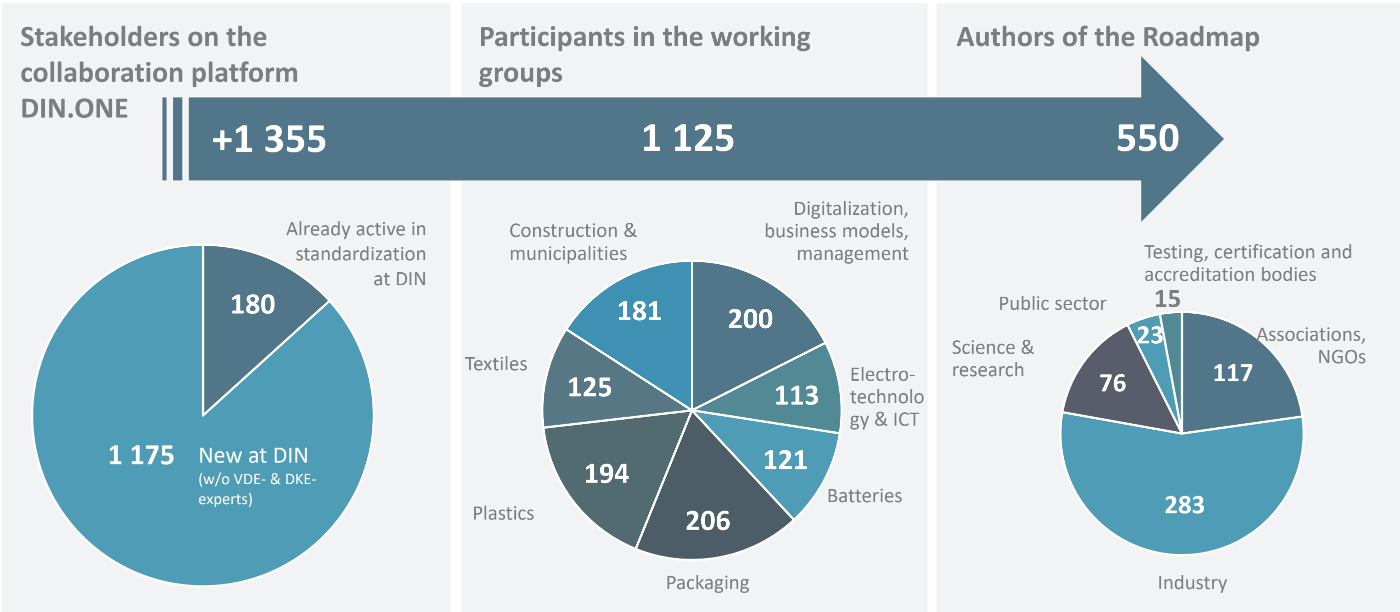


Figure 8: Participants in the working groups, as of 09.09.2022 (Source: DIN)

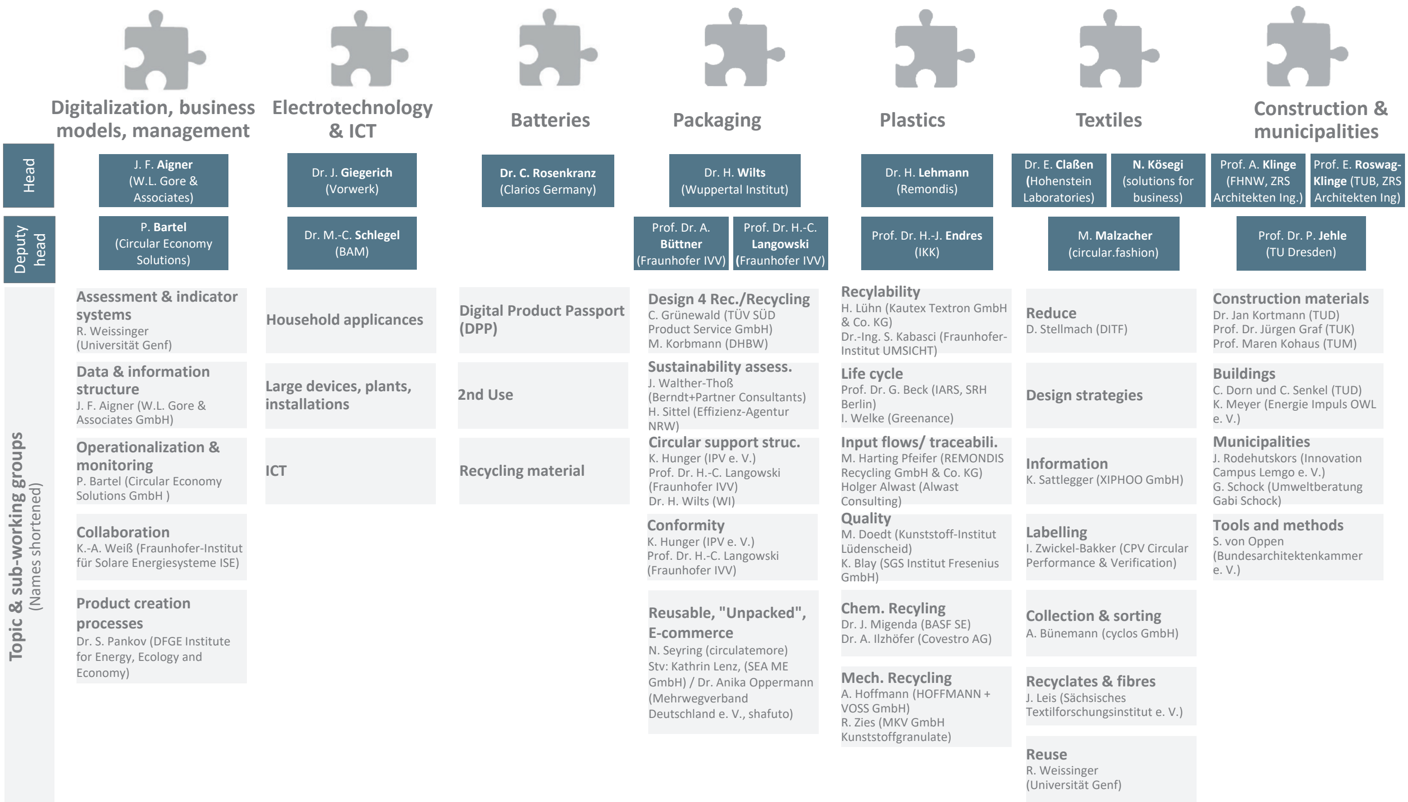


Figure 9: Project structure Standardization Roadmap Circular Economy (Source: DIN)

groups and supplemented with currently running projects. The results can be found on the following websites:

www.din.de/go/normenrecherche-circular-economy

www.dke.de/normenrecherche-circular-economy

www.vdi.de/go/normenrecherche-circular-economy

The basic dataset was taken from the database in January 2022, the last revision status of the search is dated 19.09.2022.

The following results were obtained for the key topics of the Roadmap:

There are numerous standards and specifications relevant to the Circular Economy. It can be seen that there are already a large number of standards and specifications relevant to the Circular Economy, but in most cases they are not directly related to the Circular Economy, but rather in a broader sense, and also do not have a systematic effect across all the “R-strategies” (see Chapter 1.6.3). This is because a large proportion of the standards have an impact in the area of recycling, which has been a key topic in the past in the area of Circular Economy. This was evident across all key topics. Higher-level strategies such as “rethink,” “refuse,” and “repurpose” were barely addressed. These strategies have little or no presence in the collection of standards.

In the key topics, an evaluation was then carried out by product group per “R-strategy” (see Chapter 1.6.3). The results served as a gap analysis for missing standards, but also for revision needs in the groups. These are examined in more detail in the following chapters.

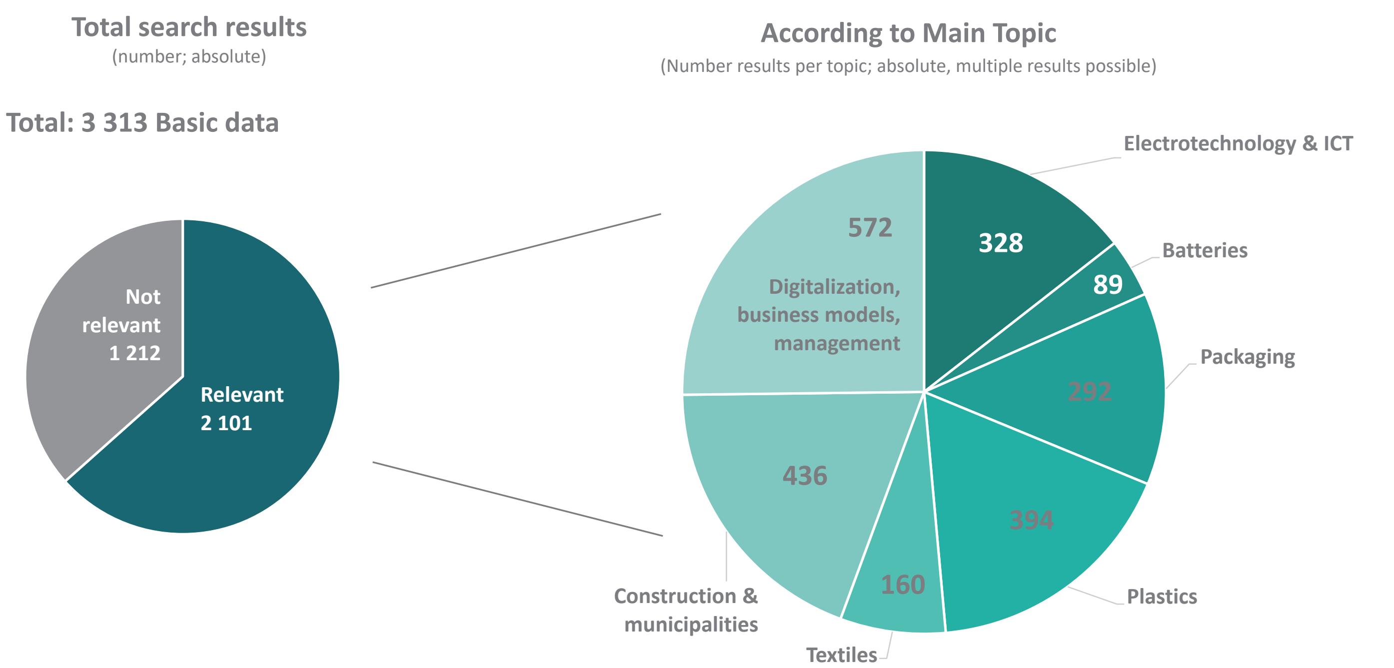


Figure 10: Results of the research of Circular Economy standards (Source: DIN)

1.6.3 Development of standardization needs in terms of the "R-strategies"

The Standardization Roadmap Circular Economy is based on the model of the "R-strategies" of the Circular Economy. These strategies aim to reduce the consumption of natural resources and support the recycling of materials. They systematize different utilization strategies in a hierarchy, complement each other and coexist. These are seen as the core framework of the transformation toward circular value creation. In the following, the 9R framework, which is also used in UN publications, will be presented. It is then shown how standardization can be used to support the various R-strategies. A detailing of the strategies took place in the respective key topics. The identified standardization needs were each assigned to a key strategy.

Refuse: Doing without a product or replacing the same function with a radically different (e.g., digital) product or service. Eliminating or reducing the use of raw materials, designing production processes to avoid waste.

Rethink: Take a systemic view, plan and design for cycles (also plan circular systems around the product, incl. reverse logistics), develop new business models, conscious material selection for cycles (substitution of substances of concern, material innovations). Intensification of product use (e.g., through product-as-a-service, reuse and sharing models, or by offering to bring multifunctional products to market).

Reduce (by design): Implementing design that enables circularity (design for circularity), increasing efficiency in the manufacture or use of products by consuming fewer natural resources and materials as well as energy, reducing the environmental footprint.

Reuse[1]: Reuse of a product that is still in good condition and fulfilling its function (and is not waste) for the same purpose for which it was designed, possibly after repair or refurbishment [41].

Repair: Repair and maintenance of a defective product so that it can be used again with its original function.

Refurbish: Recover an old product and bring it up-to-date (to a certain quality level)

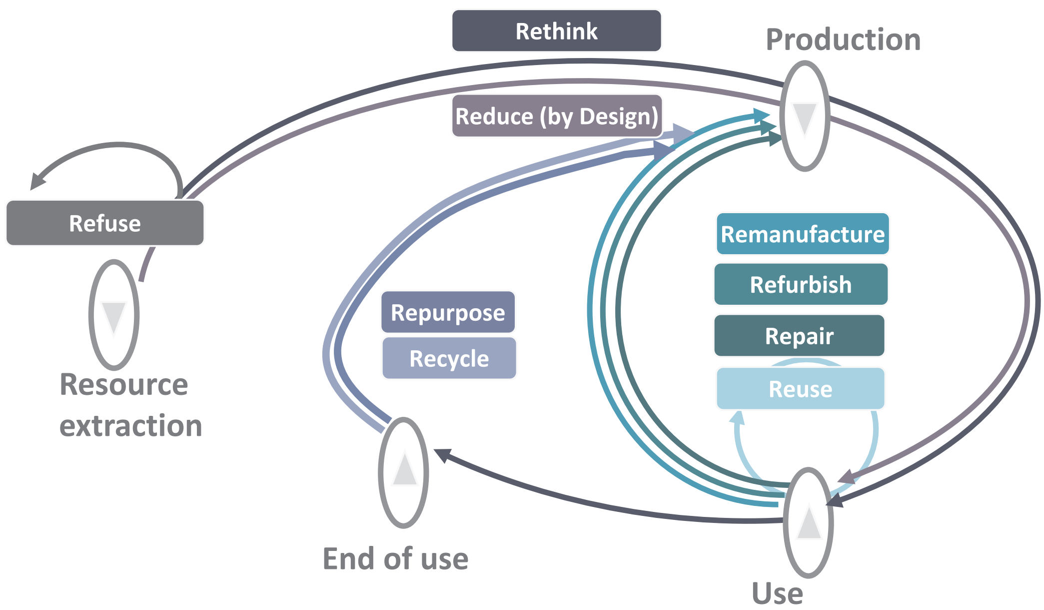
Remanufacture[2]: Use of parts of a discarded product in a new product with the same function (and in new condition)

Repurpose: Use of a redundant product or its parts in a new product with a different function

1 The German translation "Wiederverwendung" is as in DIN EN 4555X [46]

2 At the time of writing this Standardization Roadmap, DIN SPEC 91472 „Remanufacturing (Reman) – Quality classification for circular processes" is currently being developed [132].

Figure 11: R-strategies of the Circular Economy as a starting point for structuring the standardization needs to be elaborated (Source: See 9R framework of the UNEP [44] (based on Potting et al. (2017) [45])



Recycle (Recycling[1, 3]): Recovery of materials from waste for reprocessing into new products, materials or substances for the original or another purpose. It includes recycling of organic material, but does not include energy recovery and recycling into materials to be used as fuels or for backfill operations.

Functions of standardization in support of the R-strategies

Traditionally, the main objectives of standards have been to ensure functionality, safety, quality and compatibility of products and services. By focusing on resource conservation, product life extension, value and quality preservation, and waste prevention, standards can help give these aspects far greater weight than they have in the past.

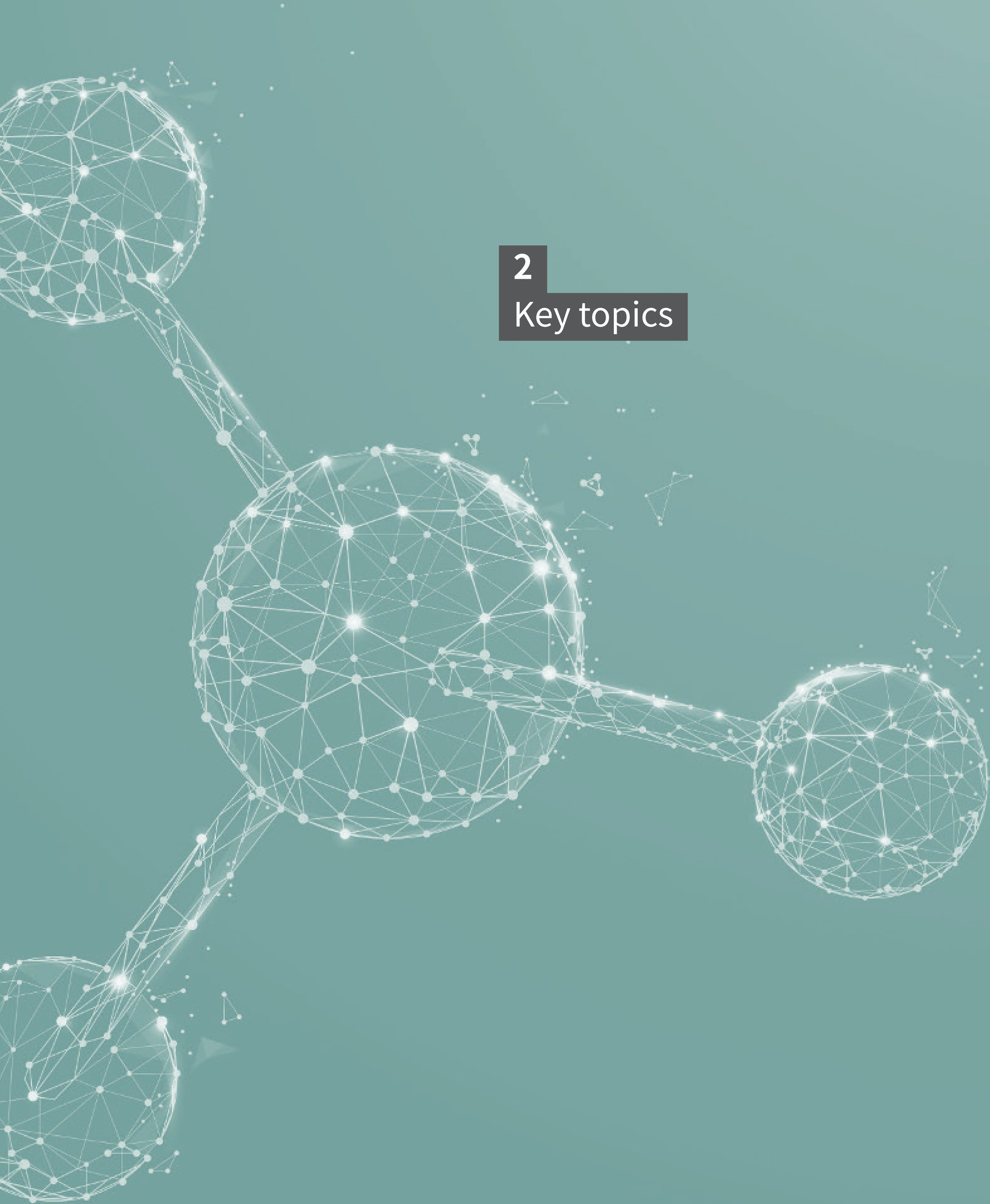
Standards with the following functions can support these goals. Standards on

- → environmentally conscious product design (design 4 circularity) for all product groups and resources (not only energy),
- → modular design principles for increasing the repairability of products,
- → reduction of product and material variants (variety reduction) through a concentration on basic product functions,
- → design 4 circularity (e.g. design 4 repair, “remanufacturing” and “recycling”),
- → quality classes of recyclates (supported by corresponding test methods),
- → minimization of the use or complete replacement of toxic substances,
- → development of digital product passports with material and product information,
- → digital platforms that store information on materials, parts and products and their availability.

As a general principle, standards development must avoid specifying requirements in ways that limit or hinder meaningful R-strategies in later phases of the product life cycle. By integrating Circular Economy principles into operational business models and management systems and systematically applying standards with indicators, assessment methods and technical procedures that support Circular Economy, standards can help to gradually initiate a transformation of business processes and networks of cooperating companies to a higher degree of circularity.

3 Translation according to Directive 2008/98/EEC [47]

2
Key topics



The aim of the Standardization Roadmap Circular Economy is to describe at an early stage a framework for action that will strengthen German industry, politics and science in the market launch of circular services and products, thus laying the foundation for a transformation.

The Roadmap thus makes a significant contribution to developing circular business models, innovations and scalable applications.

Standards and specifications ensure transparency, quality and reliability, and contribute significantly to the trust in Circular Economy solutions. They are essential building blocks when it comes to scaling the Circular Economy. This can achieve the broad social acceptance of circular products and services, which in turn is a prerequisite for economic success. The Standardization Roadmap thus offers great potential for Germany to take on a pioneering role in the Circular Economy. Not least for this reason, the implementation of the standardization needs presented should be initiated in a timely manner.

The Standardization Roadmap Circular Economy will focus on and name concrete standardization needs on the following key topics: (Chapters 2.1 to 2.7)

→ Digitalization/Business Models/Management
→ Electrotechnology & ICT
→ Batteries
→ Packaging
→ Plastics
→ Textiles
→ Construction & municipalities

During the development of this roadmap, cross-cutting issues were identified that are relevant to several key topics (See Chapter 3).

All chapters include normative, policy, and research-specific standardization needs. What all the standardization needs have in common is the fact that the instrument of standardization is specifically considered and pushed. Standardization needs are primarily addressed to national and international standardization bodies, but also to legislators and the scientific community, depending on the degree of maturity and the framework conditions.

In the following chapter, the standardization needs and addressees are described, derived and justified in concrete terms. An overview in tabular short form can be found in the Annex: Overview of standardization needs.

2.1 Digitalization/Business Models/Management

2.1.1 Status quo

Within the framework of this key topic, which is fundamentally understood as a horizontal topic to the following six sector- or product-specific key topics, starting points for standardization are to be developed which serve either as a strategic or management-oriented framework or as a fundamental foundation for the specific and implementation-oriented standardization needs in different sectors.

For the identification of these needs (i.e., potential gaps in the current standardization landscape), a distinction will be made between the following starting points for standardization:

- → new needs that address new, transformative elements of the Circular Economy (compared to the current linear economy) to provide an appropriate impetus;
- → a systematic harmonization of existing standards and specifications to link fragmented elements of the Circular Economy;
- → a selective supplementation or revision of existing standards to integrate relevant aspects of the Circular Economy.

Procedure to date

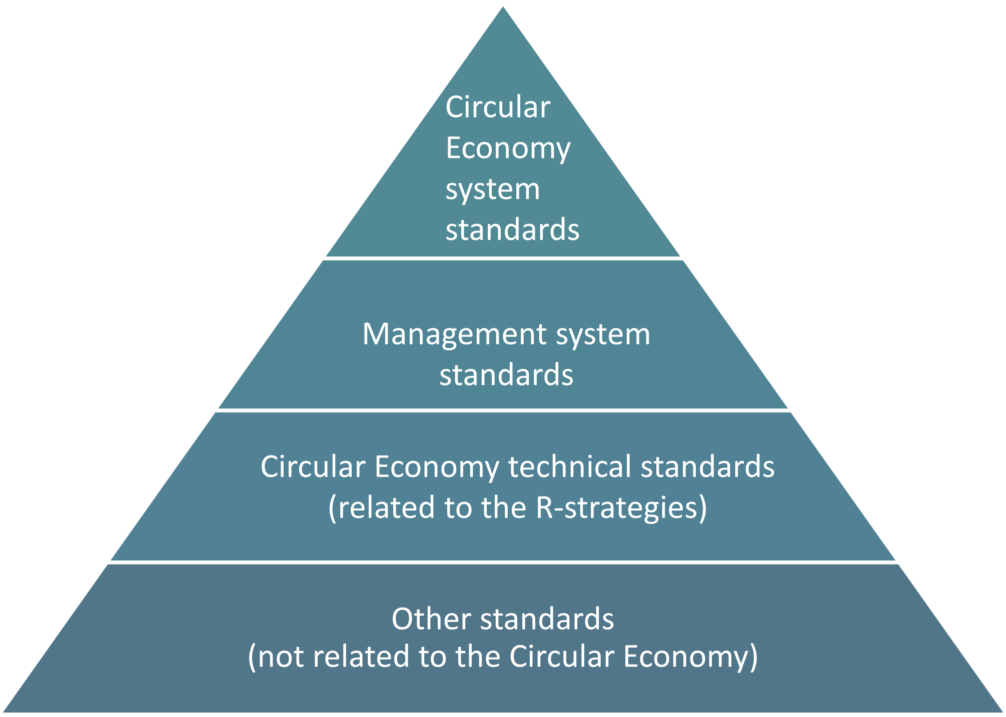
The participant-dependent identification and preliminary description of the potential standardization needs took place within five subordinate topic clusters, which as a whole are intended to reflect the broad spectrum of the key topic "Digitalization, Business Models and Management". The derivation of these topic clusters is based on the initial collection and consolidation of possible topics, and was iteratively adapted or shaped in the course of the work.

Evaluation of standards research

During the collaborative working meetings within the key topic "Digitalization, Business Models and Management", it became evident that a clear assignment of the identified needs to the R-strategies proved to be difficult. This is due in particular to the fact that the standards-based implementation of R-strategies is to be designed primarily on an industry-specific basis. Horizontal topics and horizontal standardization needs are by definition cross-industry and cross-product. Therefore, it can be assumed that the identified needs of this key topic mostly implicitly cover or potentially support several R-strategies, although the actual needs may be rather unspecific with regard to the industry-specific implementation of the R-strategies.

Based on previous considerations and discussions, a novel classification [53] of existing standards is therefore used to evaluate the standards research in the horizontal focus topic "Digitalization, Business Models and Management". This heuristic approach differentiates between four levels of standards (see Figure 12).

Figure 12:
Circular Economy – four levels of standards (Source: DIN [53])



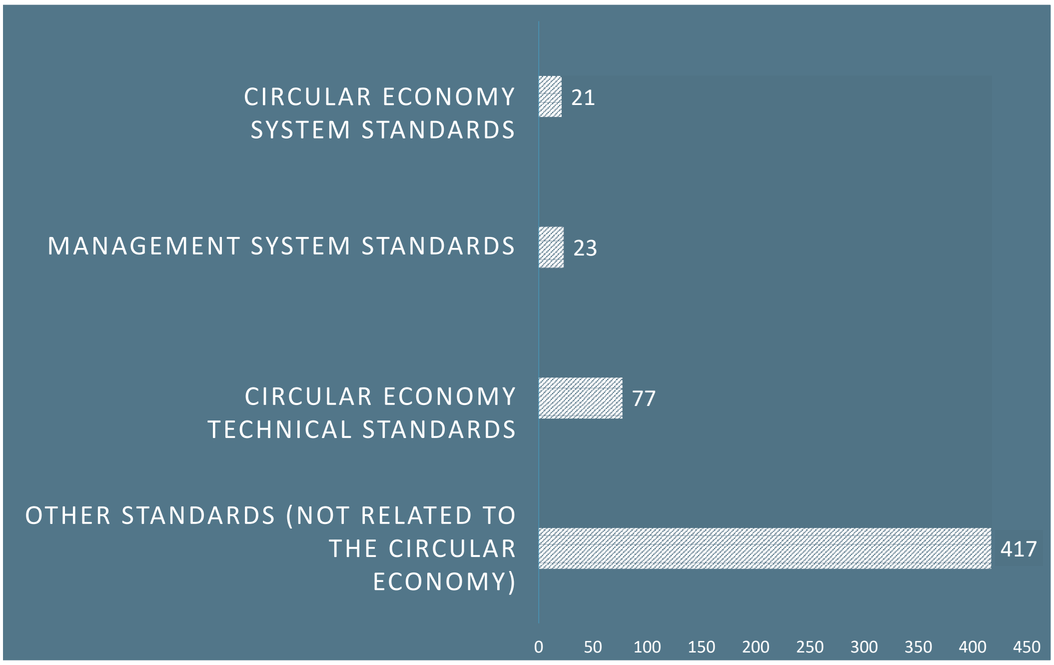
Level 1 – Circular Economy system standards:
The fundamental function of these standards is to establish a basic circular orientation by establishing a common understanding of the Circular Economy through them. Standards at this level include overarching concepts, indicator systems, definitions, taxonomies, frameworks, assessment and calculation procedures through which orientation of organizational units at different levels towards circularity can be achieved. This includes both generic standards as well as sector-specific standards that define a circularity architecture for a certain sector.

Level 2 – Management system standards:
As already mentioned in the Introduction to this Standardization Roadmap, the market potential of the Circular Economy is closely linked to increasing demands on the management of complexity and the radical transformation of entire value chains. Standards and specifications at this level help to increase the competitiveness of the circular industry compared to the linear models established today. This can be achieved, for example, by standardizing operational and organizational rules and procedures and by adopting appropriate policies. Management system standards have, among other things, the function of anchoring Circular Economy system standards in organizations, implementing objectives of circular processes and making successes in implementation measurable.

Level 3 – Circular Economy technical standards:
Standards at the third level mostly serve to provide technical assistance in becoming more circular at this level. There are many standards, such as on "repairability," "remanufacturing," "recycling," etc., i.e., aspects or segments of the Circular Economy that were developed outside of explicit Circular Economy concepts and that can now be more fully integrated into circular operations through overarching Circular Economy concepts. These standards thus contribute to increasing the circularity of products and services from the ground up. Standards at this level may in some cases relate to specific R-strategies; in many cases, they can often be clearly assigned to them.

Level 4 – Other standards (not related to the Circular Economy):
These standards are potentially relevant regulations and prerequisites for a successful Circular Economy, without the respective standards making direct reference to the concept of the Circular Economy. This category includes, for example, standards on sampling and test methods [53].

Figure 13:
Distribution of the identified standards and specifications for digitalization, business models & management to four levels of standards for the Circular Economy (Source: DIN [54])



Methodology

In April 2022, the standards research [54] made available via DIN.ONE contained bibliographic data on a total of 538 documents for this key topic. The standards research was carried out in three phases:

→ **Phase 1:** Generic search using title words, descriptors and ICS groups, etc.
→ **Phase 2:** Assignment of the results from phase 1 to the defined seven subject areas (based on a combination of ICS groups).
→ **Phase 3:** Intellectual post-processing of results to correct obvious misclassifications or other issues.

Furthermore, the standards within this key topic can be classified into the following sub-areas (see Figure 14) (multiple classifications possible):

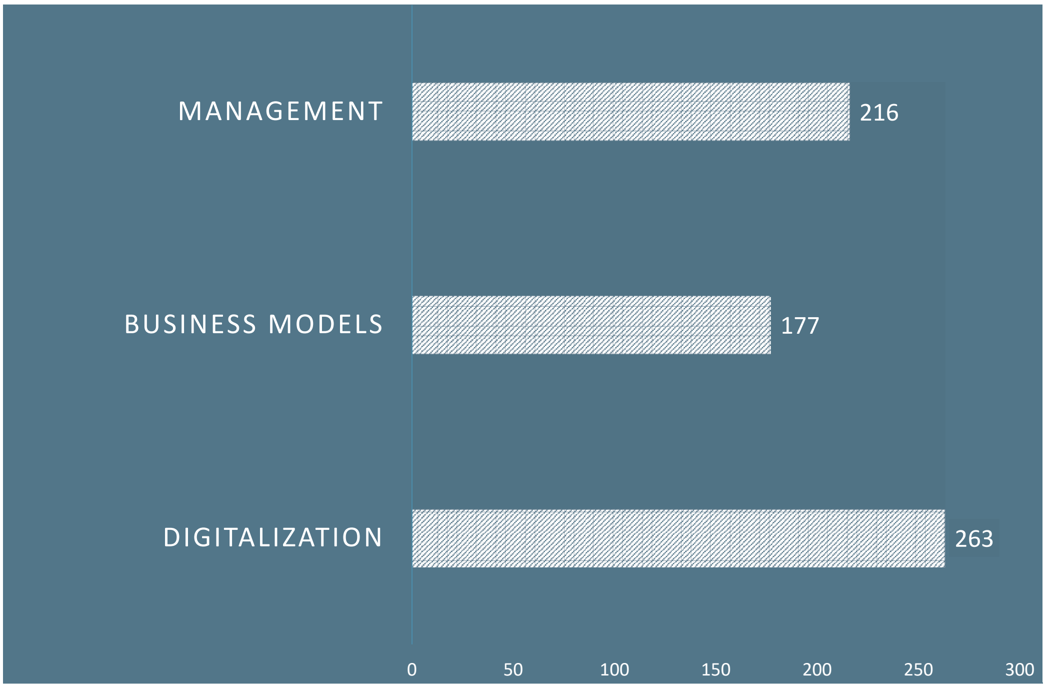
The respective assignment to the sub-areas of this key topic was based on the title of the standards. Thus, this is an indicative assignment to the areas.

Interpretation

The following preliminary findings for further work and the identification of standardization needs can be derived from the analysis:

→ In principle, work is already being done on many strategic and fundamental topics of the Circular Economy (cf. Level 1). In this context, the work within the framework of ISO/TC 323 "Circular Economy", the contents of which are based on consolidated national positions, should be emphasized in particular. In the context of this Standardization Roadmap, requirements at this level should therefore primarily be of a supplementary or harmonizing nature.
→ At Levels 3 and 4, mainly sector- or product-specific standardization needs are expected. These, in turn, are only indicated marginally or selectively in this key topic and are primarily the subject of the following key topics. In this context, it can be assumed that many standards will have to be developed in order to (1) align existing processes and technologies with circularity and (2) integrate standards originally developed for other purposes into circular structures. In addition, standards that support circularity assessments and measurements for specific processes and applications are also needed.
→ Based on this heuristic analysis concept, gaps (especially with regard to the adaptation of existing management systems) can potentially be assumed at Level 2, as these should have a significantly higher number compared to the Level 1. Gaps can be identified above all in the process-related approach of the Circular Economy. For example, the operationalization of the Circular Economy is currently not sufficiently standardized (ISO 14009 [56] goes in this direction, but is limited to material circularity and environmental aspects). Accordingly, there is a need for standardization with regard to the value-preserving

Figure 14: Classification of the sub-areas of this key topic (Source: DIN [55])



processes of the Circular Economy as a supplement to current end-of-product-life related standards and specifications.

→ The three areas (digitalization, business models, management) are not to be understood separately, but are ideally closely interlinked. Therefore, the assignment of a standard to one of these three dimensions is to be understood in such a way that the respective main, but not sole, focus of the corresponding standard lies there.

2.1.2 Requirements and challenges

With regard to the range of topics covered by the key topic “Digitalization, Business Models and Management”, the following general challenges (obstacles) were identified in connection with the operationalization of the Circular Economy (based, among others, on Corvellec et al. (2021) [57]):

→ The Circular Economy is not an entirely new strategy or agenda, but rather a combination of previous approaches (e.g. recycling).
→ There is no uniform definition of the concept (> 100 different definitions).
→ Research and practice mostly focus on material streams and ignore material stocks of products (as well as rebound effects associated with efficiency gains).
→ There is a lack of expertise within companies for implementation.
→ There is an insufficient availability of standards and associated measurement methods to provide objective evidence on the application and development of the measurable components and indicators of the UN’s proposed R-strategies.
→ There is an unclear contribution to sustainability (e.g., measurement of a business model’s contribution to sustainability must be case-specific and systemic, taking into account all stakeholders).
→ Often the introduction of the Circular Economy is described, but less often its operational implementation.

Standards can therefore contribute to the above-mentioned obstacles. In particular, standards can act as a link between the contributions of policy-makers, industry and academia. Here, the generic contributions are to be understood as follows [58]:

→ Policy-makers set framework conditions, targets and economic incentives to give priority to shorter loops (“reuse”, “repair”, “refurbish” and “remanufacture”).
→ Companies evaluate the general approach of the Circular Economy and identify specific technical and organizational starting points.
→ Academia develops consensus on definitions, degree of circularity, normative character and relation to other sustainability concepts.

Furthermore, it is recognized that a large part of the standardization in the topics of digitalization, business models & management could be horizontal (i.e., generic and cross-product).

2.1.3 Standardization needs

Assessment and indicator systems

Need 1.1: Development of circularity criteria for specific product categories
A large number of circularity criteria and indicators already exist, almost all of which originate from the field of material flow analysis (MFA) and are currently being standardized in ISO/TC 323 Circular Economy. Therefore, there is no additional need for the standardization of MFA indicator systems, but there is a need for product-related circularity criteria (see also Need 2.1).

Products can be roughly divided into three groups based on their resource consumption and environmental impact [59]:

Product group 1: Disposable products with a very short service life (for single use).

Product group 2: Products that require little or no consumption of water, electricity or other resources during their use phase.

Product group 3: Products that consume a high level of resources during their use phase.

There is a need for product-specific circularity criteria and indicators for all three product groups, especially for product group 2. The following aspects should be addressed (without compromising product performance or functionality):

→ Durability of a product and thus longevity (assuming typical user behaviour)
→ Modularity in design
→ Maintainability (incl. availability of parts and maintenance instructions)

- → (Dis)assembly options for the entire product and product parts
- → Reusability of the product and product parts
- → Measurement of the proportion of reused materials and parts (in new and second-hand products)
- → Identification of toxic substances that affect or prevent the longevity and reuse of materials and parts
- → Extent and measurement of the expected waste generated during production
- → Achieved resource reduction through the use of reused materials and parts
- → Saving energy through reuse
- → General reduction of negative environmental impacts
- → Further aspects

The aim of these criteria and indicators is to extend the lifetime of products through appropriate product design. However, the main objective is not circularity, but sustainability with its three dimensions – ecological, economic, social. Circularity measures must always be checked to ensure that they are in line with sustainability criteria.

Recommended measures for Need 1.1:

- → Development of generic criteria and indicator catalogues that – like the ones mentioned above – can be applied to a large number of product groups in different fields and that can have an orientation function.
- → On the basis of this: Development of product group-specific indicator catalogues that address the design and later use phases of the product groups, especially for product group 2 with low resource consumption during the use phase.
- → Monitoring the implementation of these proposals and reviewing the application of the indicator catalogues (also with the intention of incrementally optimizing them and adapting them to new requirements).
- → Development of standards to support the achievement of criteria and indicators through appropriate technical procedures.

Such (product) criteria and indicators could complement MFA-based criteria and help support inner cycles and promote product developments designed to save materials and extend product lifetime.

Need 1.2: Quality assurance, conformity assessment and declaration of reused products and products with extended service life ("product life extension")

The **market for second-hand and extended-life products** should be significantly expanded. Potential buyers should be able to choose between purchasing new products and already used, good-quality or high-quality products when making many purchasing decisions. This would help reduce resource use by replacing new products with products that have already been used. In addition, such a switch could help companies focus more on services to keep products functioning, i.e., maintenance and repair. This would lead to an increase in the supply in this service sector and thus to a reduction in the currently often high prices for maintenance services.

However, a significant expansion of the second-hand market and of extended-life products requires a substantial increase in the transparency in this market.

Figure 15 shows the basic challenge: The period between initial use and further use by subsequent users ("reuse") can often be years, during which time maintenance work and refurbishment may also have been carried out on products.

A reliable quality assurance system prior to a transfer to subsequent users could significantly increase transparency and trust in the functionality and quality of extended life products. Successful inspections would be supported by a conformity assessment system (which may include certification) with declarations of conformity to communicate in a simple form information about current quality and functionality to potential purchasers. The focus here should be on the condition of the core functionality of used products and address, for example, the question: "What is a realistic expectation of use of a product (measured in number of cycles of use or over a period of time) without expecting loss of functionality?"

Recommended measures for Need 1.2:

- → A **reliable system of quality assurance for products in later stages of life** should be developed. Quality assurance can be supported by quality indexes for different product groups, in which different quality classes are defined, which signal the current condition of products to potential buyers, in order to achieve security and trust for all business partners.
- → Quality assurance should be supported by a **system of conformity assessment and declaration** for products in later stages of life.

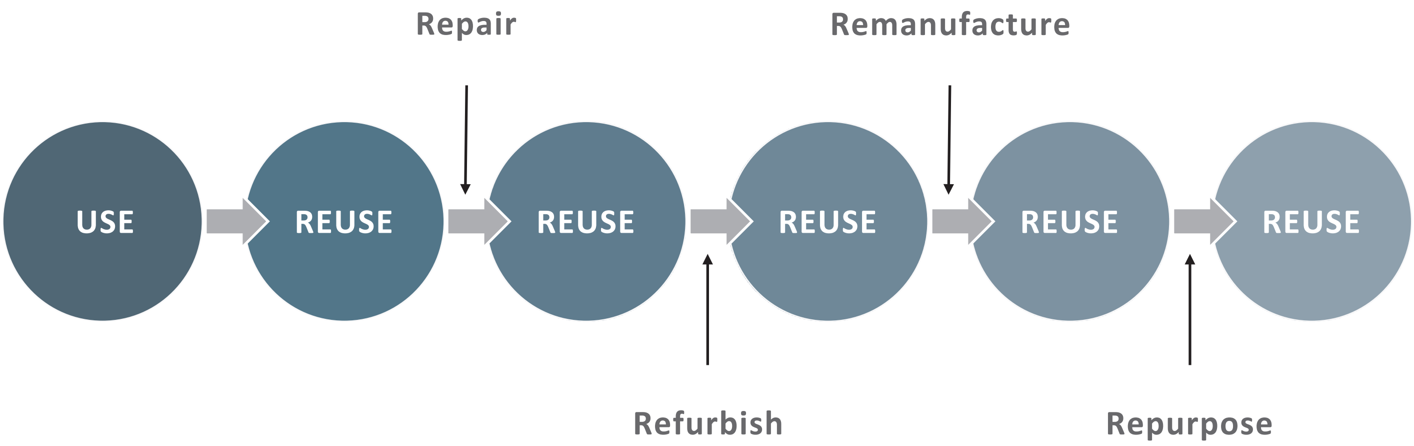


Figure 15: Product lifetime extension due to reuse by sequences of users (Source: DIN)

Need 1.3: Definition and valuation/measurement method for determining the financial value of raw materials (originally waste)
As explained in the cross-cutting theme "End-of-Waste" (EoW, 3.4), the term "waste" is defined differently in the legal systems of different countries and standards. Different waste policies force waste to be classified and declared in different ways, which impacts the ability to reuse waste as a raw material source (including exporting waste). For this reason, the definition of waste should be standardized, especially to encourage, wherever possible, the reuse of waste as a secondary source of raw materials.

The economic loss from not using valuable materials in waste is enormous. One example is eWaste, estimated at approximately US$ 57 billion in 2019 in the Global eWaste Monitor 2020 [60], of which only about US$10 billion is recovered through recycling (17,4 %). Other examples include textiles (losing US$ 460 billion in value per year, according to the Ellen MacArthur Foundation [61]) and food.

Recommended measures for Need 1.3:

→ Standardization of technical guidelines for the definition of waste and waste categories with the intention of promoting reuse/recycling as raw materials (See Chapter 3.4) wherever possible, thereby significantly reducing the amounts of waste.

→ A method should be developed for calculating the value of certain materials or substances currently declared or treated as waste.

Need 1.4: Circular Economy and sustainability reporting
Sustainability reporting has gained further importance due to the decision of the European Commission in 2019 to tighten the requirements for sustainability reports and to initiate the development of European Sustainability Reporting Standards (ESRS). The responsibility for the development of these standards lies with EFRAG, the European Financial Reporting Advisory Group [62]. In April 2022, EFRAG published a series of drafts, one of which addresses resource use and the Circular Economy of organizations (ESRS E5) [63]. Other standards relate to climate change, pollution, biodiversity and other environmental as well as economic and social issues.

The indicators in ESRS E5 address strategy, governance, and materiality assessment for an organization. The indicators applied for performance evaluation are MFA-based indicators (input of resources, output of resources, waste generation, optimization of resource use, and measures to support circular economy). In addition, financial implications of resource use and impacts, risks and opportunities of Circular Economy measures are to be reported.

The importance of sustainability reporting standards will be very great. This opens up the possibility for national, regional and international standardization organizations to support the tightened reporting obligations by providing lists of suitable technical standards and specifications, e.g., for measuring circularity measures taken in operational processes and products.

Recommended measures for Need 1.4:

→ Standards organizations should identify such standards and specifications that are suitable to support the new reporting format of EFRS E5 and the other new reporting standards. Lists of relevant standards (with a focus on European and International Standards, but also other standards) should be compiled and kept up-to-date, which can be used to implement circularity measures in companies and to fulfil the various reporting obligations.

→ Sample reports based on the new reporting format should be prepared to demonstrate, using practical cases, how standards and specifications can be used for sustainability reporting with the help of the lists of standards that have been prepared. This could be developed into a new information service on the part of DIN for its customers.

Data and information structure

BASIC REQUIREMENTS AND PRINCIPLES

Need 1.5: Definition and delimitation of the different concepts for making product-related data available on the basis of a suitable framework concept

Digital solutions such as the digital twin (DT) and the digital product passport (DPP) can help to implement the Circular Economy by providing product-specific data and information at an economically justifiable cost to enable the operationalization of R-strategies. The DT is considered a promising trend in the industry and is versatile. The field of application ranges from condition monitoring to autonomous systems. As a result, there are multiple requirements, challenges, and goals for the DT that have led to a lack of a common understanding of the concept of the DT in practice Although the terms DT and DPP are often used synonymously, it is important to keep in mind that these are different instruments that may be linked by appropriate interfaces (see also Needs 1.24 and 1.26). In addition, other precursors and implementation ideas can be identified (e.g. environmental product declaration according to DIN EN ISO 14025 [64], ISO/WD 59040 [65]) that pursue similar goals. Therefore, there is a need to distinguish the basic precursors and implementation ideas (especially the DT and DPP) from each other, where necessary, as well as to define their different manifestations. Furthermore, it is suggested that terminology and implementation strategies be harmonized or aligned by establishing the appropriate references between existing works (see, for example, the Industrie 4.0 administration shell (as a manifestation of a DT) according to DIN EN IEC 63278-1 [66] as well as ISO/IEC JTC 1/SC 41/WG 6 (DT). For this purpose, it may be suitable to develop an orientation framework (e.g., delimitation based on the respective properties and possibilities of the instrument: from passive/static to proactive/automated), linked to clear product categories from the perspective of the Circular Economy (for this, see Need 1.6 as well as the DIN/DKE Standardization Roadmap Industrie 4.0 [67]), since the use of the concept of the administration shell over the life cycle is described there).

Need 1.6: Development of a taxonomy of abstracted product groups in the context of the Circular Economy

The basic applicability of Circular Economy strategies and measures (see Chapter 1.6.3) depends first and foremost on the respective product characteristics. Furthermore, it can be observed that successful measures to improve the Circular Economy have to be designed very specifically to the product [68] and the corresponding context (e.g., value chain, user behaviour). The complexity in identifying appropriate measures is further increased by the unavoidable interactions and trade-offs that can be induced by certain interventions within a product life cycle. In order to be able to recommend suitable strategies, instruments, business models and indicators to industrial companies and political stakeholders in particular, and to facilitate the identification process, an abstracted and Circular Economy-oriented classification of product groups (see also Need 1.1) could provide an initial framework for orientation. A suitable level of abstraction should be developed to ensure cross-industry applicability (i.e., horizontal standard). Potentially suitable dimensions for differentiation could be, for example, as follows:

→ inherent product characteristics (dimensional/non-dimensional)

→ product complexity

→ service life and characteristics of the use phase [59]

Another point of reference for the development of possible product groups is the “Resources States Framework” developed by Blomsma and Tennant (2020) [69], which distinguishes between “particles” (elements, substances, molecules, materials), “parts” (components, modules, assemblies) and “products” (finished products).

The elaboration of these dimensions as well as the ultimate taxonomy of products from a Circular Economy perspective is therefore a fundamental need, to be located at the level of the Circular Economy system standards (see Chapter 1.6.2).

Need 1.7: Use of semantic technologies for data exchange in the context of the Circular Economy
The digital exchange of information on products throughout their life cycle is seen as a prerequisite for the large-scale and economic introduction of a Circular Economy. Digital information exchange can take place at different levels of digitization:

1. Digitized: Information is exchanged through electronic media (e.g., e-mail) rather than physical media (e.g., paper). However, the information itself must be read and interpreted by a human. Example: Scan of a paper document.
2. Machine-readable: The exchanged information is prepared in such a way that a machine (software) can read the data. The interpretation of the information must still be done by a human. Example: A software detects that there is a field "efficiency" with a value "95". Since the definition of "efficiency" is not clear to the software (the context is missing), a human must decide to which evaluations the specified value can be used. (Note: Artificial intelligence systems may also be able to provide interpretation of such information, but this will not be considered here).
3. Machine-interpretable: For the transmitted information, the context is given in an unambiguous way that allows a machine (software) to draw automated conclusions. Example: The "efficiency" field is designated by a unique "semantic identifier". This allows the software to determine what energy consumption will occur in the operation of a machine given an expected usage profile and the specified efficiency. In this way, decisions in selecting a machine can be (partially) automated.

Semantic technologies encompass a variety of different methods and technologies used to represent, manage, exchange, or process semantic data. The core of this work is on machine-readable formats for data and schema information (ontologies) [70]. On the part of standardization, semantic features of the Common Data Dictionary (CDD) according to DIN EN 61360 [71] and ISO 13584-1 [72], and corresponding formats for the description of DT come into play here (see also Need 2.13). The CDD describes not only the features, but also their classification (semantics and ontology).

By leveraging semantic technologies, the unambiguous use of data can be achieved across the value chain and life cycle. This is a prerequisite for the machine interpretability of data and for the automation of work steps.

Recommended measures for Need 1.7:

→ When developing product-specific standards for data exchange in the context of the Circular Economy, the semantic technologies described should be applied and the standards listed should be referenced or built upon.

→ To achieve interoperability, the semantic technologies described and the standards listed should be applied when implementing Circular Economy use cases.

DATA MODELS

Need 1.8: Normative principles for the structure of defined cross-sector content and its presentation in the digital product passport (basic structure for the presentation of information that can be displayed equally for all products)
The content requirements for the digital product passport are already being discussed in various bodies on a sector-specific basis. So far, however, there is no overarching approach to consistent basic elements and structures. Normative principles are required for the construction of defined cross-sector content and its representation in the digital product passport. As an analogy to a passport document, this would be the title page with the information that can be presented in the same way for all products, such as information on the manufacturing company/marketing company, picture/drawing of the product, dimensions/grain size of the product, weight/density, list of approvals if applicable, and information on critical substances or substances of concern according to the REACH Regulation [73], where applicable.

Need 1.9: Normative principles for the structure and grouping of product-specific content and its presentation in the digital product passport
In addition to cross-sectoral information, there is a wide range of product-specific information (e.g., carbon footprint, energy efficiency values, recyclate content, and recycling information (e.g., recyclability)) that will be relevant to the expansion of the Circular Economy and thus must be included in the DPP. Displaying all sector-specific information on one main page leads to confusing web pages and therefore requires standardized submodels (see also Needs 1.10 and 1.11 for specific cross-sector submodels). Furthermore, instructions on how to fill the respective information groups, as well as the assignment of responsibilities are necessary.

Need 1.10: Definition of standardized data structures of life cycle-relevant data in the digital product passport or in the form of one or more submodels for the Industrie 4.0 administration shell on the topic of Circular Economy/life cycle assessment
The life cycle assessment (LCA) of manufactured products, but also of production resources, such as robots in combination with certain manufacturing technologies such as welding, is becoming increasingly important in terms of resource scarcity and rising energy costs, also in the industrial context. In life cycle assessment, potential effects on the environment are systematically collected over the entire life cycle. In addition to production, this also includes the use phase and disposal of the product, as well as all associated upstream and downstream processes for the production of raw materials, consumables and supplies – in other words, all aspects of the Circular Economy. Required information relates to raw materials processed, necessary energy/air/water/... as well as greenhouse gas/carbon dioxide emissions, the amount of waste and the associated pollution of air and water. Information for life cycle assessment therefore not only comes from the production context, but must be collected across all phases of the life cycle and all dimensions of the reference architecture model Industrie 4.0 (RAMI 4.0) [74]. This is an example of a use case in the context of the “connected world”. This requires the definition of standardized data structures of life cycle-relevant data in the digital product passport or in the form of one or more submodels for the Industrie 4.0 administration shell on the topic of Circular Economy/life cycle assessment. This need is addressed to all stakeholders from the manufacturing sector, but especially to component and equipment manufacturing companies from industry.

Need 1.11: Standardized and exchangeable simulation models for dynamic information as a function of time or various other parameters, as well as versioning of data/information over the life cycle or various combined life cycles
In addition to the purely static information in the product passport, the dynamic digital twin also requires standardized simulation models, e.g., for the energy consumption or emissions of the products/system components. Since information changes over time, the principles of versioning and the associated configuration management for the digital product passport and the associated dynamic models must also be created and standardized. Appropriate versioning of data/information is a prerequisite for the integration and also the matching of different information from the digital product passport and dynamic digital twins. The issue of data sovereignty also plays a role here, as different versions of the information may carry different rights, obligations, ownership and guarantees. This need is addressed to all stakeholders from the manufacturing sector, but especially to system operators from industry.

Need 1.12: Normative basis for the presentation and linking of data that is already publicly available in databases and linking with the new requirements for the digital product passport (information requirements for various product groups)
At the present time, it has not been conclusively clarified where and how (substance, origin) information is to be stored (centrally or decentrally) and how the relevant stakeholder groups in the product life cycle are to have access to it. Furthermore, the integration of links to further information from any upstream products used and downstream relevant data generated during the life cycle is necessary. In the case of decentralized data storage, for example, there could be standardized linking to other relevant data that is created upstream, as well as a standardized process for linking data that is created downstream. Some information about products is already stored in various databases. For example, information based on the REACH regulation [73] is provided in the database of the European Chemicals Agency (ECHA) exclusively on substances of concern in the SCIP database (substances of concern in products) for all product groups. Multiple provision of information carries the risk of different information on the same issue depending on where the data is retrieved. Other databases exist for product information in the automotive industry (e.g. IMDS [75]/IDiS [76]) and in the electrical and electronics industry (I4R platform [77]). There is a need to define what data must or should be made publicly available and how it can be accessed or queried by machine.

Need 1.13: Development of a user-centred, digital solution through standardized methods and tools, as well as guidance on the use of the DPP for the various stakeholder groups
Digital solutions (DPP and the digital twin) that provide data and information along the value chain of a product can help to implement the concept of the Circular Economy. User-centric development is needed to ensure that data is made available. It is important that the users are made aware of the added value of the digital solution, and that the motivation to provide data and acceptance of the digital solution increases by involving the users in the development. A defined procedure for developing a user-centric, digital solution using standardized methods and tools is suitable for this purpose.

In addition, there is a need to develop guidance on the use of the DPP created for the different stakeholder groups. This is to explain to the user groups, taking into account their "perspectives", how the DPP works as a tool and how the specific use of the DPP can support the creation and establishment of a Circular Economy. The aforementioned needs have the goal of making the added value visible both in the development phase and in the use phase of the DPP by integrating the specific needs and requirements of the user groups and thus promoting motivation and acceptance for the use of the DPP.

Need 1.14: Standardization should support legislators in defining and implementing the individual access rights of various stakeholders along the value chain

The digital product passport will be used by a variety of different stakeholders with a wide range of information needs. Data protection principles, in particular a GDPR-compliant design of the DPP and individual access rights for different stakeholder groups, must be enshrined in law. In this context, it should be specifically defined which contributors along the value chain are granted the right to view, edit and use the information. Secure digital identities play a central role here, i.e. the question of how the participants in the value chain identify themselves. In addition, data integrity must be ensured with appropriate mechanisms, and the protection of data against unauthorized access and manipulation must be guaranteed. In particular, existing standards (e.g., ISO/IEC TR 10032:2003 [78]) and standardization activities (e.g., NWIP ISO 22373 [79]) should be considered when identifying stakeholders and protecting data from unauthorized access.

Need 1.15: Existing standards and specifications that define the technical features for different identifiers should be examined for their applicability to the DPP

Different possible interfaces/identifiers (RFID, QR code, NFC ...) should be considered for reading the information stored in the DPP and their usability for different products or sectors should be evaluated.

DATA QUALITY AND SECURITY

Need 1.16: Establishment or adaptation of standardized mechanisms to ensure data quality and trustworthy information in the digital product passport

The digital product passport is designed to ensure participant-specific access to relevant information This calls for aggregated quantitative information (e.g., carbon footprints as well as other LCA indicators, calculated recyclate content), among other things, to be made available. Due to the inherent complexity as well as the existing degrees of freedom and fuzziness (e.g., unavoidable allocation of data points and/or dependence on generic/non-representative industry data) in the underlying calculation methods, this area is already addressed by a large number of standards and specifications, as well as related guidelines. Nevertheless, existing standards and guidelines (e.g. DIN EN ISO 14040/44 standards [80], [81], the Greenhouse Gas Protocol [82]) and sectoral guidelines (such as the Product Category Rules (PCR) or the Product Environmental Footprint (PEF) methods) still leave much room for manipulation. In principle, it can also be assumed that the establishment of an infrastructure for the technology-supported (digital) exchange of product-relevant data (e.g., emissions data) will also create the basic conditions for greater transparency and traceability. However, this is not automatic and therefore, in addition to uniform rules (as already developed, for example, in the context of the Product Category Rules (PCR) within the EU Environmental Footprint Pilot (EFP) [83] or other EPD programs or also by the (WBCSD) [84] in its Pathfinder Frameworks) for generating and making available data, mechanisms are also needed to ensure compliance with the agreed rules. This is precisely where standardization could come in and adapt existing (already standardized) test mechanisms to the new (digital) conditions or close gaps in conformity assessment. This could make a decisive contribution to ensuring trustworthy information and data in the digital product passport and thus the acceptance of the instrument, as is also called for in the EU Commission's current "Proposal for Ecodesign for Sustainable Products Regulation" [85].

Need 1.17: Standards and specifications should provide a framework for the depth of data required

In order to strengthen the acceptance of the DPP and to simplify the handling and presentation of the data volumes, the concept of data economy should be taken into account in the design of the DPP. This should include a fundamental discussion of what data is really essential to implement the DPP.

Operationalization and monitoring

MANAGEMENT SYSTEMS/STRATEGIES

Need 1.18: Integration of the Circular Economy into strategies, business models and management systems of companies
Companies should incorporate the principles of the Circular Economy into their strategy and business model in order to develop new business opportunities and to be prepared for regulatory measures. Existing standards and management systems in companies should be supplemented with Circular Economy principles and methods. This would enable companies to systematically prepare for the requirements of the Circular Economy at a strategic level as part of an integrated management system. This ensures that they are not stand-alone Circular Economy strategies and thus ensures connectivity with management systems already in use in the company. This helps to anchor Circular Economy principles operationally in the company and thus to bring together and steer singular activities in a continual, active improvement process.

Need 1.19: Systematic approach to Circular Economy potential development
Companies need systematic approaches and suitable tools in order to be able to address and process all related and necessary fields of action. In addition, the potential for further development should be recognizable and able to be communicated. In the context of integrating Circular Economy aspects into existing management systems, a standardized approach helps to reduce the effort required for the process of identifying Circular Economy potentials and deriving strategies suitable for the respective company, and to operationalize the process as part of a continual improvement process.

MATURITY LEVELS

Need 1.20: Maturity level of the overall business concept
A company's maturity level in the Circular Economy should always be assessed for the overall business concept and operations. This ensures that management has a realistic assessment of the starting point in the transition to the Circular Economy, and that realistic targets and individual measures that build on one another are defined. In order for companies to identify their maturity level with regard to various parameters (e.g., business model, strategy, innovation/product development, customer processes), standards are required for the comparability of these parameters. This enables companies to identify where the greatest leverage for further development lies.

A maturity model enables the company to identify progress in the transformation to the Circular Economy in order to proactively manage the process. Existing standards and specifications such as DIN EN ISO 9004 [86] do not assess the Circular Economy and should be supplemented accordingly. All relevant areas of a company as well as the status on the hierarchy level of all R-strategies must be holistically recorded and evaluated. Currently, there is a lack of uniform performance parameters at the product/company level that would allow companies to be compared. The assessment at the meso (company) level should be designed in such a way that it can also be consolidated at the macro level. These parameters are necessary to enable a basis for qualified judgements on maturity levels, to ensure the credibility of assessments, to compare the level of development e.g., between companies, cities etc. and to evaluate the effectiveness of Circular Economy measures and action plans. Needs from the area of assessment and indicator systems should be considered. An example of a catalogue of criteria and indicators for determining the maturity of companies in terms of circularity is provided by the Swiss Circular Economy Status Report [87] with the following main criteria and sub-criteria for individual measures:

"Main criteria for determining the circular maturity of companies
Criterion 1: Degree to which circularity and circularity principles are embedded in a company's business model and corporate strategy

Criterion 2: Extent of investment to support measures to increase the circularity of processes within the company and its relationships with collaborative partners (other companies, R&D initiatives, logistics, etc.).

Criterion 3: Number of individual measures a company has taken to promote circularity in specific areas (with further sub-criteria 3.1 to 3.7, see below).

Criterion 4: Proportion of turnover resulting from circularity-relevant activities

Sub-criteria for individual measures under Criterion 3 for specific areas of the company:

Criterion 3.1: Circularity-related measures regarding procurement

Criterion 3.2: Circularity-related measures regarding product and service design

Criterion 3.3: Circularity-related measures concerning internal production processes

Criterion 3.4: Circularity-related measures regarding storage and transport

Criterion 3.5: Circularity-related measures regarding marketing and sales

Criterion 3.6: Circularity-related after-sales measures
Criterion 3.7: Circularity-related measures after the product use phase

Here is an example of how circularity is measured in specific business areas: In procurement, for example, the reduction of the ecological footprint when buying new products or the increasing use of used production inputs, i.e. the reuse rate, can be used as measurement criteria.

By applying such a catalogue of criteria, it is possible to determine the maturity level of companies in terms of circularity and to compare them between different companies." [87]

KEY FIGURES AND ASSESSMENT SYSTEMS

Need 1.21: Circularity assessment of services
Companies operating on the basis of a circular business model need an assessment of services and their contribution to circularity in order to identify and value the service share in the revenue stream. The focus of the assessment should be on the extension of the useful life of the products and it should possibly also consider the percentage of revenue from circular services [14].

Need 1.22: Key figure for use of recyclates
For individual companies and companies cooperating with each other, there is a need for a process-oriented standard that regulates the inflow and outflow of recyclates and makes them comparable. Such a standard would give customers and users the opportunity to compare products or manufacturers with each other. At the same time, the standard could give an impetus to companies to increase the shares.

POTENTIALS AND BUSINESS MODELS

Need 1.23: Exploiting the Circular Economy potential for business model innovation and re-design
The Circular Economy opens up potential for companies to develop new, sustainable and future-oriented business models. Existing solutions for realigning the business model can support companies in systematically shaping this transformation process. Guidelines and case studies (good practices) of companies that have successfully further developed or completely replaced their linear value creation processes with a circular business model would be helpful in this regard. Furthermore, a structured collection of possible Circular Economy business model patterns for the systematic re-design or reorientation of the existing business model would be useful to illustrate the added value that can result from the implementation of a circular business model for one's own company. A collection of possible instruments (toolbox) for systematic maturity level and position determination for continual evaluation and further development of the business model in the direction of circularity can support this (CIP).

To simplify access to these business model options, tools, and good practices for the user, they should be provided based on relevant criteria, differentiated by process, R-strategy (see Chapter 1.6.3), product type, and customer offering or industry. This field could be covered and supported by Technical Reports. Whether a standard or a specification subsequently emerges is to be decided. Publications from a scientific point of view are available and a consolidation is to be aimed at [14], [89], [90], [91]. This can be done in the context of standardization work.

Need 1.24: Creation of measurement bases to determine "circularity success factors" and to allow comparisons to be made
Various management system standards (e.g., DIN EN ISO 9004) [86] recommend benchmarking. This is a measurement and analysis method that allows an organization to look for best practices inside and outside the organization to improve its own performance. Benchmarking requires a common understanding of the characteristics of the object under study in order to make a proper comparison with the current situation in the organization. It would therefore make sense to define success factors in standards in order to make the degree of circularity of organizations assessable and

comparable in implementation. Companies can use such a comparison of success factors as a reference point to improve their own Circular Economy performance or Circular Economy business model. It should therefore be specified which indicators are suitable for adequately reflecting these circular potentials in organizations and business models. Such circularity indicators could be used to determine the success of implemented circularity measures as well as to identify areas where optimization potential exists [92], [93].

Collaboration in the value chain

The transfer of the economic system toward a Circular Economy entails comprehensive changes in all areas of the value chain (which becomes the value loop). In particular, new forms of collaboration will be required and new business models will emerge. All these changes affect the collaboration of different industry stakeholders or different industries and, in order to be efficient, require the definition of terms, data and interfaces. Providing these descriptions and definitions is a core task of standardization work and can lead to significant efficiency gains for the national economy. The current state contains multiple barriers to the establishment of a Circular Economy, as it enables inefficient communication between contributors due to unclear technical data/disclosures, and additionally contains unclear legal frameworks, which entails massive risks for the participants. These problems should be remedied by standardization work in order to specifically promote the emergence of business models and the development of offerings in the sense of a Circular Economy.

To ensure efficient collaboration and clear communication within the value loop and to promote circular value creation, the following **five needs** (1.25-1.29) were identified.

Need 1.25: Definition of terms for the Circular Economy
The transition of economic activity to a Circular Economy entails numerous terms for the cooperation of stakeholders that have not yet been clearly defined and are therefore not uniformly used and understood [7], [9], [94], [95], [96], [97], [98]. Even fundamental terms such as the "Circular Economy" itself are not clearly defined, nor are they demarcated from established terms in German such as "Kreislaufwirtschaft" (another German word for the Circular Economy). On this basis, it is also necessary to develop clear provisions and definitions for circular value loops, in particular also for regional and local loops. The need arises not only from the goal of efficient communication between stakeholders within value loops, but also from the need to make (political) targets of the Circular Economy clearly interpretable and their implementation measurable. The description of the content of the targets must be unambiguous for this purpose, for which clear provisions must be developed in the standardization work.

Recommended measures:
→ Elaboration of a standard with definitions of the fundamental terms of the Circular Economy
→ Development of normative provisions for the description of Circular Economy targets, including the definition of provisions for the achievement of targets as well as for the spatial reference and the reference to individual contributors
→ Development of terms and descriptions of the main stakeholders of circular value loops

Need 1.26: Definition of units and variables for the Circular Economy
The clear and reliable description of facts is indispensable for the collaboration of different participants in a value loop. The fundamental prerequisite for this is a clear definition of the relevant variables and units as well as reference variables and effects. Currently, this is often not the case for data relating to the Circular Economy and, accordingly, data cannot be clearly interpreted and compared. This concerns, on the one hand, information exchanged between companies (B2B) and, on the other, information exchanged with end customers (B2C). In the context of the Circular Economy, it is particularly important to define reference variables in order to make quotas unambiguous. Criteria and indicators of environmental and social impacts, such as circularity and recycling quotas, as well as the information described in Need 1.1 "Development of product category-specific circularity criteria", among others, should be mentioned here.

Recommended measures:
→ Elaboration of standards with units and variables of the Circular Economy
→ Development of normative provisions for the use of reference variables for data in reporting as well as reporting formats for Circular Economy-relevant data on companies and products, which can also be used for the DPP, for example
→ Development of normative provisions regarding data disclosure and data quality (see Need 1.16), accuracies and formats for the information on Circular Economy metrics

Need 1.27: Management of technical and legal interfaces
Due to the expected new business models and forms of collaboration, as well as flows of resources and data that are expected within the Circular Economy, there is also a need to define the interfaces between the different stakeholders within and between different product value chains in order to enable value loops in interaction. On the one hand, this is about the content-related (technical) interfaces, the transfer points of resources between different steps of the value creation cycle. On the other hand, there is a need for the definition of the legal interfaces, in particular the transfer of responsibility for products and on issues of product approval and conformity assessment. The interfaces of the participants should be described by normative rules in such a way that the cooperation of the various contributors can take place efficiently. Of particular importance for the establishment of measures for the efficient use of resources and for promoting the development of corresponding offerings and business models are the definition and safeguarding of the legal framework and the legal certainty of business models and operational decisions, including the fulfilment of technical and commercial reporting requirements. The Circular Economy also raises elementary questions about product liability and product approval, especially for "repair", "refurbishing" and "reuse", which are currently unclear or in some cases directly hinder development.

Recommended measures:
→ Elaboration of a guideline with rules for cooperation in Circular Economy networks
→ Elaboration of normative provisions for technical interfaces between various participants in a value loop or different value loops
→ Elaboration of normative provisions regarding the transfer of responsibility in the case of repair and refurbishment or further use of products, as well as in the case of the use of materials/products after recycling
→ Elaboration of normative provisions on questions of approval of products after repair/refurbishing/reuse
→ Elaboration of normative provisions for (open) interfaces for the exchange of data, e.g., material databases

Need 1.28: Communication between participants in the value loops
Basically, cooperation within the supply chain is necessary for every company. For business models of the Circular Economy, the interplay between work and task sharing is required more intensively in order to realize the value creation potential.
In order to meet the requirements, a reconsideration of the core competencies must take place. What existing expertise can be brought in and what can be built up by oneself? Which services need to be additionally staffed and which partner portfolio is required for this? At the same time, the demands on already involved service components such as IT performance, logistics or marketing are increasing. This gives rise to normative needs for communication bases to be defined on the basis of the necessary stakeholders and their roles (see Need 1.34).

Recommended measures:
→ Establishment of a stakeholder map for circular business models and their value loops (see also Need 1.29: Classification of business models).
→ Derivation of a communication matrix for the relevant stakeholders (e.g., for the minimum information to be communicated on roles, tasks, functionalities and responsibilities within the value loop).
→ Description of communication processes to ensure the implementation of the division of tasks and work ("circular functional specification").

Need 1.29: Classification of business models
It is expected that numerous new business models will emerge or existing business models will undergo an adjustment in connection with the transition of the economy to a Circular Economy. This development is necessary, explicitly desired and is to be supported, see also the description in the context of Needs 1.18 and 1.19. For cooperation in a Circular Economy, however, it is considered important that business models and the associated activities and contributions within a value loop are clear to all stakeholders and that misunderstandings are thus also avoided in cooperation. In particular, the work can also use preliminary work [14] and focus on giving detail to already defined and classified business models.

Recommended measures:
→ Development of descriptions of Circular Economy business models for classification, but not in the sense of standardization of business models or exclusivity of the described business models.
→ Development of classes of business models of the Circular Economy.

Product creation processes and service development (design 4 circularity)

STANDARDIZATION NEEDS IN THE AREA OF GOAL SETTING, BUDGET PLANNING AND STRATEGY DEVELOPMENT

Need 1.30: Establishment of an infrastructure to support reverse logistics
Numerous companies are planning to integrate flexible consumption models into their business model and offer their products "as a service" (XaaS). A successful changeover requires a suitable infrastructure that supports reverse logistics and ensures an efficient process. In most cases, the conversion to an XaaS business model fails due to the high volume as well as the complexity. Compared to traditional models, XaaS business models are customer-centric, not product-centric. Therefore, XaaS business models require a separate infrastructure that supports customers along the value chain and enables processes to run smoothly (e.g., end-of-life treatment of products, new revenue models). The XaaS offering becomes more complex when companies build this on existing business models and continue to run it in parallel.

The core idea of a service business model is that it consists of a large number of customer-related, usage-oriented units (services) that are managed independently of one another. Unlike a traditional product, these units have clearly defined customers that they address. The benefits of the service are clearly evident to the respective customer and must create added value over the usage phase that goes beyond the purchase of a product. The responsibility of the service and also product is borne by the company (service owner), which must ensure service delivery [99].

Recommended measures:
→ Here, standardization can, among other things, support (reverse) logistics and other cooperations in the development of "service spheres" via planning principles that are a basis for R-strategies as well as the perspective "from ownership to benefit".
→ Elaboration of normative templates regarding the development of an infrastructure that supports the implementation of "as a service".

Need 1.31: Design and depth of service degree/level (service depth and breadth).
Shaping service depth and breadth via service level management is now used significantly more often by top performers, at 62 %. Only 31 % of followers report using this in over 50 % of service cases [100]. Greater integration would make processing and, above all, administration more efficient and effective. Standardization can help here, since provisional, manual routines are established in companies today without a corresponding basis about technologies that could be installed in the companies. And: These design technologies are only fully usable if they are also integrated at appropriate interfaces at the customer's site.

Recommended measures:
→ Standardization can help with the design and depth of service level(s) so that new services can emerge within and between companies.
→ Elaboration of normative templates regarding criteria for service levels.

Need 1.32: Definition of circular business management processes
For companies, the Circular Economy means acting sustainably in line with economic, ecological and social targets. The basis for this is a practiced and measurable sustainability management (see also Chapter 3.1). The established sustainability targets are further defined with a focus on circular business development (circular horizon). Similarly, the focus must be fixed on the necessary circular expertise to implement the company's strategy. This gives rise to normative needs for defining circular business management processes in terms of structure, transparency and measurability.

Recommended measures:
→ Development of a normative definition of a circular corporate target (circular horizon) and the necessary contents.
→ Building a normative structure for circular business management processes incorporating R-strategies as frameworks and circular key performance indicators (KPIs) as measurement tools.
→ Development of a normative catalogue of requirements for relevant circular competencies within and outside (stakeholder map) the company.

Need 1.33: Include the Circular Economy in the design phase
Everything begins with the design. For the development of circular business philosophies and business models. For the design of circular products.

Circular Economy Design (CED): The task – how to keep the resources within the ecological cycle? This is where design comes in. The foundation for success is laid for all subsequent elements. Design initiates the processes for production, distribution, use, refurbishment, remanufacturing, upcycling, upgrading and recovery.

Circular Product Design (CPD): The quality and processing of the raw materials and materials to be used play a major role. They must allow a long period of use of the products. Resilient, robust and thus safe – requirements for multiple use. The type of ecological production and final treatment lays the foundation for remanufacturing and refurbishment, among other things. Decisions are made during the design phase. This gives rise to normative needs for design definitions (CED/CPD), which should consider all economic, environmental, and social impacts across all phases of a product or process life cycle.

Recommended measures:

→ Development of a normative definition of circular economy design (CED) incorporating life cycle thinking (LCT).

→ Develop a normative definition of circular product design (CPD).

STANDARDIZATION NEEDS IN THE AREA OF CIRCULAR PROCESSES

Need 1.34: Uniform description of roles and responsibilities for an effective change management process

Standardization can ensure that roles and responsibilities are clear within organizations and that there is room for an effective change management process and a supportive cross-functional culture.

Fixing the requirements of the overall transformation process – including the relevant elements of change management, service design and servitization – forms the basis for initiating and implementing the sustainability circularity strategy. This gives rise to normative needs for the various requirements of the above-mentioned change processes with regard to the definition of roles, responsibilities and objectives.

Recommended measures:

→ Evaluation of a normative description of roles, responsibilities and objectives in the transformation area “change management” (including focus on CSR implementation, development of USP Innovation, implementation of thought leadership)

→ Evaluation of a normative description of roles, responsibilities and objectives in the transformation area “service design” (including focus on customer journey)

→ Evaluation of a normative description of roles, responsibilities and objectives in the transformation area “servitization” (including focus on service strategy and service philosophy)

Need 1.35: Right to maintenance (maintenance/repairability) and provision of information required for this purpose

Maintenance depends on the technical possibility of availability of a maintenance service and on the costs. The possibility of non-destructive disassembly, the availability of spare parts and the availability of knowledge for repair or maintenance are important. The challenge: Interaction with other parameters such as prices, innovation cycles, demographic development [101], [102].

Recommended measures:

→ Standardization should ensure that the possibility or the right to maintain (maintenance/repairability of) products is given in the long term.

→ Standardization should lead to improved consumer information, e.g., environmental benefits of durable products, knowledge of self-service options. This goes hand in hand with the preservation of a manufacturer-independent maintenance scene. From an environmental point of view, the choice of maintenance service provider, manufacturer-affiliated or independent, is of secondary importance. In addition, it is a question of increasing the information obligations of manufacturers, e.g., a clear declaration of wear parts.

→ Further, it is a matter of reviewing and adapting existing safety standards and specifications at the component level (with a focus on components susceptible to defects and wear) with regard to their suitability for service life and durability testing. This involves the creation of knowledge about the real loads and conditions of use of products with an extensive survey of consumers and subsequent investigation of the influence of the boundary conditions of real use (e.g., thermal load peaks and peaks in the supply voltage) on product service life.

STANDARDIZATION NEEDS IN THE AREA OF PEOPLE

Need 1.36: Social standards for circular jobs
Many organizations are building their Circular Economy strategy on a "cherry picking" approach to fill out the Circular Economy agenda. Little attention is paid to whether or how these strategies affect people positively or negatively. This is problematic because circular practices can come at the expense of social value creation. The compulsion to close loops as quickly and efficiently as possible intensifies this danger unless minimum social standards are demanded. The implementation of a Circular Economy business model should therefore be thought of integratively and ensure compliance with social standards in addition to ecological ones [79], [103], [104]. A framework for social standards in the Circular Economy does not yet exist. Rather, Circular Economy standards bring up social principles without specifying them in greater detail. In terms of a holistic approach, the Circular Economy must also include social principles to prioritize the collective benefits of this system. Specifically in these areas: business practices, business models, legislation, and funding mechanisms. Minimum social standards and parameters are needed along the entire value chain (see also Chapter 3.1).

Recommended measures:
→ Review of existing social standards for circular business models (e.g., sharing economy)
→ Elaboration of normative requirements for social standards for the implementation of circular business models

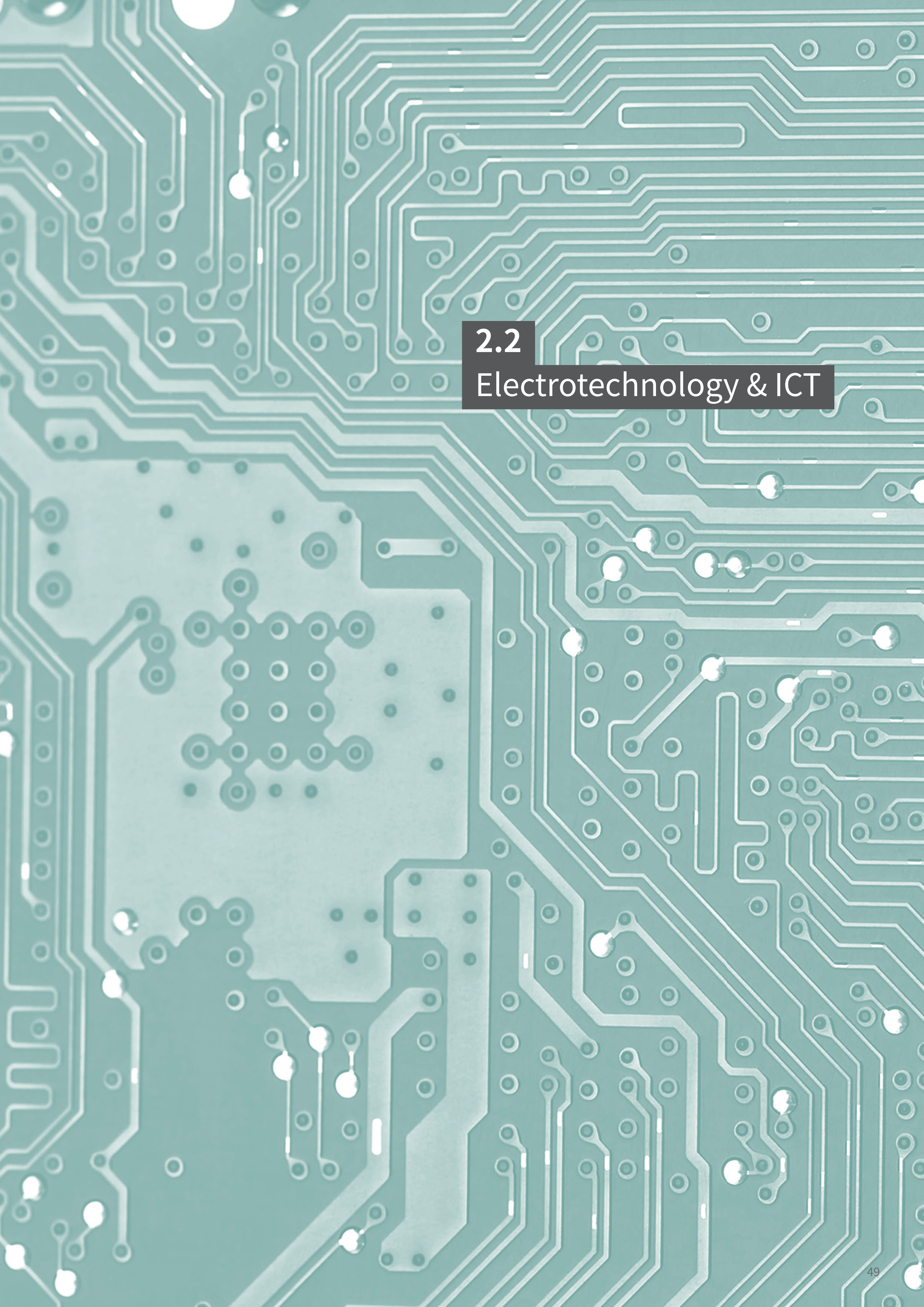
Need 1.37: Training/qualification for the Circular Economy
The Circular Economy requires a redefinition of the role of human resources for the implementation and execution of Circular Economy business models. Here, special training, knowledge, skills and safeguards are needed to maintain or increase social value. The requirements that must be met have not yet been set down. This results in the need to build inter- and transdisciplinary approaches that are detached from the current understanding of human capital and support the transformation of the Circular Economy. Specifically: What technical knowledge (e.g., repairing) is required, what networks (e.g., Circular Economy ecosystems) need to be created for this purpose, and what formats (e.g., training programmes, repair labels) can support this?

Recommended measures:
→ Elaboration of normative requirements for the (minimum) qualification of people for the implementation of circular business models
→ Elaboration of normative requirements for training of people for the implementation of circular business models

STANDARDIZATION NEEDS IN THE AREA OF BUSINESS MODELS

Need 1.38: Definition of features for the identification of services for the Circular Economy
The implementation of circular business models is associated with regulatory, financial, technical, and organizational barriers that create challenges for both consumers and the value chain [14]. Unlike conventional services, services for the Circular Economy are more complex and require a multidimensional approach in their design. We did not arrive at a concretization of these features, but we would like to emphasize the relevance of reducing barriers through services.

Recommended measures:
→ Standardization should ensure that services for the Circular Economy are subject to specific features and require multidimensional consideration in their design
→ Definition of criteria for the identification of services for the Circular Economy



2.2 Electrotechnology & ICT

2.2.1 Status quo

The electrical and electronics industry is Germany's second largest and most innovative sector, with sales of around 200 billion euros in 2021. This corresponds to 10 % of German industrial production. It generates a quarter of its revenues from new products. It is characterized by a broad product portfolio and a high degree of internationalization. More than 90 % of the companies are SMEs. The electrical industry currently employs 876,000 people in Germany [106].

The following section introduces the status quo, requirements and challenges, as well as the individual R-strategies in terms of their significance for electrotechnology and ICT, followed by a discussion of the identified standardization needs, including the respective contexts. In some key topics, a distinction is made between household appliances, large appliances, electrotechnical systems, building installations and installation equipment, and ICT due to the different target groups, application and usage profiles, or business models.

DIN, DKE and VDI carried out a research of standards to ascertain the status quo (see Chapter 1.6.2, [Version 1.8.8, September 2022]) From the results list of a total of 2,101 Circular Economy-relevant standards, 328 documents could be assigned to the area of electrotechnology and ICT. In order to obtain an initial impression of standardization needs, these standards were evaluated on the basis of the nine R-strategies (1.6.3) and the cross-cutting issues of the carbon footprint (see also section on sustainability assessment) and the digital product passport (see Chapter 3.1). Some normative documents could not be sorted into any of these categories and were therefore grouped under "General" (Figure 16).

It can be seen that a significant number of relevant standards have already been produced, especially for the "rethink", "reduce" and "recycle" strategies. The strategies "reuse", "repair", "refurbish" and "remanufacture" are the subject of a few standards. "Refuse" and "repurpose" are hardly taken into account

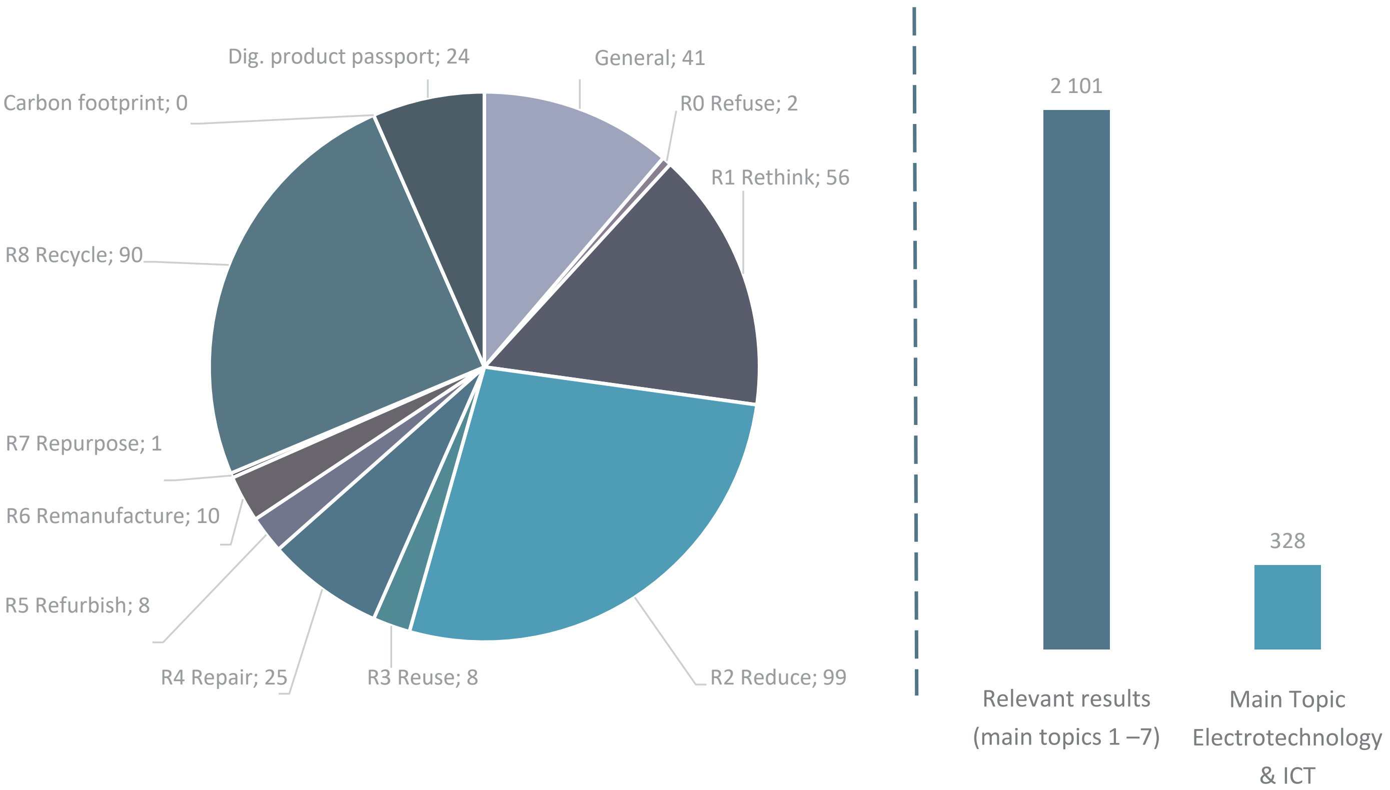


Figure 16: Allocation of the standards search results to the respective R-strategies (Source: DIN)

The same picture emerges when looking at the individual sectors of household appliances, large appliances, systems and installations, and ICT (Figure 17).

The large number of standards for the R-strategies "reduce" and "recycle" can be explained by the fact that electrotechnology and ICT have been the subject of environmentally relevant European legislation for some time. The protection targets contained therein are generally technically specified or made measurable by standards. Examples of relevant European legislation include:

→ the Ecodesign Directive establishing a framework for the setting of ecodesign requirements for energy-related products (2009/125/EC) [21] and implementing acts based on it, which primarily set minimum requirements for the energy, resource and material efficiency of regulated products,

→ the Directive on waste electrical and electronic equipment (2012/19/EU) [108], which regulates the collection and recycling of waste electrical and electronic equipment,

→ the Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (2011/65/EU) [109], which restricts the use of certain substances in electrical and electronic equipment, and

→ the Regulation on the registration, evaluation, authorization and restriction of chemicals (1907/2006/EC) [73], which restricts or completely prohibits the use of certain substances in products.

Mention should also be made of the standardization mandate M/543 [110], which was issued in 2016 in the context of the then planned further development of the Ecodesign Directive. In this mandate, the European standards organizations CEN, CENELEC and ETSI were asked to develop standards and specifications for the evaluation of different material efficiency aspects (durability, repairability, reusability, remanufacturability, recyclability, recycled content) in energy-related products. This has resulted in the horizontal DIN EN 4555x series [46], which provides the basis for the development of product-specific standards on R-strategies (see also Needs 2.3, 2.22, 2.31, 2.43).

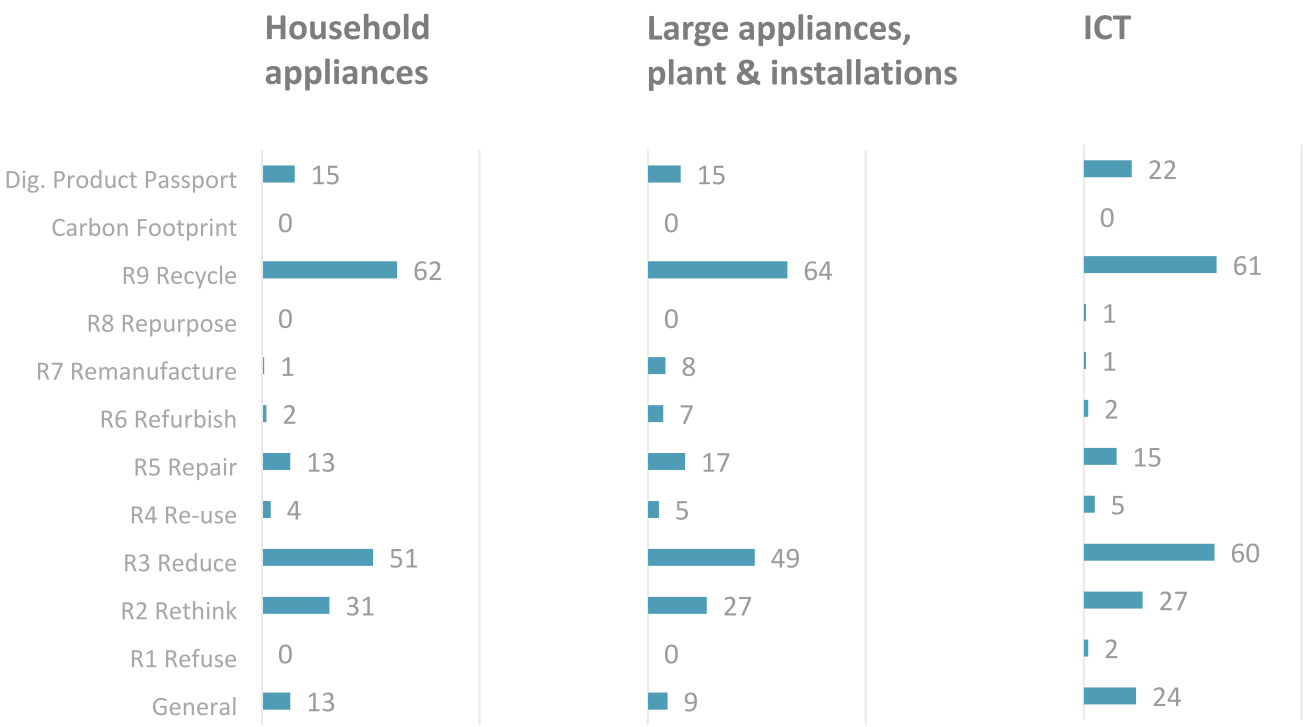


Figure 17: Evaluation of the search by sectors (Source: DIN)

2.2.2 Requirements and challenges

During the discussions with the experts on horizontal and normative foundations for increasing the circularity of products from electrotechnology and ICT, two key aspects were identified: (i) the general need for a comprehensive set of indicators related to all R-strategies, and (ii) standards to accompany existing and future digital mapping of product attributes, such as populating relevant databases. It was also reported that a timely and ambitious implementation of fundamental political decisions on the energy transition is taking place, but that the normative basis and thus the uniformity of the implementation have not yet been considered. Basically, the legislation accompanied by the standardization needs is seen by the experts in the field of product regulation and not in the field of waste legislation.

In increasing the circularity of products, there are almost no restrictions imposed by the type of product. However, different products have two things in common: First, it is advantageous to look at the entire cycle, to abstract and to include future scenarios. Second, product safety and other safety aspects, e.g. occupational health and safety, must not be compromised. In both areas, the standardization landscape is very well positioned, both nationally and internationally, and an increase in product circularity is in prospect.

Designing products according to the R-strategies represents a crucial step towards the Circular Economy. In order to successfully implement the R-strategies, it is necessary to consider not only with companies, but also with consumers. Awareness raising for the Circular Economy should take place here, so that a corresponding demand is generated on the market for products designed with R-strategies in mind.

In the areas of reuse, repair, remanufacture and repurpose, there may be a change of user/owner. Correspondingly comprehensive product information enables a detailed description of the products and a finely granulated differentiation of the products on the market based on this. Products could be purchased, used or installed in a more targeted and needs-based manner. This includes a greater number of reused, repaired, refurbished or remanufactured products, thus increasing the overall circularity of electrical and ICT[4] products in general. Likewise, the secondary use of products can be increased through the high transparency of product properties and overall confidence in product quality can be strengthened in secondary use.

An information standard for consumers can help them assess the circularity of products. However, an assessment in this respect should also take place on the part of the companies. For this purpose, a suitable set of indicators should be developed that enables a numerical assessment of the circularity of products and is thus suitable for assessing product developments in relation to the R-strategies.

In some subject areas, cooperation and coordination with policy-makers to initialize new standards projects is particularly important, e.g., with regard to possible mandates. The following departments of the German federal government and Directorates General of the EU Commission should be addressed on individual issues:

→ Directorate General for Environment (DG ENV) [111], the Committee on the Environment of the EU Parliament [112] and the responsible departments in the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection (BMUV) and the German Federal Ministry for Economic Affairs and Climate Action (BMWK):
  - Topic: A more intensive collection and capture of products to keep them in the cycle longer or to return them to the cycle. Reference should be made here to existing standards, and further standardization activities should be initialized and coordinated (e.g., application of the DIN EN 4555x series) [46].

→ Directorate General for Communications Networks, Content and Technology (DG CONNECT) [113]:
  - Topic: Relevant standardization on software and update topics and the Cybersecurity Act [107].

→ Directorate General for Internal Market, Industry, Entrepreneurship and SMEs (DG GROW) [114] and the BMWK:
  - Topic: Standards are referenced to give detail to the technical design of laws and directives. In this context, reference is made to a specific version of the standards. However, standardization and legislation are not synchronized: If the standard is revised, the law will continue to cite the same, now obsolete version. This aspect is becoming more and more critical with the increasing complexity and dynamics of technical development. Here, it must be clarified how the newer standard editions are to be dealt with.

4 Electronic products are understood as a subgroup of electrical products.

2.2.3 Standardization needs

Some standardization needs can be assigned to multiple R-strategies. Needs with possible multiple allocations were assigned to the most relevant R-strategy (or general standardization needs).

General standardization needs

Need 2.1: Normative foundations for indicators for the comparison of individual R-strategies, combinatorial approaches and for the measurement of overall circularity
The creation of uniform calculation foundations on indicators of the individual R-strategies would allow the consideration of the overall circularity of a product, system and/or installation (see also Need 1.1). The indicators thus enabled active consideration of the Circular Economy in controlling and ultimately in opportunities for the (re)orientation of business models and corporate strategies. Methods to compare R-strategies and possibilities of combinatorial considerations, for example by converting them into CO_2 savings, would be fundamental. The latter requires a definition of system boundaries at European and, possibly, international level A national view of the circularity of products, especially against the backdrop of international value chains, is not considered expedient. IEC/TC 111 "Environmental standardization for electrical and electronic products and systems" [115] and IEC SMB ahG 94 "Carbon Footprint Data Collection" [116] are mentioned as examples of international standardization activities. The application of R-strategies must not reduce essential product properties such as product safety, and manufacturer obligations and responsibilities should be taken into account.

Need 2.2: Guides for filling and checking the SCIP, EPREL and other databases
Product properties can be described by key figures. These can be the indicators of circularity mentioned in the previous paragraph. Other key figures such as the energy efficiency or the pollutant load of a product are already collected and reported to relevant bodies or entered in the existing databases SCIP (**S**ubstances of **C**oncern In articles as such or in complex objects (**P**roducts)) and EPREL (European Product Registry for Energy Labelling) [126], [127]. With regard to the databases, the reduction of efforts for data entry has been increasingly mentioned. Manufacturing or importing companies would make data entry guides, tailored to existing and future (see Chapter 3.3) databases, as well as quality assurance or checking the completeness and accuracy of information more efficiently and effectively for manufacturing and importing companies.

Need 2.3: Product group-specific standards for durability, repairability, reusability, remanufacturability and recyclability based on the DIN EN 4555x series
The European Commission has recognized the need for a normative basis for establishing a Circular Economy and in 2015 issued a mandate (M/543) [110] to CEN/CENELEC and ETSI for the creation of a series of standards on various topics of resource and material efficiency The resulting DIN EN 4555x series of standards [46] includes standards for assessing the durability, repairability and recyclability of energy-related products (ErP). The ErP group was first defined in the Ecodesign Directive [21] and includes a wide range of household appliances and ICT products, but also large appliances with industrial application. The standards of the DIN EN 4555x series are generic. They are intended to serve the technical bodies of standards organizations as a framework for action in the design of product group-specific standards. To date, a committee has examined the applicability of the series to household appliances (CEN/CLC TC 59X WG 23 "Material efficiency of household and similar electrical appliances") [117] and is currently developing a product group-specific standard on the durability of washing machines. Should the Commission's announcements in the European Green Deal [2], Circular Economy Action Plan [4] and the draft Ecodesign for Sustainable Products Regulation [140] be implemented with regard to the creation of legal requirements for the material efficiency of ErP, a large number of product group-specific standards for resource and material efficiency will be required, and the DIN EN 4555x series [46] provides the appropriate basis for this.

Need 2.4: Guidelines on "design 4 recycling" and "design 4 circularity" and an approach to evaluate the optimal R-strategy for a specific product
In order to be able to implement the R-strategies, it is essential that they are already taken into account in the development phase of the products. This "design 4 recycling" requires guidelines with a global approach, such as those currently being developed by the Circular Plastics Alliance [118] on recycling. It must be taken into account here that, as a rule, not all R-strategies can be implemented equally for a product; rather, an appropriate focus must be set. For example, some products focus on maintenance and repairability, while others focus on recyclability. Therefore, a feasible approach to life cycle analysis should be found that allows (with

a special focus, if necessary) the testing and evaluation of the individual strategies for a specific product or product group in order to find an optimized balance between the R-strategies. Basically, product group-specific design guidelines are necessary for all R-strategies.

Need 2.5: Coordination of standardization activities on the Circular Economy
The increase in circularity not only affects individual markets. The international value chains, sales and reuse of electrotechnology and ICT products that have arisen as a result of globalization require close cooperation between national and international standards organizations. It would be beneficial for existing supranational organizations to coordinate and cooperate in order to coordinate developments on the individual R-strategies and to achieve a holistic understanding of a Circular Economy at international level. Involvement of the International Resource Panel of the UN Environment Programme (UNEP IRP) [119] would need to be explored. An existing positive example is the cooperation between ISO/TC 262 "Risk Management" [120] and ASTM F42 "Additive Manufacturing Technologies" [121] on additive manufacturing – more such cooperation would be desirable

Need 2.6: Establishment of standardized information transfer based on international standards and development of cost-effective and simple analytics for quality assurance of secondary raw materials
Particularly in the quality assurance of secondary raw materials, standardized information transfer (see also Need 1.5) plays a decisive role in the implementation of the Circular Economy. It is expected that an increase in circularity will also increase the variety of materials and material compositions. Due to the very long life cycles of certain products and accordingly not always available information, standards for the analysis of certain substances may therefore be required for the quality assurance of secondary raw materials in cases of doubt.

Need 2.7: Necessity of European/International Standards
The Circular Economy is a fundamentally different way of doing business that, when fully implemented, is not limited to one country or region. For this reason, European (CEN, CENELEC, ETSI) or International Standards (ISO, IEC, ITU) should be preferred for standards relevant to the Circular Economy in order to be able to exploit their potential to the full. Among other things, it is important to counteract limitations from the history of these standards. In Europe, for example, there are currently still national standards on specific technical solutions for the safety of power outlets. In the course of a Circular Economy, care must be taken to achieve harmonization of requirements wherever possible.

At this point, special attention should be paid to the areas of waste treatment and recycling. In order to be able to recycle products efficiently at the end of their service life, appropriate markings are sometimes required on them. The free flow of goods in the European internal market makes uniform labelling across member states necessary. In addition, European harmonization of nationally developed process standards can lead to further improvement.

Need 2.8: Assessment of the usefulness of the digitalization rate of products and services
When bidding for funding programs, it should be noted that even in the age of digital transformation, not every form of digitalization should be positively included in the evaluation of project eligibility. Here, a standardized consideration of the usefulness of the digitalization rate of products and services would be beneficial. Digitalization that goes too far creates avoidable consumption in the provision of computing power through data centres and data transfer.

Need 2.9: Inclusion of circular-oriented funding criteria to promote innovation and research in addition to the energy efficiency of products
An additional field of action for the establishment of a Circular Economy would be given in public funding. The assessment of eligibility for funding mainly includes criteria on energy efficiency, sustainability strategies and targets, etc. Circularity-relevant aspects such as reuse or refurbishing of products have not been applied so far. Frequently, innovation and research funding promotes the development of novel products and partly excludes aspects of reuse. In this case, it would be advantageous to open up the criteria catalogue in order to promote a circularity-oriented product design. Standards for the Circular Economy of a wide variety of products could be added here without neglecting the energy efficiency of products, which has been taken into account up to now.

Need 2.10: Standards for the decommissioning and dismantling of renewable energy power plants
The measures taken by the German government and the European Union to achieve clearly defined energy and emissions savings are set out in several strategic plans. The establishment of renewable energies, for example through the expansion of wind power or solar systems, is mentioned

as being essential. In this regard, the experts discussed the predicted lifetimes of renewable energy power plants and increasingly referred to the need to reflect the decommissioning and dismantling of obsolete plants (see also the section on dismantling buildings) in the standardization landscape. A consideration of the circularity of the plants promotes on the one hand their overall benefit, creates on the other hand new business models, and possibly reduces the dependence on suppliers of components or raw materials for the production of components. Need 7.14 in Chapter 2.7 also relates to the dismantling of structures.

Refuse

A link to the UN's refuse strategy (see Chapter 1.6.3) can be found in conceptual (product) standards, for example in standards on environmentally conscious product design or the orientation to the principles of the Circular Economy discussed here. According to the definition of the refuse strategy, a product is to be dispensed with or the same function is to be replaced with a radically different (e.g., digital) product or service. A corresponding field is, for example, the standard-accompanied establishment of "digital twins", which are intended to replace the analogue labelling of services, materials and products.

Need 2.11: Revision of the normative basis for the use of flame retardants, taking into account recyclates and integrated measuring systems
A need for revision was identified in a discussion on the use of flame retardants in plant construction. The consideration of recyclates in general, as well as of integrated measuring systems is suggested. If temperature or voltage peaks can be avoided by measuring systems and the associated intelligent plant control, different requirements for the use of flame retardants should apply than for plants without integrated measuring systems. However, negative effects on occupational health and safety and/or product safety must be avoided.

Rethink

The rethink strategy (see Chapter 1.6.3) is suitable for use in (product) standards to a limited extent Similar to the refuse strategy, it can be found in standards for environmentally conscious product design or in service models. For standards bodies, this means ensuring that product-as-a-service, reuse, or sharing and service models are not hindered or prevented in the standard being developed or revised. This can generally be ensured by a technology-neutral approach. In addition, standards can intensify the use of products by setting frameworks on alternative applications (see also section "Repurpose"), not least with regard to safety-related aspects, and by providing the normative basis for the corresponding legal framework. Standards for environmentally conscious product design based on the principles of the Circular Economy should be developed and applied here.

Need 2.12: Holistic product evaluation based on environmental and material efficiency parameters
Similar to the description of indicators in the chapter on general standardization needs (Need 1), an integrative approach between different product parameters is suggested for the evaluation of product circularity. Besides CO_2 equivalents, additional other environmental impacts (pollutants, land use, etc.) and material efficiency parameters, such as durability or recyclability, can be taken into account. Essential for consideration would be the negative influence of individual parameters on the overall evaluation of the product. Conflicting targets are likely, as simultaneous optimization of all parameters is often technically difficult to achieve. For example, increasing the functionality of products can have a negative impact on recyclability should complex materials such as composites also be used for higher complexity functions. Solutions to the conflicting targets should be sought, taking into account possible synergy effects.

Need 2.13: Consideration of standards on data interfaces in the digital product passport
In the past, holistic considerations have led to design solutions that could be implemented in a technology-neutral manner. Positive examples can be found in interfaces, e.g. standardized, digital interfaces such as digital nameplates in accordance with DIN EN IEC 61406 [122].They could sometimes be applied as a QR code on the product or at component level, and refer to the product documentation at the manufacturing company. This could also be linked to the service documentation "Identification Link". Static (manufacturer name, production location, etc.) and dynamic information (usage cycles, repairs, etc.) would have to be taken into account. The digital interfaces in building services are also assessed positively. Special attention should be paid to the developments in the context of the establishment of a DPP (see also general Needs 1.5-1.17) by the European Commission and current developments at IEC level (CDD, Common Data Dictionary [105]). The standardized digital interfaces of the positive example in building services mean that there

are no limitations, and suppliers of control systems generally offer uniform digital interfaces.

In order to enable a later automated system view (e.g. of a production plant using many products), the necessity of providing the DPP data in a standardized, machine-readable form is seen.

The DPP should take into account information on digital products related to ICT products. One example is the emission of CO_2 equivalents during the manufacture and operation of digital products.

Need 2.14: Standards for the measurement of product change during the uploading and installation of updates
In line with the rethink strategy, intensification of product use could also be achieved with regard to the software used. This should include a consideration of liability, copyright and licensing terms when uploading and installing updates. Criteria for maintaining type approval and product safety would also have to be described. The criteria should also illustrate the extent to which product updates are foreseen and can be described accordingly in advance.

Reduce (by design)

In addition to energy efficiency, the frequently mentioned product efficiency can also be understood as material and resource efficiency. The “reduce” strategy (see Chapter 1.6.3) is supplemented by the addition “... by design” and is thus reflected in a wide variety of standards. In addition to measuring and calculating the energy consumption of products and the resulting design changes, increased durability, repairability, reusability, etc. can also help to reduce resource and material consumption over the entire product life cycle.

Need 2.15: Guide to circularity-oriented information on substances
Standards that take the “reduce” strategy into account promote the longer use of products and can create basic conditions for any Circular Economy aspects through the respective product design (see Need 1.10). Normative frameworks on joining and fastening techniques can increase the dismantlability of products and increase the yield of recycling processes. Declaring hazardous substances in standardized formats would increase knowledge about the presence of these substances and greatly reduce the capacity needed to share information.

Need 2.16: Standard for changing product performance through software updates
Product failures can also be caused by software (errors). The normative framework should be created to make obsolescence by software more difficult for electrotechnology and ICT products and to maintain operability in the long term without sacrificing product safety. In addition, standardized criteria should be created to determine when a software update changes the basic function of a product and to allow a distinction to be made between reused, refurbished or remanufactured.

Need 2.17: Standard for application-related differentiation of joining and fastening techniques
Restrictions on the dismantlability of products sometimes prevent simple repairs and additionally reduce the number of potential recycling processes at the end of the product life cycle. For neutral evaluation and as a tool for selecting joining and fastening techniques during the product design phase, a standard that differentiates on the basis of frequently used joining and fastening techniques, depending on the application and product type, in the sense of the goals of a Circular Economy (“reuse”, “repair”, “recycle”) would be expedient. Using this standard, the increase in product circularity due to the use of adhesives in respective applications can then be assessed.

Should it be necessary to disassemble the products for repair or even for a recycling process, there are many possibilities for loosening the joint connections. For example, DIN/TS 54405 [123] provides users, and especially designers of products, with a guideline for separating bonded joints with the aim of reusing the recyclable materials.

Need 2.18: Quality standards and reference materials for recyclates
The increase in the use of recycled materials in new products, especially plastics (see Chapter 2.5), can be promoted by defined material properties. Material standards based on the material type, taking into account the required technical properties of the intended application, are decisive for this. These can be supplemented by information on the presence of declarable substances according to harmonized or international standards and specifications. This would also increase the acceptance of secondary raw materials in general and thus make a significant contribution to a Circular Economy.

The considerations mentioned in the previous paragraph go well beyond plastics. Another example would be variations in the pollutant load of non-ferrous metals, which are included in the substances already covered by REACH. According to the experience of experts from electrotechnology and ICT, the ranges of substances in non-ferrous metals, even in standard alloys, are very wide in terms of a possible reporting obligation. Thus, standard materials of one manufacturer could not be subject to notification, but those of another manufacturer could be subject to REACH [73] requirements. A standard for the harmonization/limiting of standard materials, if necessary accompanied by the development and provision of suitable reference materials, can remedy this situation and increase the use of new and recycled materials in new products.

Need 2.19: Standard for determining the consumption of (industrial) systems

Further standardization needs with regard to the "reduce (by design)" strategy relate to large-scale appliances, systems and installations. In the case of industrial systems, it would be beneficial to have a standard for determining the consumption of the entire plant, which would be a strategic parameter for operators when choosing the appropriate time for modernization measures. Consumption could be used as another decision criterion for the procurement of new systems or system components. Components of functional safety or building security are of particular importance. These often operate according to the closed-circuit current principle, i.e. they are constantly supplied with energy. Standards that contribute to lowering the energy demand of these construction elements can significantly reduce the energy demand.

Need 2.20: Standard for functionally stable operation

A normative description of the optimal operating and environmental conditions, regular maintenance and minimum qualification of the operating personnel would have a positive effect on the functional stability of products, systems and installations. These descriptions are not expected to circumvent the requirements for safe operation or to counteract other aspects relevant to circularity, such as repair, but should go beyond the minimum requirements for commissioning by operators.

Need 2.21: Standardized assessment criteria for energy and material efficiency of building services and installations

A standardized consideration of energy savings in building installations, similar to the criteria of the existing KfW subsidies for residential and non-residential buildings, would be a suitable way to modernize the building stock with regard to electrical installations and the electrotechnical products used. There would be considerable potential for energy savings through the use of more efficient system technology. Consumption would be reduced, and modern switchgear would enable targeted readjustment, e.g., when the usage profile of a building changes or individual components wear out. This is partly taken into account in the field of air conditioning and ventilation systems in the specification for energy inspection (DIN SPEC 15240 [124]) and could be extended to other areas of electrical engineering in residential and non-residential buildings.

The frequently considered building automation could be supplemented by further, fundamental aspects of the building installations, profitably for operators and users. If, in the future, the expansion of renewable energies is also to be supported in the residential and non-residential building sector by generating and storing energy in the building, suitable infrastructure and building services engineering will be required. In addition, the previously described modernizations support building safety such as fire protection. For this purpose, it is necessary to develop appropriate standards Existing practical examples include the normative fundamentals for the mandatory replacement of outdated heating systems and subsidies for the optimization of air conditioning and ventilation systems in existing buildings.

Need 2.22: Standards for determining the durability of products

For consumer products, standards to determine product life would support future legislation to extend product use. They could form the basis for calculating statutory minimum requirements, contribute to a warranty obligation in line with the current German government's Coalition Agreement [1], or promote comparability among products and provide consumers with highly relevant information for their purchasing decisions, analogous to the energy efficiency labelling provided by the EU energy label [125]. In addition to the environmental aspects of extending product life, additional operating costs for consumers due to additional repairs or procurement of a replacement product can also be considered. Standards at the component level (number of switching cycles, mating cycles, etc.) already exist in the field of type testing and could, for example, be incorporated into the elaboration of product group-specific standards using DIN EN 45552 [318] on the basis of standardized assumptions about the product environment and use. Further standards on the service life of components, such as the processor of smart products, would need to be developed.

Need 2.23: Normative basis for the definition of circularity-oriented warranty claims of consumer products
Should the warranty obligation mentioned in the previous paragraph come into play, standardized warranty claims would be fundamental to avoid consumer confusion at the point of sale. Experience from other legally required labels, e.g. the EU energy label [125], has shown that uniform labels that are independent of manufacturers in terms of content and design are taken into account by a majority of consumers when making their purchasing decisions. In addition, when formulating any warranty claims, it would be necessary to consider whether options for action to strengthen the circularity of products (e.g., a repair) could be brought forward.

Reuse

Like the “reduce (by design)” strategy (see above), the “reuse” strategy (see Chapter 1.6.3) can be applied in a wide variety of standards When drawing up their documents, standardization bodies must ensure that the reuse of functioning products for the same purpose is not prevented in principle, but that basic principles for reuse are taken into account. These documents include information for the secondary user, for example about the composition/structure, pollutants, usage history, etc. If product-related data is stored on a product, the handling of this data and the complete deletion before the product is reused must be mentioned.

Need 2.24: Criteria for classification of repaired, refurbished and remanufactured products
A potential transfer of responsibility is another key aspect of intervening in product design through reuse of used components, repair, refurbishment and remanufacturing. Criteria must be standardized as to up to which degree of change to software, component and/or the overall product the original manufacturing company continues to be responsible, from which point a new placing on the market takes place, or when another market participant is responsible. This could also be normatively reflected in the creation of a legal foundation for the establishment of markets for used components, refurbished and remanufactured products, and reduce corresponding concerns about product safety among consumers, distributors and in procurement. According to the assessment of the electrotechnology and ICT experts, function- or safety-relevant changes should only be carried out by persons who subsequently assume manufacturer responsibility. Trust in reused products (and components) can be increased through standards-based product labelling or information provided to consumers. Standards for the quality assurance of “reused”/”refurbished” products can be used for this purpose, which describe the necessary process steps. Here, too, there is a product-specific need for standardization.

Need 2.25: Design standards for defect-free disassembly/removal and secondary installation
Reuse of products, systems, or installations can involve a change in location. Damage during component removal and installation should be considered accordingly when considering standards for reuse. This includes damage to the components to be used in another place and also the product itself, which could be damaged during the installation of the component to be reused. These circumstances should be considered at least in relation to product safety and, in addition, the cost-benefit ratio should be determined to verify the functionality of components and the overall product. In addition, it would have to be examined at what level of use of reused components a product is placed on the market again and a corresponding conformity assessment or type approval has to take place.

Design standards are required to ensure that electrotechnical or ICT products can be used in another location for secondary use. These could define the type and location of fasteners, power supply, water supply line, etc.

Need 2.26: Revision of the standard on data destruction DIN 66399 with regard to the reuse, refurbishment and remanufacturing of electrotechnology and ICT products
If there is a change of ownership and sensitive data is stored on the product, system or installation, it should be possible to delete it. A possible technical solution would also be to store the data on the data carrier in encrypted form. Requirements and best practices for on-device data erasure through off-device solutions for secure and consumer-friendly data erasure should be developed and standardized.

Repair

The core of the “repair” strategy is to extend product life through maintenance and repair, thereby reducing the need for new equipment and consequently saving raw materials and energy in production. Standardization bodies are encouraged to consider defects as well as their remedies when preparing their documents. On the one hand, this concerns product design and a corresponding avoidance of normative provisions that prevent subsequent repair. On the other hand, other areas, such as standards to ensure product safety, are also affected. Here, it is important to consider the case of product repair, including requirements that map the safety of the repairer as well as the safety of the product user (e.g. according to DIN EN 50678 [128]). Both aspects, the possibility and the safety of the repair, should be accompanied by standardized information. Information gaps in this regard would prevent repair from the ground up.

An important aspect of repairing a product is the availability of spare parts. This is currently not ensured without restriction beyond the period of the statutory warranty. Standardized interfaces for components with a high expected failure rate could lead to stimulating the third-party market and thus counteracting bottlenecks in spare parts. Standardized interfaces have the greatest possible effectiveness in connection with modular product design. Product group-specific standardization is expedient here.

The promotion of product repairs and the associated extension of service life is linked to advancing legislation. It is not uncommon for long-lived products to outlive one or more revisions of relevant legal frameworks such as chemicals legislation (RoHS [109], REACH [73]), relevant product safety legislation (Low Voltage Directive [129], Machinery Directive [130]) or environmentally sound product design (Ecodesign Directive [21]). This may result in spare parts not being allowed to be placed on the market without restriction. Qualification of new spare parts that comply with the current legal framework is only possible to a limited extent due to the product design. One way to counteract this would be to consider the “repair-as-produced” principle. This principle has already been incorporated into legislation, e.g. in the drafting of the Directive on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (RoHS) [109] or the End-of-Life Vehicles Directive [131], and should be accompanied by standards beyond these examples.

In addition, existing knowledge on the ageing of various product components from repair databases can be used to prevent product failure through timely intervention. For this to succeed, this information should be made publicly available and supplemented with relevant safety aspects. Analogous to this is the confidentiality of intellectual property, which can have a negative impact on the repairability of products (monopolization of certain spare parts or diagnostic software).

Need 2.27: Standards for assessing repairability at the product level

At the time a product is purchased, it is generally difficult for users to anticipate the possibility of repair in the event of a defect. The labelling of products with a repair index can compensate for this information deficit and, at the same time, contribute to the development of repair-friendly products by establishing a distinctive feature. In principle, repair marking of products should be based on European, ideally International Standards tailored to the respective products or product groups. When drawing up the standard, particular attention should be paid to the external verifiability of the assessment parameters, as this is the only way to establish confidence in the assessment metric. While repairability labelling for consumer products has an indirect positive effect on longevity, labelling for commercial and industrial products has limited applicability and should be limited to operating equipment such as control elements. In addition to spare parts and especially for wear parts, consumables and their accessibility should also be considered in product design standards.

Need 2.28: Standards on product information (see Chapter 3.3) and interoperability of components and wear parts

There is also a perceived need for standards relating to the availability of information, and to the interoperability of wear parts in order to ensure the comparability of different products. The interoperability of components is not limited to the necessary geometric and electrical properties to be used in different products, but can also include communication with the product. One example is batteries, which, for example, transmit the state of health of the battery to the product.

Need 2.29: Standardized criteria for the provision of product or system information on composition, structure and usage history

Product and system information, e.g. on repairability or usage history, should be made available in a standardized form via a digital product passport (see Chapter 3.3). This includes information on the availability of spare parts and required (special) tools. The question of warranty after a repair not carried out by the original manufacturing company should also be included in the design of the digital product passport. This could be done by means of dynamic components in the product passport, which could evolve over the life of the product and contain, for example, entries on repairs that have been carried out. With the digital product passport, however, it is important to consider what information is useful to consumers. Extensive information and documentation can be daunting and overwhelm consumers. A possible workaround would be to subdivide the information by service level, and in addition, the information can be provided in a database-driven manner.

Need 2.30: Standard for onboard diagnostics of products
Onboard diagnostics, such as those already established in the automotive industry, could be extended to consumer, commercial and industrial products. If no diagnostic tool is available, this may prevent repair, product refurbishment or remanufacturing. In some cases, product groups are equipped with the appropriate diagnostics, but access regulations, for example a restriction to only reading out the error sources, should be considered in a standard.

Refurbish

The refurbish strategy deals with the extension of product life by renewing and/or repairing individual but essential components. Refurbishing must be clearly distinguished from remanufacturing: During refurbishing, the product identity is retained, i.e. it is not placed on the market again. During remanufacturing, the product identity is lost; the remanufactured product is a new product that must be placed on the market anew. Accordingly, it must meet the legal product requirements at the time of re-marketing (at the time of writing this Standardization Roadmap, a DIN SPEC with approaches to definitions for refurbishing and remanufacturing is being prepared [132]).

For standardization bodies, this means that the possibility of product refurbishing must also be considered and clearly distinguished from remanufacturing. This concerns product safety as well as product design requirements.

Currently, there is no normative basis for when a renaming (rebranding) of the product, i.e. the removal of the original manufacturer's name and the addition of the name of the remanufacturer, must take place. While this process is common for industrial machines, the situation is unclear for consumer goods. The possibility of renaming can be limited by various factors such as product design and copyright protection (design patents). This makes it difficult to differentiate between original equipment manufacturers and remanufacturers, e.g. in liability issues. Therefore, a need is identified for a document that provides guidance on the circumstances under which a renaming should occur.

Need 2.31: Extension of DIN EN 45554 to include metrics for refurbishing
In order to be able to design products in the future that allow for easy refurbishing, there needs to be a uniform metric on how to measure or evaluate this. For remanufacturing, there is already a horizontal European standard (DIN EN 45554 [338]), which explicitly takes into account the work steps in a remanufacturing process. This standard should be supplemented by the refurbishing of products or, alternatively, a separate standard based on DIN EN 45554 should be developed.

Need 2.32: Standards for implementing upgradeability-by-design
Refurbished products are usually products that have been used for a long period of time. Depending on the product group, new products have higher performance or a higher range of functions (e.g. memory capacity or processor speed of PCs). It is therefore important to take into account the possibility of increasing or expanding the performance or range of functions of a product at a later point in time, right from the product design stage. Product group-specific standards for product design should be developed to provide guidance for product development.

Remanufacture

The "remanufacture" strategy deals with the preservation of raw substances and materials contained in components by substituting already used components in used products. Regardless of the number or percentage of substituted components, the product must be placed on the market anew and is therefore no longer a used product. This product must meet the requirements of the relevant product standard at the time it is placed on the market. For a differentiation of "remanufacture" and "refurbish", please refer to the previous section "Refurbish".

The following aspects should be considered when creating new standards or revising existing ones: (i) modular product design, (ii) simplified removability of components and, where relevant, ensuring (iii) standardized interfaces (e.g. for electronic products and ICT). Standards on suitability tests for used components are also fundamental. The product safety of the overall product must not be compromised, and must comply with the requirements for placing on the market/commissioning.

In summary, no urgent need for standardization on remanufacturing was identified during the development of this Standardization Roadmap.

Repurpose

The “repurpose” strategy deals with the use of a product for a purpose other than that for which it was specifically manufactured, thus distinguishing it from reuse, refurbishment and remanufacturing. This “intentional change of purpose” can lead to an increase in the circularity of a product. A frequently discussed example is the use of energy storage from the mobility sector for the heating sector. The capacity of the storage unit is no longer sufficient for operating an e-car, but it can be used as energy storage for a heating system (e.g. combination of PV and heat pump), for which the capacity is sufficient for operation in the medium to long term.

Need 2.33: Standardized catalogue of criteria for evaluating the change in product purpose
The change of purpose can be simplified or made possible in the first place by a software update. It is important to mention that such a software update serves the purpose of changing the basic function of the product. The product is to be categorized and treated according to the changed purpose.

The future “intentional change of purpose” can only be foreseen to a limited extent by the manufacturing companies and standardization bodies and can therefore be taken into account to a limited extent. However, if an intentional change of purpose does take place, it must be accompanied by an appropriate normative framework on product safety and other safety aspects, e.g. occupational health and safety. It would also be helpful to have a standardized catalogue of criteria in the form of a guideline that helps to clearly differentiate between purpose retention and “intentional change of purpose”.

Recycle

The recycle strategy aims to recover valuable materials from disposed products. For this to succeed efficiently, various aspects must be taken into account in standardization work: (i) material compounds must be separable as far as possible if they are not recyclable in the same process, (ii) additives (e.g. flame retardants) should not inhibit recycling, and (iii) in the case of safety-related requirements for materials or components, subsequent recycling of the product must also be taken into account. Technical specifications, in particular those that ensure the safety of a product (e.g. against impact or fire), must be complied with and should not be restricted by specifications aimed at increasing the recyclability of products. Also crucial is the consideration of standards on partial aspects of the recycling processes themselves, for example thermochemistry, process analytics and material separation. They must mesh with quality management and quality assurance standards. Very durable products require special attention. Legal requirements change in the course of revisions. As a result, products may no longer be recyclable or the secondary raw material obtained may no longer be used in new products. Examples include batteries, some of which have a very long service life, as well as capital goods, e.g. from the mechanical and plant engineering sector. Recent European regulations, such as the POP Regulation [133], make it more difficult to use secondary raw materials obtained from material recycling.

Need 2.34: Standard for calculating the environmental impact of materials (conversion factors)
The development of harmonized calculation methods of recycling efficiencies should take place in standardization. Here, the calculation methods can be established by consensus, while the percentage targets are to be defined in political discourse. The calculation of recycling efficiency can be based on both the masses recycled and the environmental impacts avoided. For the latter, there is a lack of standardized conversion factors.

Need 2.35: Standard for the description of reference materials for secondary raw materials
Standards on secondary raw materials must be developed in cooperation with the other sectors concerned, since electrotechnology and ICT rely on the recycling flows of the upstream chains (uniform conventions must be developed there). A distinction should be made between secondary materials from regulated products, such as products within the scope of the Ecodesign Directive [21], the Electrical and Electronic Equipment Act (ElektroG) [134] or RoHS [109], and secondary raw materials from unregulated products, as these may contain substances that may not be placed on the market in new electrotechnical or ICT products under current legislation. In principle, the exclusion of hazardous substances is necessary in order to be able to reuse secondary raw materials. To test this, the development of standardized reference materials is necessary (see also Need 2.18).

Need 2.36: Information standard for the provision of information relevant to recycling

A material passport (see Chapter 3.3) for products can help to increase the recycling efficiency of products and, for example, indicate the presence of any substances that are detrimental to recycling. However, this requires process standards for waste treatment and recycling that are tailored to this purpose. The material passport should clearly state the necessary information on weight fractions and volume fractions and be limited to the necessary information. In addition, the material passport could help to identify particularly valuable components and mark them on the product. Concrete standards are needed both for the material passport and for the uniform marking of components and materials.

Need 2.37: Standards on design 4 recycling

The recyclability of a product is already determined during product development by the respective design. This is precisely why product development is the greatest lever for products suitable for recycling. Guidelines or standards for the design of recyclable products can help here. These guidelines should consider, among other things, a modular product design (see also the sections on Repair and Remanufacture). Different joining and fastening techniques should also be included in these guidelines, depending on the anticipated recycling process. This can mean that housing connections should be detachable with simple tools.

Need 2.38: Standards for calculating the recycling rate of electrotechnical and ICT products based on the products actually disposed of

The European Union's minimum recycling efficiency requirements under the WEEE Directive [108] are currently calculated on the basis of the number of electrical appliances placed on the market in a given year. The time lag between the acquisition of a product and its disposal leads to a fuzziness in the calculation of the actual recycling efficiency. Therefore, in order to determine the recycling share of electronic and ICT products, appropriate standards are required that describe the qualitative collection of end-of-life devices in relation to the requirements of the German Electrical and Electronic Equipment Act (ElektroG).

Need 2.39: Extension of the DIN EN 50625 series of standards to include consideration of the current state of the art as well as quality requirements

With the DIN EN 50625 series [135], standards already exist for the treatment of waste electrical and electronic equipment. These largely deal with the description of how the monitoring targets required by the German Electrical and Electronic Equipment Act (ElektroG) can be met. Added value could be achieved by expanding the DIN EN 50625 series of standards to include a consideration of the current state of the art as well as quality requirements for the resulting secondary raw materials.

Need 2.40: Recommendations for standardized information transfer and extension of the DIN EN 62321 series of analytical standards to include recycling-relevant substances

One challenge in the recycling of valuable materials, including electrotechnical and ICT products, is the removal of harmful substances. In order for materials derived from recycling to be used as secondary raw materials, the absence of harmful substances must be guaranteed. Standards for material declaration (e.g. according to IEC, ISO/IEC or IPC standards) or for information transfer (e.g. according to DIN EN IEC 63000 VDE 0042-12, Technical documentation for the assessment of electrical and electronic products with respect to the restriction of hazardous substances [137]) can help to provide reliable statements on the presence or absence of harmful substances. The DIN EN 62321 series [136] of standards should be used when the presence of certain products is to be tested by chemical analysis.

Need 2.41: Revision of the DIN 66399 series to enable the recovery of critical raw materials, such as neodymium from hard drives

A concrete need for standardization could be identified in relation to the recycling of hard drives and the recovery of rare earths, specifically neodymium. The data destruction standards in the DIN 66399 series [138] should be revised to allow the recovery of critical raw materials such as neodymium from hard drives. DIN 66399 requires mechanical destruction of data carriers such as hard drives, which are therefore usually completely shredded without separating the neodymium magnets as a whole from the hard drive. Thus, the magnets are effectively lost for recycling where data protection requirements have to be met. Data protection and rare earth metal recycling are in opposition to each other, since after mechanical destruction, large-scale separation of neodymium magnets is no longer possible. Non-destructive alternatives for data destruction (e.g. degaussers [139]) are available, but currently not considered in the DIN series.

Need 2.42: Standards to provide common material compositions in the case of established technical solutions
Standards are basically technology-neutral and allow different technical solutions for a specific requirement. This ensures fair competition and does not inhibit innovation processes. However, should increased interoperability lead to technical solutions that use the same materials, standards aimed at making this information available would be beneficial. The information generated using these standards would have added value to the recyclability of the products concerned, as waste management can adapt to it and possibly provide tailored solutions. One example where a particular technical solution has become established is the uniform charging plug for e-vehicles, which is standardized.

Need 2.43: Standards for the traceability of materials for secondary raw materials
In order to promote the use of secondary raw materials generated through recycling, there is a need for guidelines or standards that can be used to determine the proportion of secondary raw material in the product. DIN EN 45557 [341] provides a horizontally applicable metric that should be extended depending on the material or product. Traceability (see also Need 1.22) along the supply chain, in particular, is often discussed in general terms and should be viewed in a differentiated manner. Only a credible determination of the proportion of secondary raw materials in products allows advertising claims to be made, greenwashing to be avoided, and this information to be made available to purchasers when making purchasing decisions.

2.3 Batteries

2.3.1 Status quo

The future model of the all-electric society includes an energy demand that is almost completely covered by renewable energy. For this, intermediate storage, such as in the form of large battery energy storage systems, is essential. The use of battery storage systems is becoming more attractive due to the current rise in the price of fossil fuels. The increased use of batteries in electrically powered vehicles should also be mentioned in the context of the green traffic revolution and CO_2 emission-free individual transport. The EU Commission's decision to ban internal combustion engines as far as possible will certainly accelerate this development.

In the course of the holistic approach of the Circular Economy, it will be crucial to also consider batteries across sectors. This means enabling the use of different storage possibilities in as many applications as possible. But other R-strategies, such as repair, repurposing and recycling, also need to be implemented more.

The following considerations are subject to the particularity that the upcoming EU Battery Regulation [141] (see also Chapter 2.3.2) is the first regulation that takes into account the Green Deal [2] and the Circular Economy Action Plan of the EU [4]. This Regulation already contains extensive requirements for establishing a Circular Economy in the area of batteries. Therefore, the requirements for the Circular Economy within the Battery Regulation are reproduced according to the current status in Table 1, as are needs that are not or only partially covered by the Battery Regulation. In addition, the preparation of specific standards has already been requested via standardization request M/579 [145] (see also Chapter 2.3.2).

Evaluation of standards research

A total of 89 standards were identified during the standards research [146], 57 of which address the topic of the Circular Economy and batteries. 32 other standards and specifications could be applied to a digital product passport (see Figure 18). Most standards relate to the area of recycling (classic area of the Circular Economy), whereas there are only a few on the R-strategies "refuse", "rethink" and "reduce". The different R-categories are evaluated from an ecological point of view using mainly the carbon footprint as an indicator. There is only one draft standard for this, which deals specifically with the carbon footprint of batteries. Three others deal only marginally with the issue of the carbon footprint (see Figure 19). Regarding "repair", many requirements are already formulated in the Battery Regulation, which will lead to a number of new standards.

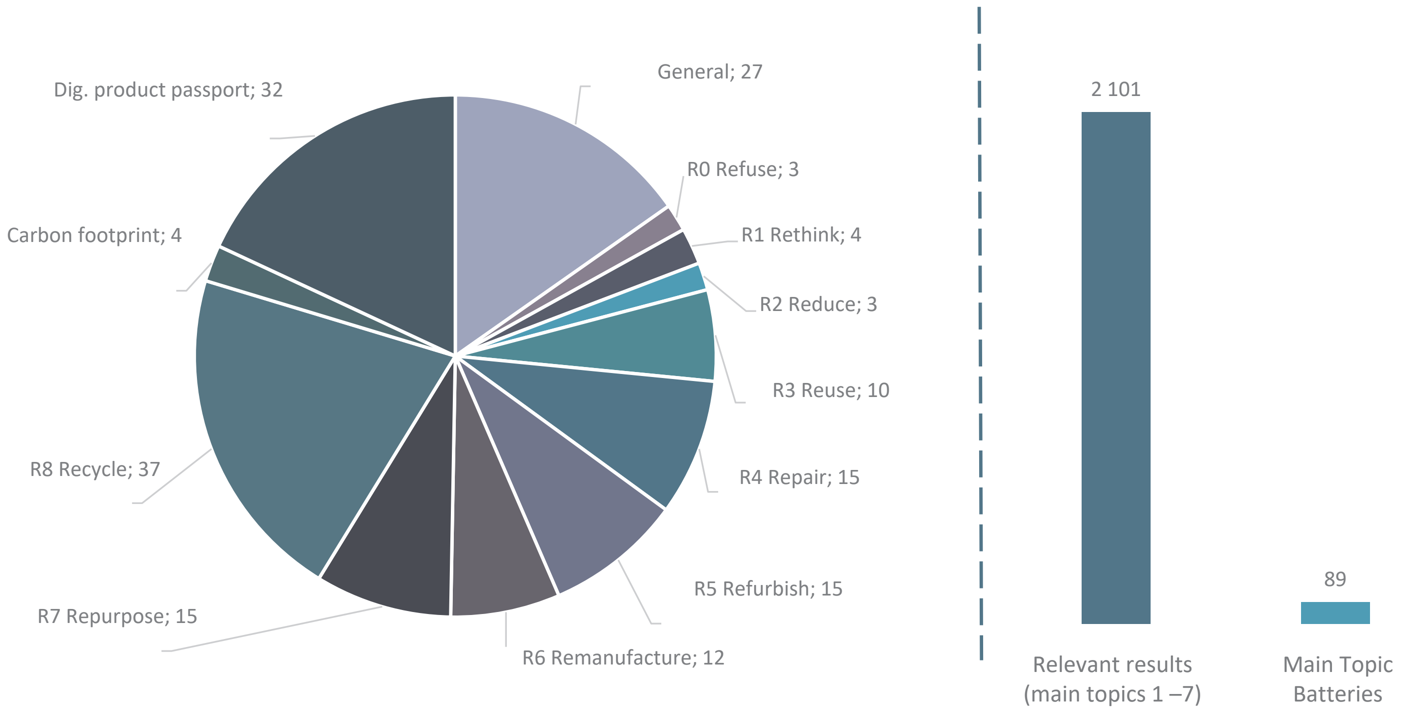


Figure 18: Allocation of the standards search results to the respective R-strategies (Source: DIN)

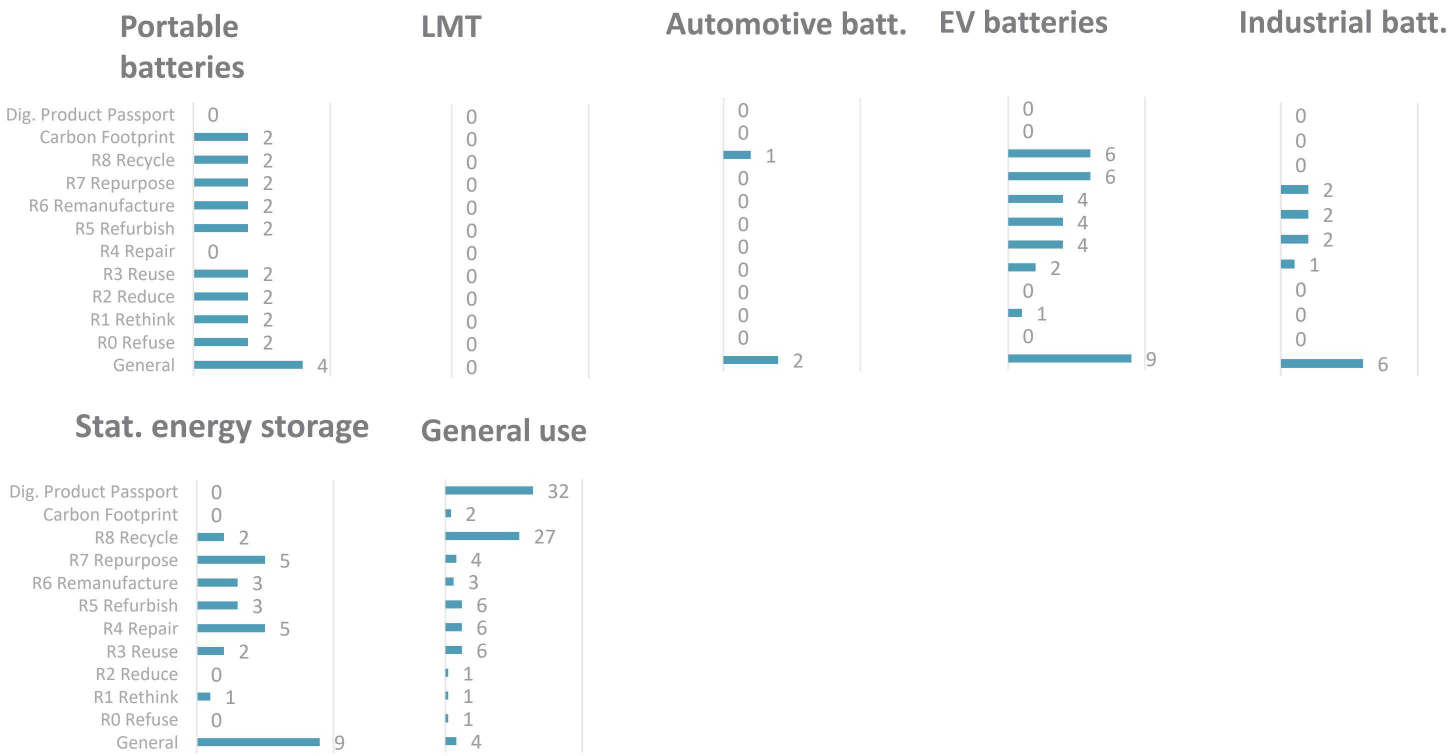


Figure 19: Allocation of the R-strategies to the various battery categories (Source: DIN)

2.3.2 Requirements and challenges

The Battery Regulation
The publication of the Battery Regulation [141], expected in mid-2023, is an integral part of the European Green Deal. It replaces the previously valid German Battery Act (BattG) [147]. New requirements such as the battery passport with the electronic exchange system and the carbon footprint are intended to serve as a blueprint for the introduction of a general product passport and are a first step in the EU's Circular Economy Action Plan. At the time of writing this Standardization Roadmap, the Commission proposal for the Battery Regulation, together with the amendment by the EU Parliament and the draft by the Council, is in a "trialogue" stage between the Commission, the Parliament and the Member States of the European Union. The exact date of publication and the content of the document are therefore not yet determined.

In the Regulation proposal, the EU Commission cites three justifications for its creation:

1. strengthening the functioning of the internal market (including products, processes, waste batteries and recyclates), by ensuring a level playing field through a common set of rules,
2. promoting a Circular Economy,
3. reducing environmental and social impacts throughout all stages of the battery life cycle.

To specifically address these three fields of action, 13 measures were formulated, which are included in the draft of the Battery Regulation. Table 1 lists the respective measures and compares them with the implementation variant prioritized by the EU Commission. For ease of reference and overview, the relevant articles of the relevant measures are listed, as well as any legal acts arising from them. Legal acts are separate additions by the Commission to establish specific actions.

Furthermore, in order to establish a more differentiated market coverage, further distinctions were made in addition to the previously known battery type categories. Thus, batteries for light means of transport (LMT) are included in the Regulation, and there is a five-kilogram weight limit for portable/industrial batteries. The Regulation will also affect areas outside the ordinary scope of applications. European waste and chemicals legislation (e.g. REACH [73]) is also affected.

Overview of measures in the upcoming Battery Regulation

Table 1 summarizes the measures of the Battery Regulation and shows to which battery categories these measures apply. Also included is the time frame envisioned for each measure and whether legal acts are planned. The final version of the Battery Regulation is expected to be published in early/mid 2023. Table 1 gives an overview of the three proposal variants of the Regulation.

We expressly point out that the following Table 1 can only provide guidance and that the original texts must always be consulted. This particularly applies when the Battery Regulation has been published.

A: The underlying EU Commission Proposal of 10.12.2020 [141]

B: Deviations according to the amendments adopted by the EU Parliament on 10.03.2022 [142]

C: Deviations according to the EU Council draft of 14.03.2022 [143]

Table 1: Overview of measures in the upcoming Battery Regulation

Measures of the Reg.	Version	Summary/content	Article	Battery categories[1]							R-strategies	Timeframe	Legal Acts
				P	LMT	Auto	EV	Ind	BESS	General			
Classification and definition	A	Existing regulations to be updated to include any new battery categories; including distinction between portable and industrial batteries above 5 kg limit; new "EV battery" category; the more precise classifications to help identify "collectible" batteries; based on this, a new collection rate methodology is to be created; definition of R categories;	1, 2	X		X	X	X	X	X			
	B	Category "batteries for light means of transport" (LMT) added;		X	X	X	X	X	X	X			
	C	Category "batteries for light means of transport" (LMT) added;		X	X	X	X	X	X	X			
2nd life of industrial batteries	A	Establishment of specific criteria for the end of waste status; repurposing and remanufacturing are considered treatment processes – resulting products are considered as new; provision of information of stationary and EV batteries (> 2 kWh) and requirements for economic operators for repurposing and remanufacturing	59				X	X			Repurpose Remanufacturing		59: Implementation act for waste status requirements and on the methodology for determining the state of health
	B	Expansion to include multiple battery categories (with battery management system, (BMS)), power limit eliminated; additional inclusion of the term "reuse"		X	X		X	X	X		Repurpose Remanufacturing Reuse		
	C	Expansion to include multiple battery categories; term "remanufacturing" omitted			X		X	X			Repurpose Reuse		

Measures of the Reg.	Version	Summary/content	Article	Battery categories[1] P	LMT	Auto	EV	Ind	BESS	General	R-strategies	Timeframe	Legal Acts
Collection rate portable batteries	A	Formulation of collection targets for portable batteries	48, 55	X								Portable batteries: 1. 45 % by 31.12.2023 2. 65 % by 31.12.2025 3. 70 % by 31.12.2030	Commission review of targets by Dec. 31, 2030 – collection rate for LMT batteries, if applicable
	B	Increase collection targets for portable batteries and include general purpose portable batteries (55-1a); add collection targets for LMT batteries (48a and 55-2a);		X	X					X		General purpose portable batteries: 1. 45 % by 31.12.2023 2. 70 % by 31.12.2025 3. 80 % by 31.12.2030 LMT batteries: 1. 75 % by 31.12.2025 2. 85 % by 31.12.2030	55-2b: Delegated act by Dec. 31, 2023, to calculate and review collection targets for LMT batteries
	C	Changes in collection deadlines for portable batteries; introduction of collection rates for LMT (48a)		X	X							for portable batteries: 1. 45 % within 24 months after entry into force 2. 65 % within 72 months after entry into force 3. 70 % within 96 months after entry into force LMT batteries: 1. Minimum 54 % within 96 months after entry into force	48-8: Delegated act within 48 months of entry into force on the calculation method of the collection rate and on collection targets of portable batteries 48a-7: Delegated act within 48 months of entry into force on the calculation method of the collection rate and on collection targets of LMT batteries
Collection rate for automotive, industrial and EV batteries	A	No specific formulation of collection targets for automotive, EV and industrial batteries; however, a high collection rate is expected through provision of a new reporting system	49			X	X	X					
	B	–				X	X	X					
	C	–				X	X	X					

Measures of the Reg.	Version	Summary/content	Article	Battery categories[1]							R-strategies	Timeframe	Legal Acts
				P	LMT	Auto	EV	Ind	BESS	General			
Recycling efficiency	A	Formulation of chronologically increasing recycling efficiency of Li-ion and lead-acid batteries; energy recovery is prohibited	57	X	X	X	X	X	X	X	Recycle	by 01.01.2025 Li-ion batteries: 65 % lead-acid batteries 75 % other waste batteries: 50 % by 01.01.2030 Li-ion batteries: 70 % lead-acid batteries: 80 %	57-4: Implementation act by 31.12.2023 on calculation and verification of recycling efficiency and recovery rates 57-5: Delegated act on minimum recovered materials
	B	Expanded R-strategies; additional quota for nickel-cadmium batteries; increased quota for other waste batteries in 2030;		X	X	X	X	X	X	X	Recycle Repurpose Reuse	by 01.01.2025 Ni-Cd batteries: 85 % by 01.01.2030 Ni-Cd batteries: +85 % other waste batteries: 70 %	57-4: Delegated act by 31.12.2023 on calculation and verification of recycling efficiency and recovery rates 57-5: Delegated act by 31.12.2027 on minimum recovered materials 57-5a: Delegated act on the battery chemistry
	C	Amended deadlines on legal acts; amended deadlines on recycling efficiency; additional quota for nickel-cadmium batteries		X	X	X	X	X	X	X	Recycle	by 36 months after entry into force: Li-ion batteries: 65 % lead-acid batteries: 75 % other waste batteries: 50 % Ni-Cd batteries: 75 % by 96 months after entry into force Li-ion batteries: 70 % lead-acid batteries: 80 %	57-4: Implementation act within 18 months after entry into force on calculation and verification of recycling efficiency and recovery rates 57-5: Delegated act within 96 months of entry on minimum recovered materials and recycling efficiency 57-5a: Delegated act to include further components

Measures of the Reg.	Version	Summary/content	Article	Battery categories[1]							R-strategies	Timeframe	Legal Acts
				P	LMT	Auto	EV	Ind	BESS	General			
Recovery of mate-rials	A	Formulation of chronologically increasing recovery rates of the components Co, Ni, Li, Cu, Pb	57	X	X	X	X	X	X	X	Recycle	by 01.01.2026 Co: 90 %, Cu: 90 %; Ni: 90 %, Li: 35 %, Pb: 90 % by 01.01.2030 Co: 95 %, Cu: 95 %; Ni: 95 %, Li: 70 %, Pb: 95 %	
	B	Changes to the recovery rate of lithium		X	X	X	X	X	X	X	Recycle Repurpose Reuse	by 01.01.2026 Li: 70 % by 01.01.2030 Li: 90 %	
	C	Changed deadlines on acts (see **Recycling efficiency**) and changed deadlines on recovery of materials		X	X	X	X	X	X	X	Recycle	by 48 months after entry into force: Co: 90 %, Cu: 90 %; Ni: 90 %, Li: 35 %, Pb: 90 % by 96 months after entry into force: Co: 95 %, Cu: 95 %; Ni: 95 %, Li: 70 %, Pb: 95 %	
Carbon footprint	A	Initially mandatory declaration for industrial and EV batteries (> 2 kWh) on footprint from 01.07.2024; subsequently work towards classification into performance classes for carbon footprint (from 01.01.2026) and setting maximum values for batteries over entire life cycle (from 01.07.2027)	7				X	X			Refuse Rethink Reduce	From 01.07.2024, obligation to provide information in the form of a declaration on the carbon footprint From 01.07.2025 classification into performance classes for the carbon footprint From 01.01.2027 maximum values for the carbon footprint over the entire life cycle	7-1: By 01.07.2023 delegated act on the calculation method and implementation act on the format; delegated act on information obligations 7-2: By 31.12.2024 delegated act on performance classes and implementation act on their format 7-3: By 01.07.2026 delegated act on maximum values

Measures of the Reg.	Version	Summary/content	Article	Battery categories[1]							R-strategies	Timeframe	Legal Acts
				P	LMT	Auto	EV	Ind	BESS	General			
	B	Inclusion of LMT batteries (> 2 kWh); additional information on recyclate content; revised deadlines for acts; introduction of performance classes from 01.07.2025; maximum values from 01.01.2027; examination of whether extension to portable batteries possible (7-3a)			X		X	X			Refuse Rethink Reduce		7-1: By 01.01.2023 delegated act on the calculation method and implementation act on the format; delegated act on information obligations 7-2: By 01.01.2024 delegated act on performance classes and implementation act on their format 7-3: By 01.07.2025 delegated act on maximum values 7-3-4: Act on the reclassification of maximum values 7-3a: By 31.12.2025 review as to whether portable batteries (< 2 kWh) will be included
	C	Amended deadlines of measures and acts					X	X			Refuse Rethink Reduce	Carbon footprint: EV batteries: From 18 months after entry into force or 12 months after entry into force of act 7-1 Industrial batteries: From 42 months after entry into force or 18 months after entry into force of act 7-1 Performance classes: EV batteries: From 36 months after entry into force or 18 months after entry into force of act 7-2 Industrial batteries: From 60 months after entry into force or 18 months after entry into force of act 7-2 Maximum values: EV batteries: From 54 months after entry into force or 18 months after entry into force of act 7-2 Industrial batteries: From 78 months after entry into force or 18 months after entry into force of act 7-2	7-1: By 6 months for EV batteries and by 24 months for industrial batteries after entry into force of the delegated act on calculation methods and the implementation act on format; delegated act on information obligations 7-2: By 18 months for EV batteries and by 42 months for industrial batteries after entry into force of the delegated act on performance classes and the implementation act on their format -threshold values will be reviewed every three years 7-3-3: By 36 months for EV batteries and by 60 months for industrial batteries after entry into force of the delegated act on maximum values

Measures of the Reg.	Version	Summary/content	Article	Battery categories[1]							R-strategies	Timeframe	Legal Acts
				P	LMT	Auto	EV	Ind	BESS	General			
Perfor-mance and durability	A	Initially, only information requirements on performance and durability of general purpose portable batteries; later, minimum requirements for market access will be formulated on the basis of collected data; for general-purpose portable batteries, minimum values for performance and durability already apply from the first step	General purpose portable batteries: 9 EV and industrial batteries (> 2 kWh): 10				X	X		X	Rethink Reduce	From 01.01.2027 general purpose batteries must meet values for durability and performance By 31.12.2030 review to gradually phase out non-rechargeable general purpose portable batteries. 12 months after entry into force information on performance and durability of industrial and EV batteries From 01.01.2026 minimum values for performance and durability of industrial batteries	9-2: By 31.12.2025 delegated act on durability and performance of general purpose portable batteries; delegated act to adjust the parameters possible 10-3: By 31.12.2024 delegated act on minimum values for industrial batteries
	B	Reference to portable batteries excluding general purpose portable batteries; deadline changes for legal acts; LMT batteries are included; 2 kWh power limit is removed; reference to Electronic Exchange System (10-1a); listing of new legal acts.		X	X		X	X		X	Rethink Reduce	By 31.12.2027 review to gradually phase out non-rechargeable general purpose portable batteries By 01.01.2026 information on performance and durability of industrial, LMT and EV batteries via Electronic Exchange System From 01.01.2026 minimum values for performance and durability of industrial, LMT and EV batteries	9-2: By 01.07.2025 delegated act on durability and performance of general purpose portable batteries; delegated act to adjust the parameters possible 10-1b/c: Delegated act on performance and durability of EV batteries 10-3: By 31.12.2024 delegated act on minimum values for industrial, LMT and EV batteries; delegated act to adjust the parameters possible (10-3a)
	C	Amended deadlines; inclusion of LMT batteries			X		X	X		X	Rethink Reduce	From 72 months after entry into force or 24 months after entry into force of act 9-2, general purpose portable batteries must meet minimum durability and performance From 48 months after entry into force or 18 months after entry into force of act 10-3, industrial batteries must meet minimum durability and performance	9-2: By 48 months after entry into force delegated act on durability and performance of general purpose portable batteries; delegated act to adjust the parameters possible 10-3: By 30 months after entry into force delegated act on minimum values for industrial, LMT and EV batteries; delegated act to adjust the parameters possible (10-3a)

Measures of the Reg.	Version	Summary/content	Article	Battery categories[1] P	LMT	Auto	EV	Ind	BESS	General	R-strategies	Timeframe	Legal Acts
Primary batteries	A	Definition of performance and durability for efficient use of resources; market launch only if values are met	9							X	Rethink Reduce	From 01.01.2027: Compliance with performance and durability parameters of (general purpose) portable batteries (see above) By 31.12.2030: Review whether a gradual phase out of non-rechargeable batteries is feasible	9-2: By 31.12.2025 delegated act on durability and performance of general purpose portable batteries; delegated act to adjust the parameters possible
	B	Amendment of deadlines								X	Rethink Reduce	By 31.12.2027: Review whether a gradual phase out of non-rechargeable batteries is feasible	9-2: By 01.07.2025 delegated act on durability and performance of general purpose portable batteries; delegated act to adjust the parameters possible
	C	Amendment of deadlines								X	Rethink Reduce	From 72 months after entry into force or 24 months after entry into force of act 9-2, general purpose portable batteries must meet minimum durability and performance By 108 months after entry into force review of gradual phase out of non-rechargeable general purpose portable batteries	9-2: By 48 months after entry into force delegated act on durability and performance of general purpose portable batteries; delegated act to adjust the parameters possible

Measures of the Reg.	Version	Summary/content	Article	Battery categories[1]							R-strategies	Timeframe	Legal Acts
				P	LMT	Auto	EV	Ind	BESS	General			
Recycled content	A	Technical documents show mandatory declaration of recycled content of automotive, industrial and EV batteries (> 2 kWh); following this, mandatory specifications for recycled content of recovered Li, Co, Ni, Pb are introduced	8			X	X	X			Recycling Reduce	From 01.01.2027: mandatory declaration of recycled content Mandatory recycled content: From 01.01.2030: 12 % Co; 85 % Pb; 4 % Li; 4 % Ni From 01.01.2035: 20 % Co; 85 % Pb; 10 % Li; 12 % Ni (revision of values by 31.12.2027)	8-1: By 31.12.2025 implementation act on the calculation and review of the recycled content; by 31.12.2027 delegated act on the amendment of the recycled content
	B	Inclusion of portable and LMT batteries; amendment of deadlines and scope		X	X	X	X	X			Recycling Reduce	From 01.07.2025: mandatory declaration of recycled content for portable batteries Mandatory recycled content of portable batteries: from 01.01.2030: 12 % Co; 85 % Pb; 4 % Li; 4 % Ni from 01.01.2035: 20 % Co; 85 % Pb; 10 % Li; 12 % Ni (revision of values by 31.12.2027)	8-4: Review by 31.12.2027 of how much recycled content is on the market 8-4a: Delegated act on inclusion of further recycled content/materials
	C	Amended deadlines				X	X	X			Recycling Reduce	From 60 months after entry into force or 24 months after entry into force of act 8-2 mandatory declaration of recycled content Mandatory recycled content of portable batteries: From 96 months after entry into force: (see A) From 156 months after entry into force: (see A) (revision of values by 31.12.2027)	8-1-2: From 36 months after entry into force: delegated act on the calculation and review of recycled content 8-4: By 72 months after entry into force delegated act on amending recycled content

Measures of the Reg.	Version	Summary/content	Article	Battery categories[1]							R-strategies	Timeframe	Legal Acts
				P	LMT	Auto	EV	Ind	BESS	General			
Producer responsi-bility	A	Clear specification for extended producer responsibility and minimum standards for organizations assuming producer responsibility for portable batteries; information on registration must be provided by producing companies on online marketplaces	47	X	X	X	X	X	X	X			47-12: Implementation act possible to counter distortions of the internal market
	B	–		X	X	X	X	X	X	X			
	C	–		X	X	X	X	X	X	X			

Measures of the Reg.	Version	Summary/content	Article	Battery categories[1]							R-strategies	Timeframe	Legal Acts
				P	LMT	Auto	EV	Ind	BESS	General			
Design require-ments for portable batteries	A	Obligation for easy removability and replaceability of portable batteries; availability of the battery as a spare part should be guaranteed for ten years after market discontinuation	11	X							Repurpose Reuse Remanufac-turing Reduce Rethink		
	B	LMT batteries are included; mention of introduction deadlines; prevention of obsolescence through extended availability of battery model (11-1-2a); additional article on automotive, EV and industrial batteries (11a); additional article on safety of repaired batteries (11b); additional article for unified charger for EV and LMT batteries (11c); replacement of individual compo-nents and cells to be made possible		X	X	X	X	X			Repurpose Reuse Remanufac-turing Reduce Rethink	11-1: By 01.01.2024 portable and LMT batteries must be removable and replaceable 11c: By 01.01.2024 review of stand-ards for the uniform charger, which is to be introduced by 01.01.2026 at the latest.	11a-4: Delegated act on removability and interchangeability possible (au-tomotive, EV and industrial batteries) 11b-2: Delegated act for testing repaired batteries possible
	C	Amended deadlines; LMT batteries are included		X	X						Repurpose Reuse Remanufac-turing Reduce Rethink	11-1: From 24 months after entry into force: portable and LMT batteries must be removable and replaceable	

Measures of the Reg.	Version	Summary/content	Article	Battery categories[1] P	LMT	Auto	EV	Ind	BESS	General	R-strategies	Timeframe	Legal Acts
Information	A	Expansion of printed and digital provision of basic and specific information for users and economic stakeholders; later further development into battery passport and electronic exchange system; battery passport only applies to industrial and EV batteries (> 2 kWh); it provides information on performance and durability; access to data also via the electronic exchange system; mandatory battery management system (BMS) for industrial and EV batteries (> 2 kWh);	General: 13, 14 Electronic exchange system: 64 Battery passport: 65	X	X	X	X	X	X	X	Repair Repurpose Reuse	General: From 01.01.2027 mandatory labelling From 01.01.2027 information on capacity of automotive and portable batteries; for portable batteries also information on duration From 01.07.2023 symbol "separate collection" From 01.07.2023 information on lead and lead content above threshold value – Above and further information must be available via QR code Electronic exchange system: From 01.01.2026 provision of an electronic exchange system Battery passport: From 01.01.2026 mandatory battery passport for EV and industrial batteries	13-7: By 31.12.2025 implementation act on labelling requirements Electronic exchange system: 64-5: By 31.12.2024 implementation acts on the architecture, format and access rules of the electronic exchange system Battery passport: 65-7: Implementation acts on access rules possible

Measures of the Reg.	Version	Summary/content	Article	Battery categories[1]							R-strategies	Timeframe	Legal Acts
				P	LMT	Auto	EV	Ind	BESS	General			
	B	Amended deadlines; expanded information; new articles on non-rechargeable general purpose portable batteries (13-2a) and colour code for type and chemistry identification (13-3a); BMS for battery systems, EV and LMT batteries, power limit eliminated; electronic exchange system extended to LMT batteries;		X	X	X	X	X	X	X	Repair Repurpose Reuse	General: From 24 months after entry into force mandatory labelling. From 01.01.2027 information on capacity and duration of automotive, LMT and portable batteries. From 01.01.2023 labelling of non-rechargeable general purpose portable batteries and information on Cd and Pb content From 01.07.2023 uniform colour code for type and chemistry and symbol “separate collection” From 01.01.2024 conception of the communication “BMS with charging system” Electronic exchange system: – Battery passport: By 01.01.2026, all EV, industrial and LMT batteries must have an electronic file (battery passport).	General: 13-6a: Delegated act on the alternative for a QR code possible. 13-7: By 01.07.2025 implementation act on labelling requirements 13-7a: By 01.01.2023 implementation act on uniform colour code 14-3-1a: Delegated act on determination parameters possible. Electronic exchange system: – Battery passport: –

Measures of the Reg.	Version	Summary/content	Article	Battery categories[1] P	LMT	Auto	EV	Ind	BESS	General	R-strategies	Timeframe	Legal Acts
	C	Amended deadlines; partially expanded to include multiple battery categories; Article 14 limited to batteries with BMS and expanded to include LMT batteries; expanded electronic exchange system to include LMT batteries; expanded battery passport to include LMT batteries;		X	X	X	X	X	X	X	Repair Repurpose Reuse	General: From 48 months after entry into force or 18 months after entry into force of act 13-7 mandatory labelling From 48 months after entry into force or 18 months after entry into force of act 13-7, information on capacity of EV, industrial, automotive and portable batteries. From 48 months after entry into force or 18 months after entry into force of act 13-7, information on durability of non-rechargeable portable batteries (13-2a). From 24 months after entry into force: symbol "separate collection" From 24 months after entry into force: labelling of information on Cd and Pb content. From 24 months after entry into force: required QR code (for EV, industrial and LMT batteries access to electronic exchange system) Electronic exchange system: From 48 months after entry into force: provision of an electronic exchange system. Battery passport: From 48 months after entry into force all EV, industrial and LMT batteries must have a battery passport.	General: 13-7: By 30 months after entry into force implementation act on labelling requirements 14-2b: Delegated act on determination parameters possible Electronic exchange system: 64-5: By 36 months after entry into force implementation acts on the architecture, format and access rules of the electronic exchange system Battery passport: 65-6c: Delegated act on information provided possible. 65-7: By 36 months after entry into force implementation acts on the architecture, format and access rules

Measures of the Reg.	Version	Summary/content	Article	Battery categories[1]							R-strategies	Timeframe	Legal Acts
				P	LMT	Auto	EV	Ind	BESS	General			
Supply chain due dili-gence for industrial and EV batteries	A	Binding standards and specifications within the framework of the purchase of raw materials for economic stakeholders	39, 72				X	X				39-1: From 12 months after the entry into force of the regulation, operators are obliged to comply with the due diligence requirements for batteries	39-8: Delegated act on risk raw materials and obligations possible. 72-1/2/3: Implementation acts on the information requirement, recognition of demonstration system and demonstration method possible. 72-3: Implementation act on revocation possible.
	B	Extension to all batteries; scope is extended by term “value chain” (instead of “supply chain”);		X	X	X	X	X	X	X		–	39-8a: Delegated act on obligations possible.
	C	_					X	X				–	

[1] P Portable batteries:
LMT Light Means of Transport
Auto Automotive batteries
EV EV batteries (road)
Ind Industrial batteries (incl. EV batteries that are not used for EV road vehicles, such as ship, rail, industrial trucks, mobile machinery, etc.)
BESS Battery energy storage system, within the meaning of the Battery Regulation rechargeable industrial batteries “with internal storage”
General General purpose portable batteries

Note 1: BESS are stationary systems

Standardization request M/579
In support of the Battery Regulation, and to achieve the European Union's stated goal of improving the environmental performance of batteries, the European Commission issued an Implementing Decision on the Standardization Request (formerly "Mandate") 579; for short: M/579. s. [145]

The intention is to specify the standardization needs arising in the Battery Regulation and to have them implemented by the European standardization organizations CEN and CENELEC. Both organizations have already drawn up a work programme for the realization of the standardization request and have submitted it to the European Commission on 07 June 2022. Annual interim reports will provide information on progress until the final report on 31 December 2025, at which time all required standardization needs should be implemented.

At this time, the standardization request includes the following task blocks:

1. **Performance and durability aspects** of portable rechargeable and non-rechargeable batteries (Battery Regulation Article 9)
2. **Performance and durability aspects** of rechargeable batteries with internal energy storage (Battery Regulation Article 10)
3. **Re-use and repurposing** of rechargeable batteries with internal energy storage (Battery Regulation Articles 14 and 59 etc.)
4. **Safety aspects** of stationary battery energy storage systems with internal energy storage (Battery Regulation Article 12)

Task blocks 1 and 2 provide for the establishment of methods for determining performance and durability (in accordance with Articles 9 and 10 Battery Regulation). In the case of non-rechargeable and rechargeable general purpose portable batteries, the determination of the capacity, the average minimum operating time, the shelf life and leakage testing are required; in the case of rechargeable portable batteries, the determination of the endurance in charge and discharge cycles is added.

In the case of rechargeable industrial and EV batteries, European standards are to be developed for capacity reduction, increase in internal resistance, efficiency and expected lifetime. The aim is not only to provide consumers with comprehensible information, but also to create fair and uniform market conditions for all economic operators.

Task block 3 deals with sustainability and the "Circular Economy". It contains the requirements for standards for reuse and repurposing of batteries, battery packs and battery modules (according to Articles 14 and 59 of the Battery Regulation). Here, a further distinction is made between three categories: "Design", "Diagnostics and determination of the state of health", and "Battery evaluation for repairing or repurposing".

The standard category "Design" requires that the maintenance, repair, reuse and repurposing of batteries and battery packs be facilitated or at least not prevented. In this context, the requirement for the replaceability of individual, failing battery components should also be mentioned.

Under the category "Diagnostics and determination of the state of health", procedures for determining the state of health of batteries are addressed. A reliable classification of the remaining capacity and the expected behaviour is intended to enable use in "2nd life" applications. This is particularly topical in view of the steadily increasing application of discarded EV batteries and their further use in stationary applications. Here, there is also a cross-reference to the battery management systems used, as access to the battery history seems to be advantageous for such a diagnosis and evaluation.

Finally, the last category, "Battery evaluation for repairing or repurposing," addresses the description of the necessary steps, conditions, and protocols that describe safe repair, reuse, and repurposing of EV batteries and their components.

In task block 4, uniform safety requirements for the operation of stationary battery energy storage systems are to be formulated (in accordance with Article 12 of the Battery Regulation). Test methods, including those for thermal shock, external and internal short circuit protection, thermal runaway and mechanical damage, are to be specified in standards.

Since the content of the Battery Regulation has not yet been finalized, standardization request M/579 must also be regarded as being provisional. Not only is it expected to be adapted to the final version of the Battery Regulation, but additional requirements may also be added. The standardization request was issued before the Battery Regulation was published, so that standardization work could begin before the Regulation came into force.

The work programme forwarded to and accepted by the EU Commission in June covers all task blocks of the standardization request. Not only are new standards being developed, but existing standards are also being adapted. For primary batteries, three IEC standards are to be adapted and adopted by CLC/SR 35 “Primary batteries”. In the field of electrically propelled road vehicles (EV), CEN/TC 301 “Electric road vehicles” will process eleven standards. The applications portable batteries, LMT, industrial and stationary batteries are being handled by CLC/TC 21X “Accumulators” and there are about 20 standards indicated in the work programme for editing and new elaboration. With adjustments to the standardization request M/579 when the Battery Regulation is published, there may also be changes to the standardization work programme. Comprehensive battery expertise is needed for this extensive work on performance, durability, design aspects for reuse, repair and maintenance, and also safe operation. Active support through participation of national experts in the national battery committees of the DKE, K 371 “Accumulators” and K 372 “Primary batteries”, as well as in the editing and development of the European Standards, is therefore very welcome.

Connection between the Battery Regulation, standardization request M/579 and the Standardization Roadmap Circular Economy

As mentioned at the outset of this section, the Battery Regulation, which is still under negotiation at the time of writing (September 2022), and the associated standardization request M/579 contain an entire range of requirements for the Circular Economy. Therefore, the following chapter also deals specifically with areas that are not covered by the Battery Regulation, and addresses the extent to which additions are necessary or there is a need for improvement. Critical aspects of the Battery Regulation will also be addressed.

What requirements will actually be placed on standardization beyond the current standardization request M/579, and which aspects will be addressed by legal acts is not yet clear at present, since the final content of the Battery Regulation is not yet known. Due to the ambitious time frame, topics from the standardization request will be prioritized in the standardization process. For example, standardization work has already begun in the field of batteries. Furthermore, the connections between the upcoming Battery Regulation and the Ecodesign Directive [21] or the Sustainable Product Initiative [225] are still open. Overlaps and, in some cases, contradictions still need to be clarified.

A major challenge is posed by different designations/terms, i.e. differences in the language of battery standardization and regulation. The use of certain terms has evolved in standardization and is internationally agreed. Matching them with terms in the Battery Regulation in order to identify standardization needs turns out to be problematic in some cases. As an example, the term “batteries with internal storage” does not exist in battery standards. Other terms such as “general purpose portable batteries” are not defined in standards language. Nevertheless, many requirements overlap with those defined in standards for portable batteries. Furthermore, the expressions “battery type” and “battery category” are used side-by-side without being specifically described or distinguished in the Battery Regulation. This makes it difficult to understand the text and thus to transfer the requirements from the Battery Regulation to standardization work. Besides this, however, the term “battery model” is clearly defined. It is therefore necessary to create a list for a transfer of terms from the Battery Regulation and terms from standardization. This is because the agreed terms, as also stored in the International Electrotechnical Dictionary (IEV), will continue to be used in standards [149].

Applying the R-strategies to batteries, which are often components rather than stand-alone products, presents challenges. The design of batteries with modules and cells makes it necessary to consider the assignment of R-strategies in a differentiated manner. For example, reuse applies to a single cell within a battery, while repair or refurbishment are relative to the entire battery. Thus, a clear separation of the individual R-strategies from each other is difficult and depends on the respective intention. In addition, a battery must be considered a safety-critical component where small changes can have large effects. Thus, not only the benefits must be weighed in all considerations, but also the safety limits must always be taken into account.

After all, the field of batteries is currently characterized by innovations like no other. For example lithium-ion batteries in particular are in the course of constantly new developments as a key technology of the energy and transport revolution. Normative specifications on ageing aspects (“state of health”) and durability statements are currently still difficult to implement, since both topics are still at the state of current research and have so far found little entry into technical development.

2.3.3 Standardization needs

Applying the R-strategies to batteries

The individual R-strategies and the resulting standardization needs are discussed in more detail in the following sections. As mentioned in the previous sections, it is not always possible to draw a clear line between the different strategies, as many of the resulting applications overlap. In particular, the three strategies "rethink", "refuse" and "reduce" have similarities, whereupon the examples given are applicable to several strategies at the same time. Thus, different R-strategies often have the same recommended actions. Furthermore, R-strategies for electrical and information technology products also concern the area of batteries, as electronic components. Thus, standardization needs from Chapter 4.2 should also be considered (for example, Needs 2.3 and 2.13). Table 2 gives an overview of the application of R-strategies to batteries and relates them to the specifications of the Battery Regulation. Likewise, the effects on product conformity when applying the respective strategies are shown. Furthermore, examples illustrate how the R-strategies can be applied to the product "battery".

Table 2: Overview of applying the R-strategies to batteries

R-strategy	Description (battery perspective)	Definition as in Battery Regulation	Effect on product conformity	Examples for better understanding
Refuse	Eliminating the use of batteries, e.g., by replacing human labour as in the case of a bicycle dynamo, or eliminating an additional function that does not serve the actual function of a product	Not defined	No effect	Eliminating primary batteries whenever possible. Eliminating battery-powered add-on functions in products (e.g., lighting for children's shoes).
Rethink	Developing a battery from a systemic perspective so that it is developed over the entire life cycle and with a circular approach. This means that batteries should be used more intensively, e.g. through reuse and sharing models, such as accumulators being replaceable and usable in different devices.	Not defined	No effect	Uniform battery for various power tools Exchangeable batteries in notebooks, Bluetooth speakers, cell phones, universal power banks. Unification of modules or packs. Adapt existing tests (e.g.: thermal runaway propagation test).
Reduce (by design):	By changing the design of the battery, it is hoped to use fewer resources, materials and energy, thereby increasing its circularity and efficiency. The manufacturing process of a battery in particular can offer potential for reduction here.	Not defined	No effect	Less material used for housings, e.g. pouch cells instead of round cells. Optimized structures in mechanical design. As a result, less material is used. Replace or reduce certain critical raw materials (in the sense of the Circular Economy).
Reuse	Any operation in which a battery that is not waste is reused for the same application for which it was designed. The battery remains as a whole and no parts are changed.	The complete or partial direct re-use of the battery for the original purpose the battery was designed for [141]	Conformity is maintained	Defective device, the battery is still intact and is taken over unchanged in another device.

R-strategy	Description (battery perspective)	Definition as in Battery Regulation	Effect on product conformity	Examples for better understanding
Repair	Modifications made to the original battery that has a malfunction, in order to have a fully functional battery again. A repair can be carried out, for example, by replacing defective components, adding or rearranging components.	Not defined in the Commission's proposed Battery Regulation, but included; mainly in Article 47 (Extended Producer Responsibility), Article 60 (End-of-life information), Article 65 (Battery passport).	The certification is no longer valid: Replacing parts of the battery will result in the loss of the "type approval", which means that the product must go through the full certification process, e.g. according to UN-T 38.3, and must comply again with the German Product Safety Act and all applicable (safety) standards after repair.	A replacement of defective modules e.g. in stationary battery storage systems, replacement of a defective BMS.
Refurbish	Only "cosmetic" maintenance of a battery to restore it to its original condition. It is not the replacement or modification of components of the battery, except for non safety-related components as defined by the original manufacturer.	Not defined	Conformity is maintained	Cosmetic overhaul only, BMS update (pay attention to safety aspects), do not update anything defective to the latest technical standard, clean dirty parts (as shunts are possible), replace corroded cables or contacts, top up water on lead-acid batteries.
Remanufacture	Modifications are made to a used battery to restore its performance. In the process, the functionality is changed and modifications are made in which safety-relevant components are replaced. This includes any procedures performed on the battery that are not approved by the original manufacturer.	Any operation of disassembly, restoring, replacing components of used battery packs, battery modules and/or battery cells to return a battery to a level of performance and quality equivalent to that of the original battery, for the original or a different purpose [142]	The certification is no longer valid: Remanufactured batteries lose their "type approval", which means that they have to go through and pass the full certification process again, e.g. according to UN-T 38.3, the German Product Safety Act and all applicable (safety) standards, after remanufacturing.	Components whose condition is known with certainty are reassembled, e.g. connectors, BMS and modules (safety must be observed).
Repurpose	Any operation that results in certified subunits or a completely unmodified battery being used for a different purpose than originally intended.	Any operation that results in parts or the complete battery being used for a different purpose or application than the one that the battery was originally designed for [141]	Batteries must be recertified according to their new intended use.	The battery still has sufficient power for certain (other) applications and is used in another application. (Ex: EV battery in stationary applications)
Recycle	Recovery of materials from waste batteries by crushing or disassembling the battery. For this purpose, battery chemistry labelling is important.	Any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations [47].	No effect	Use residual charge for energy generation before recycling. The waste battery is broken down into its components in a decomposition process; these can be returned to the recyclable materials cycle.

R-strategy	Description (battery perspective)	Definition as in Battery Regulation	Effect on product conformity	Examples for better understanding
Recover	Battery materials and residues from the recycling process that cannot be recycled further are sent for energy recovery.	Any operation the principal result of which is waste serving a useful purpose by replacing other materials which would otherwise have been used to fulfil a particular function, or waste being prepared to fulfil that function, in the plant or in the wider economy [150]	No effect	Recovery of the energy of a battery (electricity/heat) by thermal utilization of its components.

Refuse

Refuse is all about doing without. This can mean doing without raw materials, production processes or entire products that are not needed or can be replaced. For batteries, this is significant when considering doing without or replacing primary batteries whenever possible. Here, the Battery Regulation provides for an evaluation of whether a complete waiver of the battery is possible. Likewise, the manufacturing process of a battery can provide starting points for "refusing" by omitting certain steps. In particular, however, the complete elimination of batteries should be considered unless they perform a necessary function (e.g., battery for lighting children's shoes) or can be replaced by an alternative (dynamo for bicycle lights).

At present, no need is seen for the standardization of batteries as regards "refuse".

Rethink

"Rethinking" is about developing a product from a systemic perspective, considering its entire life cycle and using a circular approach. This means that batteries should be used more intensively through reuse and sharing models, e.g. as accumulators that are replaceable and usable in different devices. In the field of electric gardening equipment and tools, the interchangeability and multiple use of accumulators is already being implemented. However, this is only possible for the equipment of the same manufacturer. There should be new business models that make a battery more multifunctional. With batteries, however, it must always be remembered that they have a safe operating window that must be adhered to in other applications. The draft Battery Regulation requires that portable batteries can be easily removed and replaced by end-users and independent economic operators. This provision will particularly affect accumulators in laptops and cell phones. A definition of what is meant by "easily replaceable" already exists, e.g. for household appliances (DIN EN 60335-1 [151]). Fuses for infants and children in children's toys have also already been implemented [152].

Need 3.1: Standards for the interchangeability of batteries
The requirements for standardization in the upcoming Battery Regulation are clear here and will be implemented as part of the processing of the standardization request. This mainly concerns the development of products so that battery interchangeability is easy and safe. Despite all this, it must be examined whether there are groups of devices for which the simple interchangeability and removal option must be supplemented by standards, e.g. mobile devices and laptops. For power tools and garden equipment, agreeing on a format and operating limits could help make interchangeable batteries interchangeable among different manufacturing companies as well, so there is a gain in multiple use.

Reduce (by Design)

"Reducing" is primarily about changing the design of a product or process to improve circularity and efficiency. Fewer resources, materials and energy should be consumed, which would ultimately also lead to a reduction in the carbon footprint. In the case of batteries, for example, this could mean paying attention to the use of less material in the design of the housing. Optimized structures in the mechanical design can also lead to a reduction in the use of plastics in particular, but also of metals. In all cases, the highest priority is given to safety aspects.

Energy can also already be saved in the production of batteries through optimized processes at various levels (change over time or new processes). An example of this is the drying process at cell level.

When applied to batteries, the categories “reduce”, “refuse” and “rethink” repeatedly overlap, as they cannot be clearly separated from each other. Rather, they intertwine when it comes to rethinking the design of a battery and its manufacturing process to make it more efficient.

Need 3.2: Carbon footprint of lead-acid batteries
There is a draft standard for the calculation of the carbon footprint for lithium-ion batteries at IEC/SC 21A “Secondary cells and batteries containing alkaline or other non-acid electrolytes” (IEC 63369-1 Ed.1 committee draft (CD) status) [153]. This IEC Standard is expected to be published by the end of 2024. It should be checked to see if this complies with the guide IEC/TC 111 “Environmental standardization for electrical and electronic products and systems” (project IEC 63372 ED1) [154]. In addition, there is a need for a standard to determine the carbon footprint of lead-acid batteries.

Reuse

“Reuse” means reusing a battery, which is not waste, for the same intended use for which it was designed and was already in use. In this case, the battery as a whole must be reused unchanged. This ensures that the conformity of the battery is maintained. However, there may be a change of owner in the case of reuse, in which case the history of use and condition (state of health, or SoH) of the battery are relevant, e.g. for determining the value. In the upcoming Battery Regulation, the topic of reuse may no longer be included, in contrast to the Commission’s proposal. The reason for this is that the product “battery” is not changed and therefore no new requirements arise. However, there is still a need for standardization to determine the state of health (SoH). The conversion of individual cells should currently be avoided. Only when corresponding information about the condition of individual cells is available is their conversion even conceivable. In addition, information about cell chemistry and, for example, operating windows and characteristics must be known. This creates needs, some of which are still within the scope of research.

Need 3.3: Standards for the digital battery passport for reuse (see also Need 3.19)
Within the framework of standardization, there are aspects that can support the reuse of a battery. Particularly important for a secondary user is information about chemistry and structure, but also about usage history. Some important information can be passed on via permanent marking. For other information, a digital product passport (DPP) is required.

Need 3.4: Standards on data about condition
Access to the BMS regarding the usage history and the state of health (SoH) of the battery in case of further use is essential. It must always be taken into account that personal data must be deleted. Design instructions for removal and reinstallation are to be linked to the product ideally via a digital battery passport.

Need 3.5: Definition of safety limits for reuse
In addition, it should be considered whether different conditions and criteria need to be defined for batteries in different applications as to when it becomes safety critical in the context of “reuse”. The use of a 12 V automotive battery in another vehicle, for example, is significantly less critical than the replacement of an EV battery in an electric road vehicle. Thus, depending on the application, there may be significantly more requirements and restrictions if one wants to reuse the battery.

Repair

Repair applies when a faulty or defective product is made usable again to fulfil its original function. This involves making changes to the original product in batteries so that they lose their type approval. The draft of the Battery Regulation provides that, in principle, the possibility of repairability of a product, by “independent economic operators” as well, must be given and should also be facilitated. The explanatory memorandum refers to environmental benefits and resource savings due to removability and replaceability of portable batteries.

As an example, consider the case of repairing a BESS: A BESS consists of a variety of mechanical, electromechanical, electrical, electronic and electrochemical discrete components. These components are subject to different but known ageing and wear mechanisms that can cause them to no longer operate efficiently or to fail completely. The efficient usability of a BESS can be significantly extended by making components diagnosed as having a high probability of failure or susceptibility to wear easily replaceable. For this purpose, these components must be provided with appropriate mechanical and electrical interfaces so that they can be separated from the rest of the product without being destroyed. However, replacing individual battery cells or interconnected cell arrays comes with the risk of creating large imbalances in the state of health and remaining capacity across the entire cell array, which can affect the overall condition of the battery.

At the module and system level, state of the art repairability or interchangeability is generally considered reasonable. On the other hand, making battery storage systems repairable at the cell level as well, as envisaged in the Battery Regulation, is viewed critically, even if this could achieve a high level of material efficiency. In practice, the advantages and disadvantages have to be weighed up against each other, as this would also involve a high logistical outlay.

Currently, there is no solid technical framework for battery repair that is aligned with battery type approval and thus clearly defined part requirements, product/production process qualities, product responsibilities, certifications and transportation safety aspects, and battery safety testing. Without this framework, any type of battery repair can result in loss of type approval and also uncontrolled, potentially unsafe situations during use.

For the original manufacturer of batteries, it can be problematic from the point of view of product safety, for the transport as dangerous goods and especially in liability issues, if repairs can be carried out by independent economic actors. In such a case, the original manufacturer of a battery may not be able to continue product liability. There are currently generally no explicit rules for repair and remanufacturing services to work with the original manufacturing companies or even recertify the battery. In the event that any independent market participant is allowed to repair a battery, clear conditions must be created for this, which take appropriate account of the fact that the battery is a safety-critical component.

Need 3.6: Safety standards for the replacement of battery modules and cells
Replacing individual cells or modules can have dangerous consequences for certain battery types if not done properly. Therefore, normative provisions are required on how and under which conditions a replacement of individual modules or even cells can take place. At least information about the cell manufacturer and the cell type must be available. It must be ensured that only cells approved by the manufacturer are used, because otherwise dangerous operating conditions can occur and the battery would no longer conform to the standard. In addition, the manufacturing company would have to provide the “independent economic operators” with information indicating exactly which modules, and under which conditions, can and cannot be exchanged. There must not be any gaps in safety here.

Need 3.7: Standards for the mechanical and electrical design of energy storage systems
Requirements for the mechanical and electrical design of battery storage systems that enable non-destructive replacement of components should be described. Among the components, the goal is to identify those that are reasonably likely to fail during the life of the battery storage system, or that will no longer allow safe and/or efficient operation due to wear and tear. The properties of the components to be replaced must be disclosed by their manufacturers or distributors to the extent that adequate replacement components can be procured.

Need 3.8: Standards on data regarding the state of health and state of safety for better repairability (see also Need 3.3)
Furthermore, data on the state of health (SoH) and the state of safety of all individual cells must be available for the repairability of modules. These states must first be defined in standards. However, the information on this cannot currently be determined under economic conditions. Here, standards can help to facilitate the collection of data and make this collection more efficient.

Need 3.9: Standards for the digital battery passport for repair (see also Need 3.19)
Standards must describe both safety and performance conditions for repair. For this purpose, all necessary information for the repair must be described and the repair itself must also be documented in the information provided with the battery. A digital battery passport would be a suitable means for this.

Need 3.10: Standards on mechanical and electrical tests
Suitable mechanical and electrical tests should be described to ensure safe operation of repaired batteries and battery storage systems.

Refurbish

Refurbish refers to the refurbishment of non-safety-related components of a battery to achieve a certain previous performance level. The battery is then reused in the same application. During refurbishment, software updates can be performed in the BMS or worn (not defective) parts can be replaced with spare parts approved by the original manufacturer. This can extend the service life of a battery, because the performance level of a battery is essentially determined by the state of health of the cell array.

Need 3.11: Safety standard with non-destructive test methods
Suitable tests are to be described to ensure safe operation of refurbished battery systems. This would require replacing today's destructive tests with non-destructive tests so that type testing, which is based on sampling, can be replaced by unit testing, which can be performed on each cell and cell array.

Remanufacture

The process of remanufacturing a battery involves modifying parts of the battery to restore its original performance. It is also possible to use only parts of one battery in another or to reassemble a battery from parts of other batteries. In the process, functionalities are changed and safety-relevant parts are replaced using procedures that have not been approved by the original manufacturer. The original product is not retained, so the declaration of conformity must be renewed. A new product is created, for which the remanufacturer must provide a warranty, and this should be clear from the labelling.

Need 3.12: Standards for the modular design of batteries
Several aspects can be considered in standardization to enable remanufacturing: The design of the battery as modular units on different levels simplifies the reuse of the individual parts. This in turn can mean a higher carbon footprint for the entire battery, so this must be taken into account normatively as part of a life cycle consideration. In order to continue using modular units safely, the interfaces such as data exchange, connectors, etc. are also crucial. These are thus to be defined consistently within the framework of standardization.

Need 3.13: Standard for the suitability testing of used components
If used components of a battery are reused, suitability tests must be defined, because battery testing has so far been based on type tests. For this purpose, requirements for the usability of the components in another battery must be specified. In addition, new requirements arise for placing a remanufactured but still new product on the market. Remanufactured products must thus meet at least the same test requirements as new products on the market. In addition, suitable certification of individual components (composite certification) would be conceivable.

Repurpose

When a battery is repurposed, a complete and unmodified battery or an unmodified subunit, possibly certified, is used in a different application or for a different purpose than the one(s) for which it was designed. The most common use case for repurposing is the use of battery packs or modules originally planned for use in electric road vehicles in stationary applications. It must be ensured that the battery meets the safety requirements of the new application, as these may differ significantly from those in the originally planned application. Therefore, it is necessary to define safety requirements that batteries must meet in the new application. When it comes to repurposing individual cells within a module or battery, keep in mind that it may be a combination with other R-strategies such as "remanufacturing" or "repair."

Need 3.14: Standards on 2nd life
Part of the approach has already been implemented in the draft of VDE prestandard 0510-100 "Safety of automotive lithium-ion batteries for use in stationary applications" [50] when it comes to the simplest case, i.e. new, not yet used batteries or subunits. It will be much more difficult to define the safety tests for used batteries and sub-units (2nd Life). This requires the determination of the SoH and the knowledge and evaluation of ageing phenomena. To this end, criteria are currently being evaluated within the DKE/K 371 standards body [156], which will then have to be addressed in a standard. Furthermore, the quality of the components, certification aspects, and effects on the validity of the test certificates of these used batteries required by dangerous goods transport legislation must then be considered.

Recycle

Recycling refers to the recovery of materials from waste products so that they can be reused. In the case of batteries, the recycling process often begins with a physical or chemical crushing of the entire battery. This produces a mostly fine-granular mix of raw materials, the breakdown of which into the starting materials for the production of new batteries is energetically expensive and has an insufficient recovery rate. In addition, crushing can present a safety hazard depending on battery chemistry.

Recycling efficiency could be significantly increased if a battery or battery storage system could be broken down into individual components with little effort. The discrete components could then be assigned to the most appropriate recycling process for each, or could be transferred to a "reuse" or "repurpose" cycle if suitable. To achieve this, the ability to dismantle batteries and BESS would have to be made much easier without compromising safe operation. In addition, the characteristics of the discrete components must be made known by the manufacturing companies or companies placing them on the market in such a way that the recycling process is as specific as possible.

A Circular Economy requires that materials from used products can be reused in new products. In order to promote this closing of loops, the new Battery Regulation will in all likelihood provide for recyclate use quotas for new batteries.

Given the continued strong market growth, especially for EV batteries, meeting recyclate use quotas is becoming a challenge. After all, due to the long life of batteries, recyclates are only available after a delay of several years. This effect is further enhanced by extending repairability and 2nd use. This makes it all the more important to recycle used batteries.

Need 3.15: Labelling of batteries for recycling purposes
Specifying the battery chemistry is important for a safe recycling process. A corresponding label for secondary batteries has already been defined in DIN EN IEC 62902 [315]. The colour coding and thus the quick visibility of the battery chemistry should remain optional. Here, costs and benefits must be weighed. However, the parliamentary draft of the Battery Regulation provides for a corresponding colour coding on the battery type and its cell chemistry.

Need 3.16: Dismantlability
The fact that battery energy storage systems are designed to be dismantlable down to a reasonable component level after their service life should be described in a standard. The component level should be selected so that specific and efficient recycling processes can be applied to the individual components.

Need 3.17: Standards for the digital battery passport (see also Need 3.19)
A digital battery passport would help to provide various data and information important for recycling, e.g. also about dismantlability.

Need 3.18: Availability of recyclates
Standardization can help define quality requirements for recyclates, thereby enhancing the reliability of recyclate use and supporting the development of recycling capacities and markets for recyclates.

Digital battery passport

To meet the requirements of circular value creation, it is necessary to have certain information available at many points along the battery's life cycle. In order to have this diverse battery information available at the decisive points, it would be useful to document the life cycle of a battery in an electronic product passport or to digitally store the necessary data in an uncomplicated yet secure way. For this reason, the upcoming Battery Regulation will also contain requirements for such a digital product passport, which should include important data not only on the carbon footprint and the supply chain, but also the identity of the battery and its components, as well as their condition. Since there is as yet no comparable procedure for documenting a product life cycle, such a digital battery passport can be regarded as a pilot project for a general product passport (see Chapter 3.3 and standardization Needs 1.7-1.13 and 1.15, 1.16 and 1.22).

Need 3.19: Standards on the digital battery passport
Accordingly, there is a great need to define the underlying information of a battery passport and the data exchange in a standardized manner and thus to clarify technical as well as legal issues within the framework of standardization. It would be desirable if the digital battery passport could be integrated as part of a general product passport. For further information, please refer to the Chapter "Digital Product Passport".

2.4 Packaging

2.4.1 Status quo

From the perspective of the Circular Economy, packaging presents a number of special challenges: On the one hand, packaging helps to protect the products transported in it and thus reduce the amount of food waste, for example. On the other hand, the packaging systems used today are predominantly linear in orientation: After their first use, they become waste, which can be recycled and returned to the cycle with varying degrees of success or failure, depending on the material. In Germany alone, almost 19 million tonnes of packaging waste are generated each year, including around eight million tonnes of paper and board, and three million tonnes each of plastics, glass and wood. This volume has increased continuously over the past decades, more than doubling for plastic packaging [157].

In the context of the key topic “Packaging”, different strategies and approaches to make packaging systems circular were discussed: from the design of packaging and the design of circular infrastructures of sorting and recycling to the conformity of the use of recyclates. Likewise, the lack of standards for the areas of reusable packaging and doing without packaging altogether was identified, which has so far hampered or prevented the use of such concepts in practice. Given the broad spectrum of possible approaches, a particular focus was placed on standardization needs for the sustainability assessment of different packaging solutions. The analyses and discussions in the individual sub-working groups made clear the central role that standards and specifications will play in strengthening circular packaging systems in the future.

Evaluation of standards research

The Working Group Packaging evaluated the standards research on the Circular Economy (see Chapter 1.6.2) of DIN, DKE and VDI on the basis of the nine R-strategies. In addition, the topics carbon footprint and digital product passport were identified. Altogether 292 of 2101 standards and documents were relevant for the Working Group.

Interpretation

Overall, there are many relevant results for circular packaging. The majority of the standards are in the area of recycling, a classic area of the Circular Economy, or are generally applicable results. This is followed by standards on “reuse,” standards on the digital product passport in the broader sense, and standards for recording a carbon footprint. Some, especially higher-value strategies, have little or no results in the set of standards on packaging.

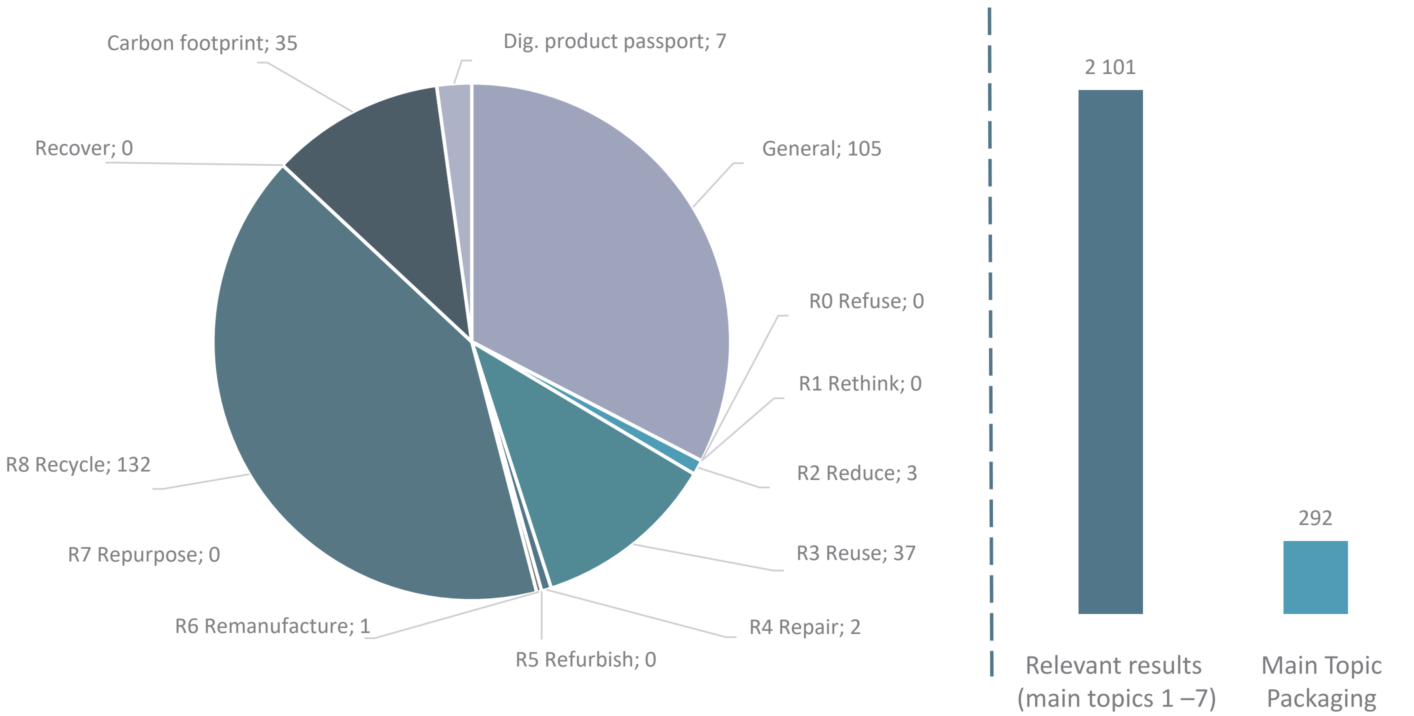


Figure 20: Categorization by R-strategies (Source: DIN)

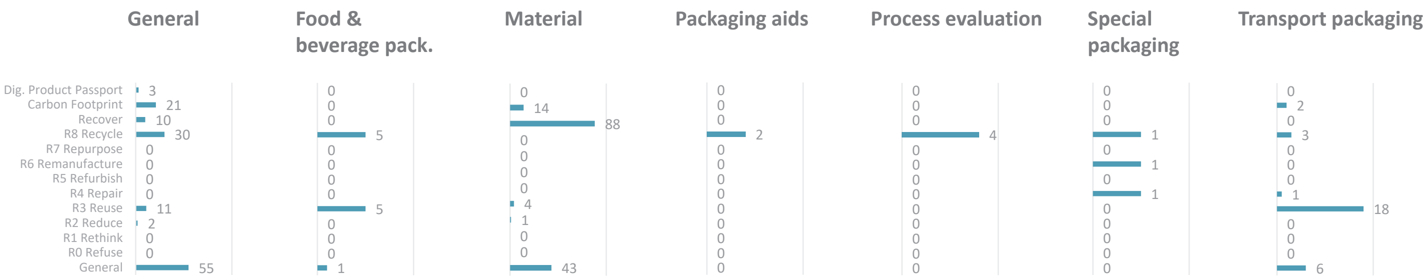


Figure 21: Breakdown according to R-strategies and product groups (Source: DIN)

Breakdown by product groups and R-strategies
In the existing set of standards, no systematic approach to the common strategies of the Circular Economy is apparent; for example, there are hardly any standards on "rethink", "refuse" and "reduce". The "repair" and "reuse" strategies are represented in isolated product groups. Applications for other product groups are to be investigated. There are a large number of recycling standards in the packaging sector. It should also be noted that no consistent product group-specific standardization is discernible in the area of the Circular Economy. Thus: There are many blind spots in the standards landscape and more detailed analysis for circular packaging is needed.

2.4.2 Requirements and challenges

Design 4 recycling/recyclability
Recyclability is of great importance for a functioning Circular Economy in the field of packaging. Here, design 4 recycling comes before the actual packaging development and the assessment of the actual recyclability comes rather at the end of the life cycle. The following diagram shows the packaging cycle in Europe in an abstract form. In this diagram, it becomes apparent how recyclability and design 4 recycling are related to packaging materials and packaging products.

The recyclability and recyclable design of packaging (design 4 recycling) are complex topics that are considered in detail in the chapter on recyclability (see Chapter 3.5). The following graphic and the supplementary explanations that follow it depict the complexity of recyclability based on eight aspects that should be considered individually as well as interdependently for recyclability.

If the various packaging materials are considered, functioning recycling infrastructures based on relevant standards already exist for the common material fractions, such as paper and cardboard. There is currently a great deal of dynamism in the plastics materials sector, which is also leading to the development of various standards.

However, paper composite packaging, which is currently often used as a substitute for plastic packaging, also presents recycling challenges.

In this area, there are various efforts to create uniform rules in order to develop a uniform assessment of the recyclability of paper composite packaging. In addition, this field is characterized by various stakeholders who have different interests in the recyclability of packaging. Thus, conflicts of interest between marketing, product protection, and design 4 recycling can present a challenge for uniform guidelines. When existing tools and labels for assessing recyclability are considered, they take into account different aspects (e.g., national context and their infrastructure and packaging material) and different metrics, adding to complexity or inconsistency.

The formulated standardization needs for recyclability and design 4 recycling should also be supported by legislators if necessary, or should become mandatory by linking them to licence fees. An overarching "design 4 recycling" guideline can also be used as the basis for regional recyclability assessment specifications (such as the minimum recyclability standard for packaging in Germany [159]). Only by linking the licence fees to these requirements can a sustainable effect be achieved, which is implemented in Germany by Section 21 of the Packaging Act [158]. Legislators should exhaust all possibilities to set uniform requirements across Europe to ensure that design 4 recycling and recyclability are implemented appropriately.

Sustainability assessments
The assessment of the sustainability of packaging is a challenging and multifaceted subject area, which, due to its complexity, leads to irritations in industry and among consumers. This starts with different definitions of sustainability and

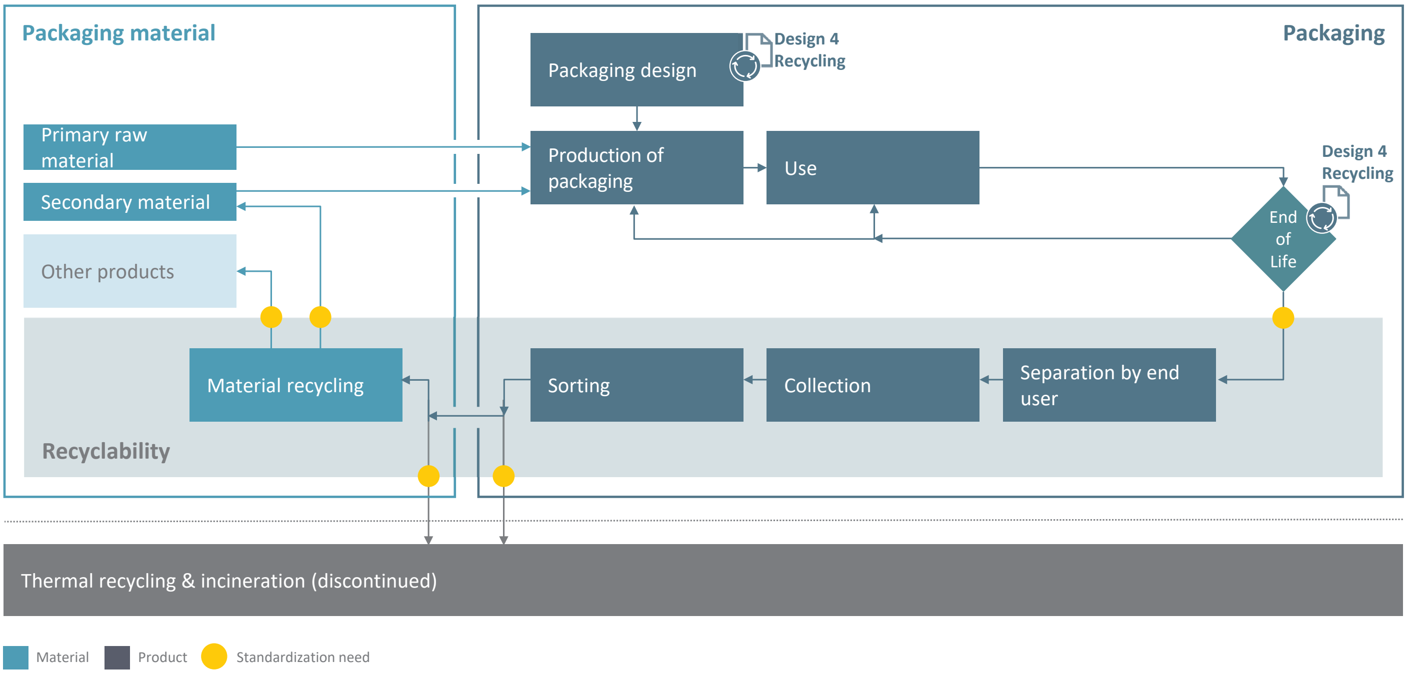


Figure 22: Simplified representation of the recyclability of packaging in Europe (Source: DIN)

Figure 23: Simplified representation of the complexity influencing the assessment of the recyclability of packaging (not complete) (Source: DIN)

continues with numerous existing methods, the framework for sustainability assessment and suitable data sources and their availability at the different stages of the value chain. Many sustainability assessment methods focus on specific raw materials or specific product applications. Packaging made of different materials or with different life cycles, such as single-use or reusable packaging, is evaluated using very different methods and standards. This leads to non-comparable results and thus to statements about the sustainability of a packaging, which, however, are not based on a methodical and comparable approach.

Standards, specifications and laws must be included when addressing the topic of sustainability assessments. These include existing standards for assessments in the environmentally relevant area such as DIN EN ISO 14040, Environmental Management – Life Cycle Assessment – Principles and Framework [80], DIN EN ISO 14044, Environmental Management – Life Cycle Assessment – Requirements and guidelines [81], and in the social area, the rules of the ILO (International Labour Organization) [163]. In addition, current developments such as the development of VDI 4095, Assessment of Plastics in the Circular Economy [164], the activities on the digital product passport or the Initiative on Substantiating Green Claims of the EU [165] should also be taken into consideration.. More specific sets of rules, e.g. for the assessment/certification of bio-based, compostable, recyclable single-use packaging (such as the minimum standard [159]) and packaging containing recyclates, are also applicable to multi-packaging. However, they do not adequately represent the specifics of multiple use. Life cycle assessments according to DIN EN ISO 14040 [80] and DIN EN ISO 14044 [81] leave much room for interpretation. The PEF (Product Environmental Footprint) [166] developed at EU level attempts to limit this scope for interpretation by means of category rules. Whether the PEF improves comparability is debatable. In principle, the first step should be to standardize the criteria for the sustainability assessment of packaging. The focus should be on an equal consideration of all criteria of all three pillars, without a priori weighting of individual effects.

Currently, there is no comprehensive matrix for assessing the sustainability of packaging. The consideration should therefore include interfaces with other topics, assessments and evaluations, e.g. communication throughout the value chain, traceability of decisions, disclosure of assessment criteria, and legal compliance. To date, not all R-strategies have been comprehensively considered in the context of packaging sustainability assessments. “Reuse”, “repair” and “refurbishment” as well as longevity are still mostly underrepresented. There are deficits in the definition of the “functional unit” or the entire packaging system under consideration, which have a particular impact when comparing single-use and systems for reuse. Research is currently underway to appropriately account for the effects of cascade use/downcycling or non-recyclable fractions. Currently, recycling of plastics and recovery with energy use (waste incineration) are already calculated as “credits” in the assessment process. However, the specific material flows into the subsequent fields of application have hardly been recorded so far, due to a lack of data and a large assessment effort. Temporary storage of atmospheric CO_2 in packaging materials made from renewable raw materials is also being considered, but not with uniform methods. Different levels of food losses are recorded only in rudimentary stages for different packaging systems and taken into account accordingly [168]. Other overarching aspects are considered in the topic of sustainability assessment (see Chapter 3.1).

Circular support structures and infrastructures
Circular support structures and infrastructures are all technical measures and facilities that are used in the collection, transport and sorting of packaging, including at the end of the life cycle, and that support reuse in the sense of the Circular Economy.

Currently, packaging in sorting and recycling plants is assigned to recyclable material streams using stationary sensor technology (e.g. near-infrared spectroscopy). Solutions in which the packaging itself already provides an identification option to support allocation are already at project status or close to market maturity. However, these are mostly proprietary solutions that can only be used in a defined “ecosystem” (labelling/sensor technology/product passport database). Sorting plant operators can therefore expect high expenses due to the necessity of operating several systems in parallel. The extent to which the databases for product passports are interoperable in terms of technology and content cannot be assessed at present. In addition, the content description of product passports in the databases does not currently include any provisions for minimum requirements to support the Circular Economy. Experience has shown that without minimum requirements for interoperability, it is to be feared that a large number of products will be established which rely on purely isolated solutions in the hope of a future market-dominating standard.

Without regulatory provisions for labelling, content, and data format, as well as for the deposit of product passports, hardly any incentive can be expected, especially on the part of the distributors, due to the necessary initial investments. Also, the different collection systems used by municipalities without general basic requirements make the development of “ecosystems” of labelling systems, sensor systems, and product passport databases unnecessarily complex.

Conformity with product contact regulations
Conformity is unilaterally declared and confirms the compliance with the applicable regulations of a product in terms of product contact, related to the specified conditions of use. The issuer is responsible for the statements made in the declaration of conformity and is thus obliged to comply with them. Particular attention must be paid to the different requirements for primary, secondary and tertiary packaging. Whereas in the case of food packaging, potential effects of the packaging on the packaged product are considered in particular, in the case of dangerous goods packaging, for example, all interactions between the product and the packaging must be examined.

Due to the large potential impact, conformity for product contact is already largely regulated in laws, ordinances, directives and other regulations at national and European level. Some examples are listed below:

- → Regulations, directives and working papers of the European Commission such as the Framework Regulation (EC) No 1935/2004 [169] and the Plastics Regulation (EU) No 10/2011 [170]
- → German laws and recommendations such as the German Food, Consumer Goods and Feed Code (LFGB) [171] and the German Consumer Goods Ordinance (BFVO)
- → Resolutions of the European Council such as that on plastic colourants AP (89)1 [172] and that on polymerisation aids AP (92)2 [173]

For almost all materials and substances, it can be seen that comprehensive rules exist, although there are significant differences in terms of implementation. As conformity work is extremely complex, especially for small and medium-sized enterprises, due to the large number of regulations, many associations and federations have produced and published guides to facilitate application.

When optimizing packaging with regard to recyclate use, recyclability and conformity, e.g. where there is contact with food, there is a conflict of objectives that can hardly be resolved. The increased use of recyclate in food contact materials usually requires the use of additional layers as functional barriers against the migration of undesirable substances. Often, these barriers then reduce the recyclability of the packaging, resulting in lower-quality recyclate. To date, the effectiveness of barriers against unwanted migration has only been tested in isolated cases (e.g. DIN SPEC 5010 [48]).

The use of recyclates in food contact materials without a barrier to the product is, with a few exceptions, almost impossible. In the case of plastic, the European Food Safety Authority has so far only approved recycling processes for PET without additional requirements [182].

The high pressure from policy-makers and supply chains to increase the use of recyclate, combined with the increasing complexity of compliance work, leads to an increased need for support for small and medium-sized companies in the packaging industry. At the same time, the increasing use of visually high-quality recycled materials without food contact compliance in production is leading to higher requirements in preventing confusion.

Dangerous goods packaging must be evaluated for liquid filling goods with regard to the chemical compatibility of the product with the packaging material. The test methods are sometimes lengthy, and so far the focus has not been on diffusion behaviour, i.e. how far the product penetrates the packaging material.

For dangerous goods packaging, too, the requirement for a mandatory proportion of recyclate in a package while avoiding direct product contact can be solved technically by using multilayer processes. However, the migration/diffusion behaviour from the packaged goods into the packaging material is largely unknown, so that it is currently not possible to assess whether an acceptable level of safety can be guaranteed with simplified methods for the approval of dangerous goods packaging produced using the multilayer process.

Reusable packaging, unpackaged solutions, e-commerce
According to Section 3 (3) of the German Packaging Act, reusable packaging is packaging that must be designed and intended to be reused several times for the same purpose after use and whose actual return and reuse must be promoted by adequate logistics and a suitable incentive system – usually a deposit. Reusable packaging is therefore assigned to the “reuse” category of the European waste hierarchy and has been established for decades for beverages, dairy products and transport packaging (crates, pallets) [158].

Unpackaged solutions enable the purchase of loose goods, which are offered in bulk containers, filling stations or dispenser systems and filled by customers into reusable containers they bring with them or into reusable packaging available on site. The goal is to avoid sales packs. In the waste hierarchy, unpackaged solutions are assigned to the "waste prevention" category or the R-strategy "refuse". Unpackaged solutions are also generally not new and have been practised for many years, for example, for fruit, vegetables or dried fruit.

In recent years, the range of products in the reusable or unpackaged solution sector has grown and completely new product groups (e.g. personal care, cleaning agents) and areas of application, e.g. in online retailing or for food and beverages for out-of-home consumption, including delivery services mandatory from 2023, are being added [158]. Further developments in digitalization and logistics also make this development possible.

Reverse logistics, i.e. the processes required to return used reusable packaging from customers for refilling, are more complex and costly than the collection and disposal of single-use packaging. Industry or pooled solutions exist sporadically (beverages, dairy products) [161] and are currently emerging for other applications (out-of-home consumption, online retail, pre-packaged food and consumer goods). In addition, there are individual solutions from retail chains and manufacturing companies, some with their own digital prerequisites and handling requirements. As a result, retailers and customers are being confronted with a growing variety of systems for reuse and return options. A variety of formats are in use for the different products and applications. However, systems for reuse should be as easy to use as possible in order to achieve customer satisfaction in dealing with the packaging used and thus to gain acceptance. The providers see the need to co-ordinate fundamental aspects, especially for the areas of return, cleaning/reprocessing and allocation/asset tracking, in order to make the use of reusable and unpackaged solutions efficient, economical and, above all, environmentally and climate friendly. For systems for reuse, cooperation creates better market conditions, and improves customer experience and environmental sustainability.

In principle, the challenges surrounding the issue of reusable packaging are based on two circumstances: First, reusable packaging should ideally be used in the pool by a variety of manufacturing companies. Secondly, the handling of return logistics, i.e. identification, pooling, transport and cleaning processes, should be as simple, efficient and regional as possible for participants along the reusable value chain. The aim is to refill reusable packaging as often as possible and to keep it in the regional cycle. The ever-growing variety of reusable solutions and the associated diversity of system properties and processes significantly increase complexity and pose a growing challenge.

The requirements and challenges give rise to a large number of concrete needs for standardization, legislation and research. However, not all standardization needs are necessary for every application. Standardization should create a basis in which a certain degree of individualization is possible. This is important for making reusable packaging attractive to the market.

2.4.3 Standardization needs

Some standardization needs can be assigned to multiple R-strategies. Requirements with possible multiple allocations were assigned to the most relevant R-strategy. Therefore, some R-strategies may not be listed in a separate section.

Rethink

RECYCLABILITY AND DESIGN 4 RECYCLING

Need 4.1: Uniform definition framework based on the German minimum standard ZSVR

There is currently no uniform framework of definitions of terms in the sense of recyclability There are various laws, treaties and standards such as the EU Packaging Directive [175], the Closed Substance Cycle Waste Management Act (Kreislaufwirtschaftsgesetz) [176], the German Packaging Act (VerpackG) [158] or the coalition agreement for the federal government [1], DIN EN ISO 14021 [177] and publications [178], [179] that define key terms. However, these sometimes vary or are not sufficiently detailed. In particular, the scope of recyclability (theoretical, practical, real recyclability) differs to some extent. This leads to confusion and a different understanding of market participants throughout Germany and Europe.

The terms listed below should be defined in a uniform or more detailed manner. The German Minimum Standard ZSVR [159] provides an excellent basis for this. The unified framework of definitions can either contain all definitions or refer to already existing laws/standards. This should not only be uniform throughout Germany, but should also apply to the whole of Europe, as many packaging manufacturers export to different countries and packaging waste is also recycled across national borders.

- → theoretical, technical and real recyclability (for example along the lines of Pomberger (2020) [179] and the German Minimum Standard ZSVR [159])
- → high-quality mechanical recycling [178], supplemented by the possible target applications of the corresponding recyclates ("open" vs. "closed loop" and "design from recycling", see also Needs 5.12 and 5.35 of the key topic "Plastics" in Chapter 2.5)
- → recyclable material and calculation of the available recyclable material content (detailed definition of what counts as a recyclable material for the respective type of packaging) (for fibrous material see Need 6.12. as well as Chapter "Plastics" Need 6.14. of the Minimum standard ZSVR [159])
- → foreign material, goods material, composite material, solid material
- → recyclate and recycling incompatibility (possibly including limit values for filling material residues)
- → object of assessment of total packaging and combination packaging

Need 4.2: Uniform methodologies, metrics, and limit values for assessing recyclability
To date, various methodologies and limit values – varying in the level of detail and requirements – exist for evaluating the recyclability of packaging. This concerns different limit values for the presence of a collection and recovery infrastructure as well as different limit values for certain material-specific packaging properties/components, which lead to different recyclability results. Furthermore, the methodologies differ in the reporting of results in terms of percentages or a scale. Thus, the results of the test methods are not comparable. In addition, the results refer either to a country region or to a specific country, which also leads to a lack of comparability and poor practicability for manufacturing companies using multilingual packaging. Moreover, in some cases not only the finished packaging but also semi-finished goods such as bottles without labels and lids or pure film are evaluated, which does not reflect the reality of the recyclability of the final packaging.

There should be a consistent methodology across Europe, but allowing for specific results for each country. If necessary, a result can also be related to a country cluster if the infrastructures are comparable. Here, it would have to be precisely defined at what point the infrastructures are considered comparable. A basis for a uniformly applicable assessment methodology can be that presented in Annex 4 of the German Minimum Standard ZSVR [159]. Uniform limit values for the "presence" of material-specific collection structures should be defined. It must be determined what is recognized as the state of the art or the more detailed state of the practice that corresponds to reality. This must be included on a country-specific basis for the respective assessment of recyclability in the respective country. The determination of the practice of sorting and recycling could be done according to the methodology defined in the UBA research project [178].

For this purpose, guidelines must be established for conducting tests on recycling processes and sensor-based separability (sorting tests). It must always be clarified whether a laboratory test is sufficiently meaningful or whether a real test in a large-scale plant is necessary. It is also necessary to determine how the result of the sorting test of individual tests must be taken into account in the overall assessment of recyclability. In addition, material-specific, uniform deductions for properties that limit recyclability should be defined and issued as a uniform percentage in a comprehensible manner for manufacturing companies and consumers.

In order not to counteract the development of innovative technologies and packaging, these should – if it can be assumed that they will be considered state of the art in the near future (e.g. 3 years) – be considered along with the current state of the art/state of practice.

Need 4.3: Catalogue/database for standardized packaging
Currently, it is difficult for manufacturing companies to measure their packaging in terms of recyclability without major effort. With regard to the further development of Section 21 of the German Packaging Act [158], a catalogue/database for packaging with standardized design (material, material combinations, size, etc.) is currently under discussion. Since a large number of distributors such as farmers ("strawberry growers") use standardized packaging, a catalogue/database could help to classify such standard packaging as either basically high-quality or basically non-recyclable. A costly certification of recyclability would not be necessary in such cases. This difficulty presents itself at the EU level as well. Such an approach would make it easier for such (micro) distributors to assess their packaging. The catalogue/database must be constantly adapted to real conditions.

Need 4.4: Catalogue for total and combination packaging
Currently, there are only isolated examples of packaging being classified as total or combination packaging within the meaning of the German Minimum standard of the ZSVR [159] (for example, three-component packaging). Thus, individual decisions may be made regarding the classification of the packaging to be assessed as total or combination packaging. This is reflected in different recyclability assessment results.

Analogous to the existing catalogue for packaging subject to system participation and the recommendation of a catalogue/database for (non-)recyclable packaging, a catalogue with a large number of concrete examples of total packaging and combination packaging would help to define the basis for the recyclability assessment. Thus, testing institutes, experts and dual systems would use the same basis for the uniform assessment of the recyclability of packaging. This catalogue should optimally take into account the country-specific differences for Europe in the classification of a packaging as total or combination packaging due to consumer behaviour with regard to the separation of materials during disposal. The catalogue is to updated on a regular basis.

Need 4.5: Uniform recyclability label/digital product passport for packaging
Currently, there are a number of different labels that indicate the recyclability of packaging. These labels are provided either by accredited companies, by dual systems or by retailers and brand manufacturers themselves. This leads to confusion among consumers, as this variety reduces the credibility, comprehensibility and comparability of the labels.

A uniform label is to be developed based on a uniform assessment methodology for labelling the recyclability of packaging. The data on recyclability should be available uniformly throughout Europe and in a defined format so that they can be easily integrated into a "digital product passport".

Need 4.6: Uniform guidelines for design 4 recycling for packaging
Existing guidelines for design 4 recycling are often related to one group of materials. Moreover, these are based on different criteria. These criteria relate to residual emptying, collection, separability, sorting and recycling [316].

A standardized guideline should be drawn up that includes all packaging materials. The criteria to be considered must be clearly defined and it should be made clear to what they refer (collection, separability, sorting, residual emptying or recycling). The requirements for materials can vary. The definition must be comprehensible for all users (distributors, manufacturing companies). In the medium term, the specification of a target application for the respective recyclates should be provided for, see also Need 4.1. as well as Needs 5.12 and 5.35 of the key topic "Plastics" in Chapter 2.5). The development of product category-related circularity criteria is addressed in the key topic "Digitalization, business models and management" in Chapter 2.1, Need 1.1.

Need 4.7: Guidelines valid throughout Europe for the country-specific assessment of the recyclability of packaging
Not only the packaging materials differ from country to country, but particularly the infrastructure in the individual countries. Existing guidelines thus either map the lowest common denominator of a region such as the EU or refer to a single country. Preferably, a guideline should be drawn up that covers the whole of Europe.

Need 4.8: Linking guideline with separation instructions/product labelling
For the end consumer, it is often not obvious how packaging should be separated during disposal. Information on separation is often lacking and is not standardized. In addition, it is often not clear which disposal route is the right one in the respective EU country. In the case of paper composite packaging, it is also often not clear into which collection it should be placed. Often packaging has the appearance of being made of paper, when in fact it is a composite material [158], [159].

Since meeting "design 4 recycling" guidelines will not provide the desired benefits without proper separation behaviour by consumers, this is an essential part of not only design 4 recycling, but of course of recyclability as well. Standardization of generally applicable disposal instructions can remedy this situation, and application could be included as an additional criterion in "design 4 recycling" guidelines to be considered at the packaging creation stage.

The collection infrastructures in the individual European countries vary. Therefore, a standard should be developed that defines uniform separation symbols for packaging throughout Europe as flexibly as possible, but that also takes national requirements into account. Standardization of the design of sorting instructions, e.g. in terms of depth of information, description as well as scope of examples and comprehensibility, can have a positive effect on the sorting quality and quantity of materials disposed of separately for recycling. An analysis of existing municipal, retail and commercial sorting guidance can provide insight into best practice approaches. However, no concrete separation instructions are to be worked out here, because these may differ depending on the infrastructure and collection system. Existing national separation notes are documented in Denmark, for example [160].

SUSTAINABILITY ASSESSMENTS

Need 4.9: Definition of sustainability
A uniform definition of the "sustainability to be considered" for packaging and packaging systems should be drawn up. Among other things, there should also be agreement on the "three-pillar" or "four-pillar" model and a definition of criteria that allow for a holistic assessment of sustainability. DIN ISO 13065, Sustainability Criteria for Bioenergy, provides an initial framework for this [183].

Need 4.10: Establishment of principles for the uniform assessment of the sustainability of packaging
In order to carry out a sustainability assessment of packaging, basic aspects such as key points, criteria and indicators, as well as the use of relevant and transparent data must be described. Standardization should establish a list of mandatory and optional criteria for sustainability assessments of packaging, a definition of specific data required and indicators of the quality of this data.

Need 4.11: Representation and naming of industry references and differences
There are industry-related differences for a holistic sustainability assessment. To take this into account, the relevant criteria (which may also be relevant across industries) should be compiled and recorded in a standard. In the form of a materiality analysis, the specific criteria/indicators can then be added to supplement this information. Here, too, only under the premise that reliable and comprehensible data sources are available for an assessment. The basic principle is that criteria should only be excluded on the basis of a transparent impact analysis.

Need 4.12: Clear definition of the term life phase including all raw material sources, production steps as well as components of the considered packaging system and possible differences in product life/product losses
The life cycle of the entire packaging system required for the packaging function ("functional unit") and the impact categories to be considered should be mapped correctly and comparably. For this purpose, for example, a kind of checklist or criteria catalogue could be developed for an iterative assessment of which life phases should be taken into account. The extent to which the requirements for data quality, documentation and transparent reporting can be further standardized should be examined. Information must be provided stating that life cycle analyses (LCA) cannot provide unambiguous results, but that here, too, it is a matter of probabilities that can be represented, for example, by Monte Carlo simulations. The following exemplary aspects are particularly relevant for the packaging sector:

Use of renewable raw materials
→ Consistent consideration of CO_2 uptake from the atmosphere during plant growth, taking into account the different time horizons (annually regenerating plants, short rotation coppice, long growing forests) and the different sequestration capacities for CO_2 in afforested areas compared to existing forests
→ Allocation rules for the use of residual materials, e.g. from food production
→ Collection of regionally specific data for cultivation

Packaging-specific product losses
→ Consideration of environmental burdens caused by production of the packaged product in combination with different loss rates for differently packaged products, collection of product- and packaging-specific data on product losses

Logistics structures for single-use systems vs. systems for reuse
→ Use of realistic circulation figures, especially for pool systems that are still being set up
→ Consideration of the differences between pool and individual systems for reuse
→ Assignment of realistic transport distances, use of real data vs. considerations of scenarios

Need 4.13: Definition of communication rules
It must be clear to users and end consumers what sustainability rating the packaging has. Here, the rules of the EU's Initiative on Substantiating Green Claims [165] are a first step towards harmonizing communication. Thereafter, it must be examined whether there is a need for further standardization.

Reduce (by design)

REUSABLE PACKAGING, UNPACKAGED SOLUTIONS, E-COMMERCE

Need 4.14: Hygiene and quality standards for unpackaged and reusable solutions
Quality control plays a role not only in pre-packaged products, but equally in unpackaged solutions, where loose and open food and consumer goods are handled. When transferring bulk containers to filling stations, it is challenging for regular food retailers to maintain hygiene standards Transparency and traceability of refilled goods, and thus quality control, occasionally pose a challenge, for example when checking the shelf life of the goods or in the event of product recalls. For unpackaged solutions, it should therefore be investigated to what extent movable gravity containers could be standardized so that they are suitable for handling in regular retail and unpackaging stores, as well as for manufacturing companies or bottlers. There is no need for standardization for gravity containers that are refilled exclusively in the store. In general, it must be differentiated which goods may be filled into the containers (food or non-food articles). Material-specific requirements for the hygienic reprocessing and reuse of reusable and unpackaged solutions must also be developed and defined, e.g., the requirements for cleaning agents, contact time, drying, etc. In principle, material-specific test standards must be developed to test the microbial load of cleaned reusable packaging.

Reuse

REUSABLE PACKAGING, UNPACKAGED SOLUTIONS, E-COMMERCE

Need 4.15: Definition of terminology relating to systems for reuse
In addition to the very general definition of the term "systems for reuse" in ISO 18603 [180], an expanded definition/standard is needed. Reusable is not the same as deposit (there are also systems for reuse that work with other incentives) and deposit is not the same as reusable (e.g., deposits are also charged on disposable beverage containers). It should be defined and thus transparently comprehensible when reusable is really reusable in order to avoid greenwashing. There is therefore a need for a standard on how to measure the "environmental performance" of systems for reuse. The term "unpackaged" also lacks a clear and overarching definition. Currently, the term is used in many different contexts and with different meanings, diluting the term. Initial approaches to a definition refer to the saving of primary packaging.

Need 4.16: Standardized requirements for properties for the compatibility of reusable packaging during take-back, return and reprocessing
Unlike disposable packaging, reusable packaging must be durable and able to withstand the conditions of return, return transport and cleaning. This also means that take-back systems such as reverse vending machines must be compatible with the various formats and that the storage of empty packaging and a return transport should be designed as efficiently as possible (e.g. stackable and nestable, foldable or collapsible, palletizable, etc.). Reusable packaging is often designed for specific products/product categories and their specific requirements. The growing market allows for a variety of (new) formats. This openness of market development is considered essential by those involved in order to do justice to the applications, some of which are still new. In principle, no general need for standardization was identified for materials and formats of primary packaging. Rather, it is a matter of requirements for properties that must be identified in order to make formats compatible, on the one hand, for common return (nestability, stackability, module scheme) and, on the other hand, for (automatic) return and cleaning (temperature, duration, chemicals). These packaging design requirements should be specified in industry standards, for example Possible test methods for hygiene requirements should also be defined on a material-specific basis.

Need 4.17: Standardization for secondary and transport packaging in the reusable and unpackaged sector
Secondary and transport packaging should be further standardized to make the transport and return of reusable packaging (including transport containers for unpackaged solutions) more efficient. These should be compatible with current logistics standards (e.g. the Euro pallet [181]), be of high quality and fully recyclable, not require branding and be universally used for different products/primary packaging in the future. Alternatively, it should be clearly specified which secondary packaging may be used for which primary packaging. The formats of primary packaging can then be designed to be compatible within the supply chain and with secondary/transport packaging to enable efficient processes in handling and logistics (keyword: modular size grading) and also to meet specifications for packaging and requirements of unpackaged stores [162]. The basic size of reusable packaging (e.g. in online retail, for pre-packaged products) should be

palletizable and, if possible, stackable to a complete layer on a standard Euro pallet [181] to simplify shipping and storage. What is needed is an assortment- and product-specific view and individual solution finding.

Need 4.18: Standardization for the use of labels, tapes, adhesive tape and closures
Labels are an important component of reusable packaging. They contain information on the product, its contents and use, markings or – in the case of shipping packages – also personal data for the delivery of the goods. During transport, labels have to withstand a wide variety of environmental influences, such as changing weather conditions. At the same time, they must be designed in such a way that they can be removed directly and in one piece by the customer in the "online mail order" use case or are suitable for the machine cleaning process. In addition, in online mail order it is important that not only labels do not adhere too strongly if possible and are removable "in one piece", but also any additionally used tapes/adhesive tapes. Closure systems used (e.g. zippers and Velcro fasteners) or attached notices for reusable packaging should, on the contrary, be designed to withstand a cleaning process. If necessary, it should be checked whether an address pocket can be attached as standard in order to avoid labelling altogether. It should be noted that automatic scanning can then lead to high error rates due to reflections. Specifications for reading the labels could also be beneficial. The challenge generally lies in the different surface textures of the materials used (glass, plastic, metal) with a variety of adhesives with different solubility, adhesive strength, environmental compatibility, etc. The challenge is to find the "sweet spot" where the labels adhere to the packaging regardless of environmental and handling influences (temperature, moisture, friction from conveyor belts, etc.), but can be removed well and as easily as possible by hand or machine after use. Provisions should therefore be developed and tested on a material-specific basis together with manufacturing companies and suppliers of cleaning equipment for different surface materials and applications.

Uniform material-specific provisions regarding adhesives and labels in other areas of application should be defined in industry standards if necessary, for example to simplify the cleaning of reusable containers from different systems for reuse in the same cleaning system.

Need 4.19: Standardization of automated take-back for reusable packaging
Reusable packaging is often taken back manually, via return boxes or via return vending machines. In the future, it can be assumed that the collection can be bundled and increasingly carried out via vending machines. Vending machines must be able to take back a variety of packaging shapes and sizes in the sense of an overarching infrastructure. To this end, it is important to develop standards for the return vending machines (e.g., minimum diameter of the return opening, approved shapes) to which the developers of reusable packaging can orient themselves. For an overarching infrastructure, standardized coding is also required on packaging that can be read, recognized and clearly assigned by vending machines. In this context, it is also necessary to work out where the packaging marking must be applied in order to enable automated processes in the future. The required image processing must also be further improved. It may also be possible to use a "digital twin" to improve sorting and the handling of empties in general.

Recycle

CIRCULAR SUPPORT STRUCTURES AND INFRASTRUCTURES

Need 4.20: Interoperability between package marking, capture, sorting and databases
To support the Circular Economy while ensuring the greatest possible technology neutrality and openness to innovation, technical and content-related interoperability should be ensured through standardization. This concerns the interfaces between the markings of packaging, the sensor technology for capturing and sorting, and the databases with the stored product passports. Here, both the technical principles of minimum interoperability and the minimum content and structural requirements of the product passports must be considered.

Need 4.21: Readability of the digital product passport in the automated sorting of recyclables
The digital product passport should be readable during the sorting of waste (products and packaging) so that the contents can be used for sorting. For this purpose, the marking of the product or packaging should be readable even after changes in geometry or other eventualities in the product life cycle. Standardization of the marking (size, location of attachment, fixation, readout criteria) may be useful here for compatibility with high-speed readers. Since materials are

used several times in the Circular Economy, suitability of the labelling for several cycles should be strived for. The selection of the data carrier must be industry- or even product-specific.

Need 4.22: Marking of packaging materials and packaging applications
The basis for the success of the unambiguous identification and allocation of packaging to defined material flows can only be the gradual introduction of an obligation to label by means of a freely selectable (interoperable) labelling technology with simultaneous deposit of the minimum data in an (interoperable) product passport database. In the long term, the standardization of collection and sorting systems in Germany and Europe should also be sought in order to strengthen the national and European Circular Economy.

Need 4.23: Uniform design of specifications for the description of sorted recyclables
After the collection of e.g. packaging waste from end users, it is separated into fractions in sorting plants, if necessary. This produces several different sorting fractions, depending on the technology and effort involved, which are then fed into a recycling process. Sorting of waste may vary depending on the sorting facility. If a recycler is able to obtain material from different sorting facilities, its processing capacity can be increased.

Standardization of recyclable material grades for post-consumer (packaging) waste at the European level enables EU-wide trade in recycling raw materials and promotes the emergence of specialized, efficient recycling facilities across countries. The following aspects are to be standardized: For frequently occurring recyclable material qualities in the EU, specific values should be defined and identified by name as well as number.

CONFORMITY WITH PRODUCT CONTACT REGULATIONS

Need 4.24: Guide for SMEs regarding compliance work
A general guide for SMEs and start-ups should be examined in order to safeguard the industry, which is strongly characterized by SMEs on a national and European level, while the complexity of compliance work is foreseeably continuing to increase. This could provide an initial introduction to compliance work as well as an overview of existing regulations. For material-specific or industry-specific topics, reference should then be made to the existing association documents.

Need 4.25: Labelling of material from or with recyclates
In order to ensure that there is no confusion in processing between compliant and non-compliant material, particularly in the food contact area in the case of material that has already been partially used, the introduction of a continuous marking/labelling system to identify products made from recyclates should be examined.

Need 4.26: Extension of DIN SPEC 91446 to include data relevant to conformity
DIN SPEC 91446:2021-12, Classification of recycled plastics by Data Quality Levels for use and (digital) trading [49] should be investigated to see if it needs to be extended to include conformity-relevant data (e.g. for food contact materials, dangerous goods).

If, for example, dangerous goods packaging is produced using the CoEx/multi-layer process, in which the inner layer in contact with the product is made of virgin material, it would have to be examined whether this could be facilitated with regard to the use of recyclates, e.g. with regard to multiple recycling. Such CoEx packaging is currently the norm in the dangerous goods sector when recyclate is used in the production of packaging.

Need 4.27: Functional barriers
As evidence of the effectiveness of barriers in the use of recyclates, the use of the approaches from DIN SPEC 5010 [48] should also be tested in other areas.

Need 4.28: Compatibility assessment of dangerous goods and packaging
For dangerous goods packaging for liquid contents, it should be examined whether a simplified procedure can be established for evaluating the chemical compatibility of the packaged product with the packaging material, which also takes into account the influence of the recyclates.

REUSABLE PACKAGING, UNPACKAGED SOLUTIONS, E-COMMERCE

Need 4.29: Labelling and identification, digital interfaces
In order to ensure a functioning system for reusable packaging, including sorting and allocation to manufacturing companies, information on the manufacturing company and owner should be included in a unique (serialized) label that has yet to be defined. In principle, manufacturer-dependent identification features can also be stored, as well as further information on the number of circulations and circulation

times via corresponding coding/identification systems. Standardization approaches are needed for this. The recyclability due to applied labelling methods (in-mould label, near-field communication, RFID, etc.) has to be considered.

For return and return logistics, a digital infrastructure is to be examined that connects the interfaces of the various systems and, if necessary, apps and also includes a system for deposit clearing.

2.5 Plastics

2.5.1 Status quo

Plastics are a widely used material that have become indispensable in today's society. Plastics are easy to process, flexible to use, durable and recyclable in many respects. Within the framework of the Standardization Roadmap Circular Economy, plastics play a key role, which was evident at many points in the concrete work on the Roadmap. Here, the interfaces to packaging, textiles and electrotechnology & ICT should be mentioned in particular.

Responsible use of plastics is about the use of primary plastics, product life, reuse, recycling and the use of secondary raw materials. In the following, the approaches of the Circular Economy are described and the need for standardization is determined under consideration of the nine R-strategies Plastics are described as a material in general in the following chapter, which includes all types of plastics.

Evaluation of standards research
The Working Group Plastics evaluated the standards research of DIN, DKE and VDI on the basis of the nine R-strategies. In addition, the topics carbon footprint and digital product passport were identified. A total of 393 out of 2101 standards were classified as relevant.

The majority of the standards already exist in the area of recycling (classic area of the Circular Economy), or are generally applicable results. Some R-strategies have little or no presence in the collection of standards.

After evaluating the search results and assigning them to the challenges (multiple assignments were possible here), the Pareto analysis in Figure 25, shows that there are four areas for potentially new standards, as a below-average number of standards were found there:
→ Sustainability assessment
→ Input streams/traceability/digital product passport
→ Recyclability
→ Chemical recycling

There are two areas in which there are standards which potentially need revising:
→ Quality
→ Mechanical recycling

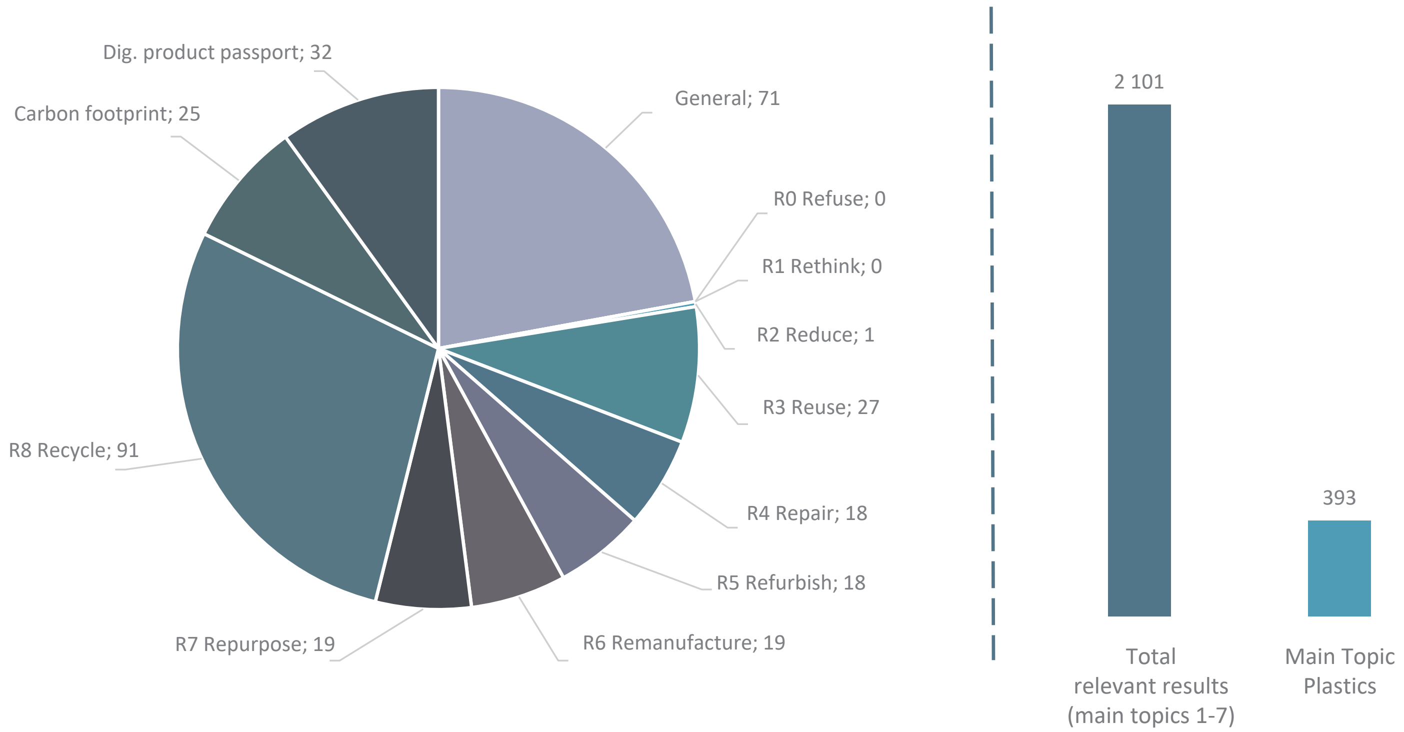


Figure 24: Categorization by R-strategies (Source: DIN)

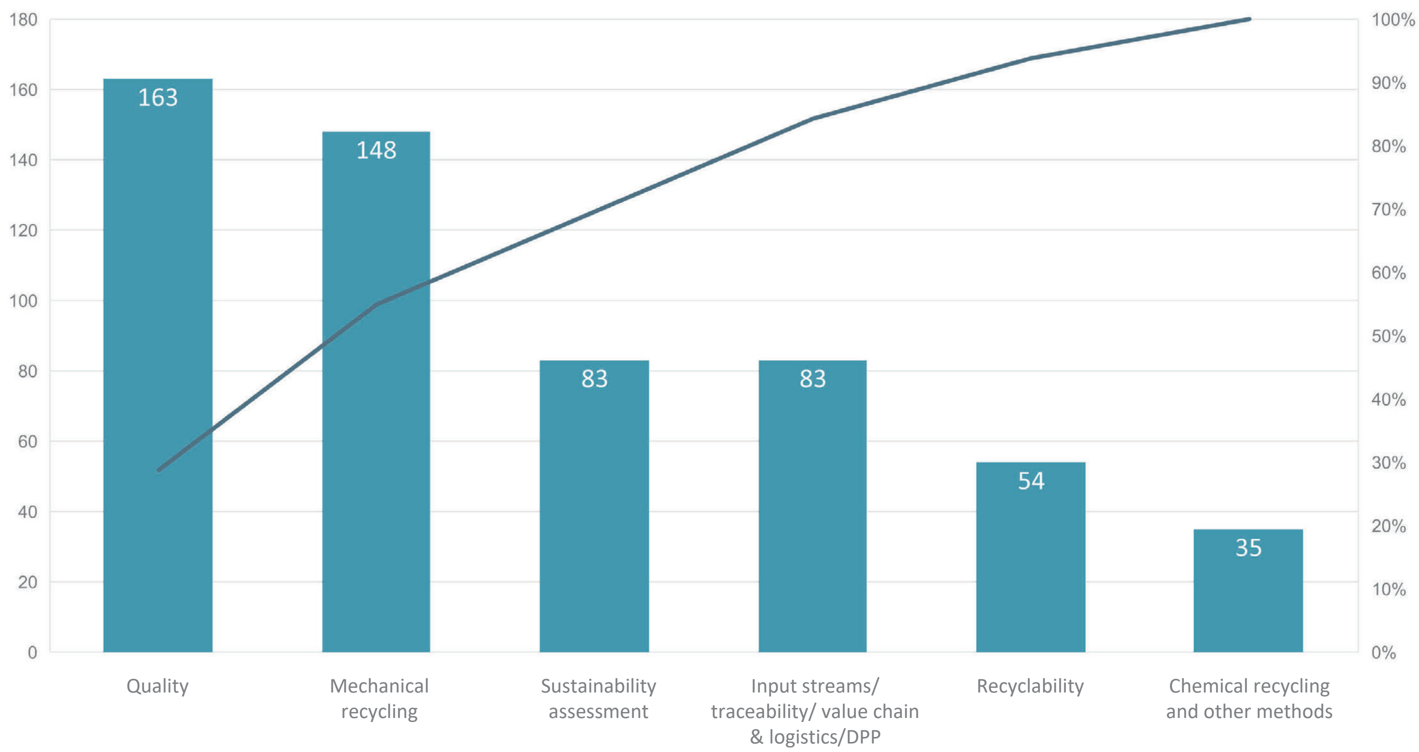


Figure 25: Breakdown of existing standards by challenges (Source: DIN)

2.5.2 Requirements and challenges

The requirements and challenges in the area of the key topic "plastics" were developed in the six challenge areas of recyclability, sustainability assessment, input streams/traceability/digital product passport, quality, chemical recycling and other recycling methods, and mechanical recycling, and are described below. The recommendations for action identified are then listed in a structured manner according to the R-strategies.

Recyclability

A recyclate, or recycled material, as defined by the EU Commission, is a plastic material obtained from the recycling of plastic waste that is no longer waste and can be used in the manufacture of new articles or products and can be assembled according to a new formulation using additives [184].

When assessing recyclability in general, the composition (polymers, fillers, additives, etc.) of the plastic products on the one hand and, on the other hand, the possible recycling processes – mechanical recycling, solvent-based reprocessing and physical recycling, depolymerization and chemolysis, and thermo-chemical and feedstock recycling (pyrolysis and gasification) – must be considered together. It is also important to distinguish between the recyclability of plastic materials as such, e.g., the homogeneous granules of known composition used to make a laptop housing, and the recyclability of plastic waste streams, e.g., the ground plastic waste generated by an electrical appliance recycling operation. The material is determined by its composition and the chemical and physical properties of the individual starting materials. The quality of the waste stream is influenced by the use of the materials (e.g. ageing due to heat and/or UV exposure, contact with fillers and mechanical stresses). Furthermore, the composition of different materials complicates the recyclability. To increase real-world recyclability, technical capabilities and quality requirements must be further defined, expanded, and aligned with the nine R-strategies.

Digitalized and transparent value chains

With the increase of the recycled content in various products (incl. packaging), the responsibility of those involved in recycling, incl. the recycling industry as local and environmentally friendly raw material suppliers, is increasing. Traceability of information on recycled plastics is an important task to meet compliance and quality requirements at the end product level. Especially in the case of closed-loop products, the question is where the supply chain begins and at which point which relevant information should be documented. Standardization in the areas of data processing, documentation, conformity assessment, and measurement methods can help make the leap from individual isolated solutions to a harmonized European and global market.

The design for plastic products has a major impact on their suitability for recyclability and can have a positive impact in the “refuse”, “rethink” and “reduce” dimensions. Supplemental labelling requirements for plastic products must meaningfully support “reuse,” “repair,” “remanufacture,” “refurbish,” and “repurpose,” as well as make the recycling of plastics more effective, of a higher quality, and more reliable. Furthermore, when different plastics are used in items or when plastics are combined with other materials, it is often too difficult and costly to separate them for recycling.

Plastics are complex in terms of their recycling, as there are several levels of sorting. Each piece of plastic waste must be separated on a polymer-specific basis, since a mixture of plastics can only be processed into applications with very low added value, such as railroad ties or park benches. Due to their widespread use, frequently used packaging materials and common variants of standard plastics are already collected in high proportions sorted by type, or can also be sorted and recycled well from mixtures. In addition to the differentiation into the various polymers – i.e., e.g., polyethylene terephthalate (PET), polypropylene (PP), polyethylene (PE), polyvinyl chloride (PVC), polyamides (PA), etc. – it is additionally relevant for their recycling that they are often designed for an intended processing, such as injection moulding or extrusion, or for an even more specific application. In addition, there are additives, fillers, etc., which are also incorporated into the polymer structure according to the properties of the product, e.g. flame retardant additives for waste electrical and electronic equipment (WEEE). In order to prepare plastic mixtures for reuse, the first step would be to sort them into those plastics of a fraction that are compatible for the intended application. Thus, a food application does not use a raw material that may pose risks to the health of consumers. The more information is available about the material in the recycling, the more targeted it can be sorted or processed.

While successful collection and sorting infrastructures have already been established for post-consumer packaging materials, other polymers, such as engineering plastics, are less likely to undergo recycling-oriented sorting today due to lower volumes or higher specialization. Voluntary collection and separation systems of the Circular Economy ensure the greatest sustainability benefits in this regard.

Mechanical recycling

Mechanical recycling is the bedrock of the plastics Circular Economy. Ever since parts have been produced with plastics, there has been waste in the form of sprues, edge trim and missing parts. These have always been processed and returned to the cycle, certainly initially for cost reasons alone. Mechanical recycling includes, among others, the process steps sorting, washing, comminution, re-sorting (e.g. density separation or spectroscopic separation), grinding or compounding. These can be cascaded and run multiple times depending on the type and complexity of the waste. It is the most important and effective recycling method and represents a preparatory, intermediate or final step for many other recycling processes: No chemical recycling would work efficiently without first sorting, washing or grinding. In the end, the separated recyclables must be further processed into compounds with defined properties.

Over the last few years, however, the nature of waste has changed significantly. Where previously almost only industrial, clean and homogeneous polymers (post-industrial) were processed, polymeric waste from households, the dismantling of buildings and from end-of-life vehicles (post-consumer) poses new challenges for mechanical recycling. Nowadays, manual sorting and grinding are no longer sufficient. For example, the waste is detected and sorted; it is centrifuged, cryogenically ground, paint stripped, and finally compounded by adding special additives to give the raw material another life in a new component. To be able to tap further sources of secondary raw materials, it is important that the innovative strength and development of mechanical recycling be advanced. On the one hand, the waste has become of lower quality, and on the other hand, the quality requirements for the recycled plastic are becoming increasingly stringent. In addition, additives or dyes that were common a few years ago are now banned and must be reliably detected in the polymer and diverted from the recycling stream.

Another challenge is that applications from some industries were developed years ago without the thought of design 4 recycling and are only now coming back into the recycling stream. These material streams, which today are largely thermally recycled, offer a high potential for high-quality plastics if they can be separated and processed economically. In parallel, however, the compounder and the designer can already do a lot to move from a linear to a circular plastics economy: Mechanical recycling is facilitated with the help of special additives, such as markers or IR-detectable dyes. Of course, design 4 recycling also has a great influence: Multilayer applications or 2-component processes with polymers that can only be partly recycled or not recycled together should be avoided. Joints of plastic components should be easier to detach, and the use of different types of polymers should be kept to a minimum.

Chemical recycling and other recycling methods
Currently, mechanical recycling processes have the largest market share in plastics recycling, but new, complementary recycling processes are already in research and development or on the threshold of industrial plastics recycling and market implementation. There is a limitation to mechanical recycling due to the return logistics of plastic waste (collection and separation), but also to the highly functionalized and complex plastic products of our everyday life. Plastics, plastic blends and fibre-reinforced plastics that are highly filled, coloured and equipped with additives for the protection and safety of the product application are only suitable for mechanical recycling to a limited extent. To increase the total amount of recyclable plastic products and components in a Circular Economy, new, innovative technologies must be used to complement traditional mechanical recycling.

PHYSICAL RECYCLING

The term physical recycling covers the solvent-based physical recycling methods. By selectively dissolving out the target polymer using a suitable solvent, it is possible to separate the target polymer from the other polymers and to separate additives, colourants, fillers and interfering substances from the polymer solution (e.g. in the separation of multilayer film waste). The method thus enables the generation of high-quality single-variety recyclates from waste streams. An important distinguishing feature from chemical recycling methods, which can also be carried out using solvents, is that the polymer structure is retained. In this context, the efficiency of the recycling process in physical recycling also strongly depends on the input material (e.g. concentration of target polymer in the input material) [201].

CHEMICAL RECYCLING

Chemical recycling of plastics involves chemical processes in which polymers, polymer blends and composite systems can be broken down into monomers or other chemical building blocks under pressure and temperature, often using chemical and enzymatic catalysts. Due to the conversion and downstream methods (purification) used, chemical recycling processes are energy intensive. Nevertheless, chemical recycling can be beneficial from an environmental point of view in terms of resource efficiency and CO_2 emission savings (including the use of renewable energies in recycling processes).

Recycling methods such as depolymerization break down the polymers back into their basic building blocks (monomers), which can then be used again in a separate step to produce new plastics. Pyrolysis is a deliberately induced thermal degradation of the polymer chains, which, depending on the process control (temperature, pressure, catalyst and reaction time), leads to pyrolysis condensates (pyrolysis oil) with different molecular structures and chain lengths. Depending on their composition, these can be processed again in a petrochemical process to produce plastics starting chemicals (cracking, hydrogenation) in the same way as crude oil processing. Compared to pyrolysis, which is run in an oxygen-free atmosphere, gasification (also known as partial oxidation of plastics) comes at the end of the chemical recycling process. Here, under defined process conditions, the plastic is converted into a synthesis gas (mainly CO, H_2, CO_2), from which any basic chemical substances can be reconstituted (see Figure 27).

STATUS QUO OF STANDARDIZATION OF NEW RECYCLING TECHNOLOGIES

The need for a strategy to bring new recycling technologies for plastic waste into the existing standards system becomes clear when looking at the established standards landscape in the field of plastics recycling. The standards system is currently focused on mechanical recycling and represents a state of technology that no longer meets the demands and needs of society and the market. A conceptual adaptation of the standards is necessary to take account of current developments and future technologies. With regard to the Circular Economy, openness to technology plays an important role for all standardization stakeholders. The existing technologies complement each other.

Chemical and physical recycling are hardly taken into account at all in the existing standards. There are very few standards that deal with definitions for chemical recycling, for example, and describe it technologically. In addition, these specifications are outdated and thus require adaptation to the current state of the art. Fundamental work is needed here in the form of describing the technologies and their characteristics, as well as methodologies and definitions. Initial projects on chemical and physical recycling are currently underway at international level. When revising existing standards in the field of plastics recycling, an adaptation or extension of existing concepts, e.g. the definition of recycled or secondary materials, for new technologies, such as chemical or physical recycling, is of central importance. New concepts such as chain-of-custody must also be incorporated into the development of standards in the plastics recycling sector [201].

Quality

Quality creates trust – this phrase may be somewhat worn out because it is much used in the marketing of many companies, but it nevertheless sums up the value of the topic of quality exactly. For many years and decades, recyclates were often associated with inferior grades and downcycling, severely limiting their use in some industries. In order to achieve the transition to the Circular Economy here, confidence in recyclates must be created, with a reliable quality of materials being a central building block that affects all areas of application.

Only comparable and reliable material qualities can ensure a lasting increase in recyclate use rates, especially in high-value applications in all industries. The importance of the topic of quality is also seen in the large number of national and international standardization projects, e.g. the current, extensive standardization request from the EU Commission, under which new standards in the area of quality will be created over the next three years [184]. In addition, there are also many other normative and private sector efforts to define qualities via joint projects or individual delivery specifications for recyclates. The German government's coalition agreement also mentions the development of quality standards for recyclates [1]. Overall, all of these initiatives agree that quality must be ensured as a central building block, even if there are different approaches to the "how" in the current standards landscape. There are specifications such as DIN SPEC 91446 [49], which apply as a framework standard across all applications and materials, standards such as the EN 1534X series [187], [189], [190], which contain specifications for individual materials, as well as material- and application-specific standards in well-functioning circuits, e.g. for PET bottles (ISO 12418-1 [199]) or PVC doors and windows (DIN EN 17410 [204]).

If we look at DIN's standards research on the topic of Circular Economy, we can already find almost 250 standards and specifications today that are related to the topic of quality (see Chapter 2.5.1). At first glance, this sounds like a lot, but the actual analysis also shows a large number of gaps, since many materials, applications and process steps in recycling have hardly been standardized to date. The large number of standards already in existence therefore shows above all how extensive and complex the subject of quality is around the entire recycling process and the various process steps of the different recycling methods (mechanical, chemical, physical, bioenzymatic). If one deals in detail with the standardization of qualities of recyclates, one encounters the high complexity in several dimensions of the subject. On the one hand, the recycling process from waste collection to sorting processes to refurbishing and processing of new materials must be considered. Furthermore, different types of recycling have different quality requirements for input and output streams. In addition, there is a great variety of materials and applications, which often have specific quality requirements.

With regard to qualities, standardized data sheets and grades of recyclates, some standards already offer initial solutions, but in some cases there are different approaches and at the same time normative regulations are still lacking in some places. There is still a lack of uniform standards for determination and documentation, especially on the subject of harmful substances or additives, both from the first life cycle and through addition during the recompounding process. The topics of sampling and homogenization are already considered for some process steps, although these standards are often not applied in practice or do not include all steps of the recycling process. There is a need for revision here with a view to practical use. In this context, the definition of batches and variations in characteristic values should also be considered in greater depth. The gap analysis also shows a lack of testing standards which provide clarity for chemical analysis. In particular, tests on odour, harmful substances and outgassing should be mentioned here. It would also be helpful to have a guideline for the evaluation of defects and defect groups for recyclates and products made from recyclates, similar to VDI 3822 on failure analysis [205].

Standards could help simplify the use of recyclates by providing guidelines on their design, construction, and processing. Such standards would also create certainty in the area of occupational safety during the processing of recyclates and allow for better assessment. In general, new standardization projects should consider the extent to which a distinction between virgin and recycled material is actually necessary. In addition, future projects should evaluate the extent to which standardization is necessary or whether a supplier specification is more target-oriented for an issue.

Sustainability assessment

In order to achieve minimum social standards and sustainable living and economic goals worldwide, a global sustainability transformation toward the 17 UN Sustainable Development Goals (SDGs) [203] is necessary. This can be achieved, among other things, by treating materials in the spirit of the Circular Economy. This is particularly important for plastics, as huge quantities of barely degradable plastic waste have so far been released into the environment, where they cause permanent damage (including as microplastics). For this reason, the expansion of the R-strategies for plastics must be driven forward rapidly. In turn, to act in the spirit of the global sustainability transformation, R-measures must meet sustainability criteria to the highest degree. For sustainable processes (i.e. also for the mechanical and chemical recycling of plastics, for example), the classification into three dimensions – social, economic and ecological – has become established. The sustainability assessment of recycling processes (and of the other R-measures) as well as of products (here mainly recyclates, see the section on sustainability assessment in Chapter 2.4) and the relevant organizations (e.g. recycling companies) must take place in these three dimensions. This requires conformity systems that contain qualitatively and quantitatively clear and comprehensible decision-making bases and ultimately lead to the fulfilment of the 17 SDGs [203]. Some conformity assessments in the context of sustainability and the Circular Economy already exist, which can serve as a basis beyond Germany as well.

However, for the recycling of plastics, there is a need to specifically certify the sustainability assessment based on a uniform standard.

Assessment systems for environmental sustainability are now established methods, but there are challenges particularly in relation to the recycling of plastics. For example, the choice of the allocation method of end-of-life plastics is not specified in the relevant standard. Another challenge is the issue of greenwashing. This covers all actions with which companies suggest an environmentally friendly image to the outside world, although they do not work or produce sustainably. Unlike the term “organic” in the food industry, statements such as “sustainable,” “climate-neutral” or “environmentally friendly” are not defined by law and there are no protected labels. Therefore, criteria for mandatory labelling of products (e.g., recycled plastics and the components made from them) are necessary. In addition to ecological sustainability, economic and social sustainability are just as important dimensions of sustainable development. Nevertheless, there are no standards for these yet, only some common methods. For example, life cycle costing (LCC) or material flow cost analysis (MFCA) can be used to assess economic sustainability.

The assessment of social sustainability presents a particular challenge. In the area of the Circular Economy, in addition to the evaluation of processes with regard to working conditions and safety, aspects such as equality and inclusion within the process implementation of products or within the organizations are also important. Previous methods build on assessment based on the 17 UN Sustainable Development Goals (with their sub-goals and associated indicators) or are based on social life cycle assessment (sLCA).

2.5.3 Standardization needs

The nine R-strategies cannot be directly transferred to plastics as a material. The identified standardization needs refer to one or more R-strategies and are listed below by R-strategy. Needs with multiple assignments were assigned to the most relevant R-strategy and R-strategies with no need assigned to them were not listed.

The scheme shown below has been developed in order to get an overview of the different material streams describing the R-strategies of plastics and how they depend on each other along the value chain, as well as a cycle leading “value preservation”. This scheme describes the value creation starting from the raw material source through the process steps of plastics production to the product, as well as the return of the product and the plastic it contains back into the process in various recycling processes while preserving its value. Here, the nine R-strategies have been broken down to the material level of the plastic, in particular the polymers it contains, in terms of chemistry, quality and recycling methods. The needs for standardization have been highlighted in this diagram as the orange dots, which are intended to describe the criteria according to which the direction of the next process step to be applied can be aligned in the material flow diagram.

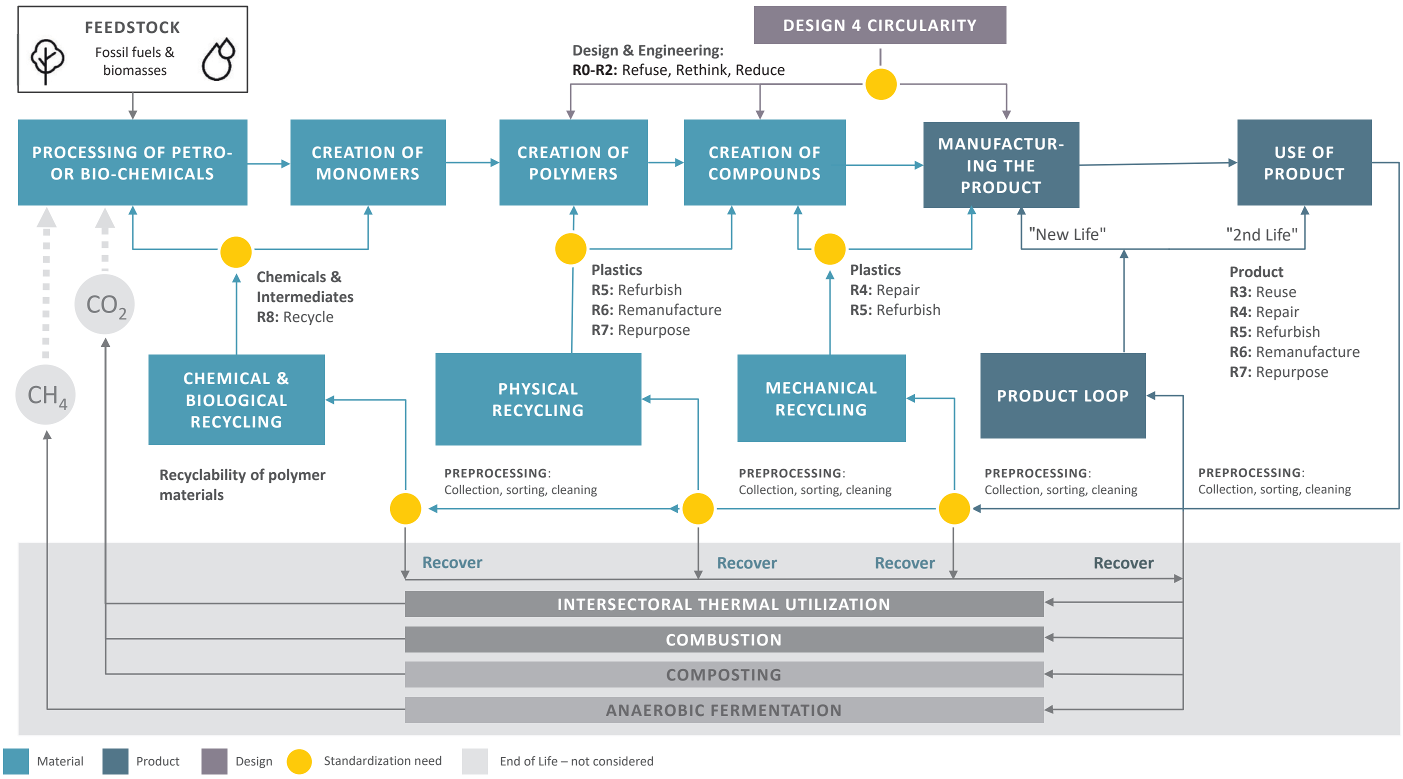


Figure 26: R-strategies for plastics and decision-making points regarding recyclability (Source: DIN)

Rethink

DESIGN 4 RECYCLING

How can the recyclability of a product, a component or a polymer be increased and which standards and specifications can support this?

In general, a distinction must be made between the recyclability of a product made of plastics, the plastic components, which in many cases consist of different polymers as well as additives, fillers and colourants, and the polymers themselves. The recyclability of a polymer depends on the technological maturity of the recycling methods as well as efficiency in terms of yield, selectivity of the target molecules and process control. In addition to the design and structure of the products, that of the components of the polymer materials is also crucial for increasing recyclability.

The goal should be to

1. "design" polymers (e.g. additives, dyes) in such a way that they can be used to produce high-quality recyclates at the end of their life cycle,
2. design product components and products to support collection and sorting and recovery technologies,
3. present the holistic ecological, economic, technical and social assessment of the recyclability in the different recovery routes, and
4. examine existing standards to determine whether a general exclusion of the use of recyclates, which may have been stipulated in the past, is still proportionate today due to the current state of the art and the material qualities.

In many product areas and application sectors, there is a lack of standards and specifications describing "design 4 recycling" principles for increasing the recyclability of products, components and polymers, which can be provided to the product developer at the beginning of a product life cycle. Today, there is also a lack of technical rules and standards for the classification of recyclability itself and in conjunction with specific recycling methods, which increases the recyclability of the products and the recyclability of the components and polymers via a standardized polymer selection. In addition, the interaction of polymers with additives and admixtures, which play an important role in the processing and recycling of plastics, for example, as well as chemical building blocks for functionalization, stabilization, homogenization and reinforcement to increase service life, has received too little attention to date in the context of recyclability.

Initial guides have been developed by recycling associations [193], research bodies [194], foundations with statutory tasks [195], consultancies and consumer goods manufacturers mainly in the packaging sector and with a focus on mechanical recycling. There is a lack of generally accepted rules and standards developed by all stakeholders for all areas of application of plastics and with regard to all recycling methods.

In general, there is a lack of sector-specific standards for determining recyclability, such as guides or guidelines for classifying products and product components in conjunction with the best possible recovery and recycling methods today. Such standards not only assist in the design of plastics, but also provide transparent guidance on recyclability to all who use plastics and the products made from them.

Need 5.1: Allocation of the end-of-life of plastics
In the context of life cycle and sustainability assessment of plastics, the allocation of end-of-life is a particular challenge. Established standards (DIN EN ISO 14040/14044 [80], [81]) do not make any recommendations for action in the selection of suitable allocation methods for plastics. At the same time, the most common methods (cut-off & avoided burden) show problems when applied to plastics. The cut-off method does not include any credits for later recycling. On the one hand, this motivates a product developer to use secondary material and to use as little primary material as possible; on the other hand, there is no incentive for the developer to pay attention to the recyclability of the product. The avoided burden method, on the other hand, allows credit for future recycling and thus sets great incentives to generate a product that is as recyclable as possible, but often does not reflect the material degradation or the real recycling rate of the plastic. The product environmental footprint [166] allocation approach attempts to address this problem by using additional information to determine the market demand for recycled material. The higher it is, the more positive the impact of future recycling on the life cycle assessment results. However, users are often faced with the challenge that this allocation method requires further data beyond the life cycle inventory in order to determine the corresponding factors in the calculation method. Particularly against the background of additives and the sortability of the material, there is a lack of suitable standards for assessment in order to select an allocation method suitable for plastics on the one hand and to determine a recycling rate corresponding to reality on the other. By standardizing the selection methods and applying allocation methods, a recyclable design is promoted, and a realistic and comparable assessment result is generated.

Need 5.2: Delineation of an LCA and PCF and PEF by impact categories and scope as well as communication type
Due to the complexity of an LCA, PCFs are often an effective means of providing an indication of sustainability. However, it is often not clear when must which instrument be used? A PCF is an LCA with only one indicator GWP 100 (Global Warming Potential, time horizon of 100 years) [167]. For the preparation of life cycle analyses in the field of plastics, it is necessary to be more concrete in order to obtain relevant and comparable results. This concretization concerns, among other things, the definition of the assessment approach, system boundaries and input parameters

Standardization can support the classification (meaningfulness of an ecological assessment) and applications (internal or external communication of the results) of materials for industry, consumers and other stakeholders. An LCA should always provide a holistic picture of ecological performance of products/material systems and evaluate the circularity. There is a need to show a hierarchy of ecological assessment (between LCA, PCF and PEF). Differences and limitations of the application should be described here.

Need 5.3: Standardized definitions of terms, methods/selection of overarching criteria, and methods for review
Environmental statements, certificates or sustainability seals that refer to environmental or social aspects are only permitted if the issuer is a recognized institute or independent organization, or if they are based on the EU Ecolabel, EN ISO environmental labelling or specific EU legislation relevant to the statement, or if the statement has been independently validated by a third party.

Today, there are already a number of certificates and seals, which can cause considerable effort for recyclers due to the data collection, provision and auditing required for them. A more practical approach would be a standard according to which a declaration of conformity is made, which is then implemented by different service providers together with the recyclers – an approach that has proven itself for many years with DIN EN ISO 9001 [206].

Standardization can give support here by providing a standardized test method that ensures a transparent basis for labelling and conformity assessment. This, in turn, also protects consumers from greenwashing, as unsubstantiated, general or vague environmental statements are more difficult to make. Establishing criteria for evaluating the fairness of environmental statements also facilitates enforcement by consumer protection agencies. There is currently a proposal for a Directive of the European Parliament and of the Council amending Directives 2005/29/EC and 2011/83/EU [196]. Two other EU-level initiatives would complement this proposal: the Green Claims Initiative [165] and the Sustainable Products Initiative [198]. In addition, the EU Product Environmental Footprint (PEF) initiative [166] should be mentioned, which aims to ensure comparable life cycle assessment and data bases for all.

Need 5.4: Methods for the assessment of the conformity of economic sustainability

There is a need for a standard on economic sustainability. While there are methods similar to environmental LCA, namely life cycle costing (LCC) or material flow cost analysis (MFCA), both of which capture the total costs of a process or product across set system boundaries and allocate them proportionately to individual products and material losses, a corresponding standard is lacking. Allocation procedures must be used here as well. MFCA is somewhat more detailed than LCC, but both methods are fundamentally different from traditional cost accounting. Their greatest benefit is that they make it possible to identify optimization potential in the production process (i.e. also in recycling processes). One type of MFCA is presented in the VDI Guide to Resource Efficiency-Cumulative Raw Material Input (KRA, VDI) [207].

In addition, the issue of supply criticality (cf. Evaluation of raw material demand – VDI 4800 Blatt 2 [207]) is relevant in the application of R-strategies for plastics, since the petroleum-based plastics that still dominate today have a higher supply criticality than bio-based or recycled plastics. In addition, some of the additives in plastics are characterized by high demand. Here, too, the use of recyclates, for example, can reduce supply criticality. Recycled materials made from plastics should therefore receive an additional positive rating in sustainability assessments, since no (or few) new raw materials are required when they are recycled.

Thus, future economic sustainability criteria to be defined in standardization processes could reflect the true cost of sustainability in materials, e.g., in bonus-malus systems. Here, classic methods of continual improvement (e.g., raw material reduction, reduction of material losses, reduction of energy consumption (energy efficiency), use of “renewable” energy sources) can be just as effective as effective idea management, the establishment of a sustainable supply chain, and a sustainability strategy that could, for example, be anchored in the company’s quality policy. In addition, indirect environmental costs can also be included, which arise from operational environmental protection (cf. VDI 3800 [208]).

It would also be advisable to include external environmental costs (e.g., through a damage cost approach). This involves determining the costs of resource consumption within the set system boundaries (for example, the costs arising from land and water consumption in the extraction of petroleum as a feedstock for plastics) that are incurred in the short, medium or long term. For this, the “damage” to the environment must first be quantified and then monetized.

Need 5.5: Regulating occupational safety in chemical and mechanical recycling or in the processing of recycled material

Special hazards occur during the mechanical and chemical recycling of plastics. In chemical recycling, this may be due to the polymers themselves (e.g. PVC) or may occur due to additives that are hazardous to health. In mechanical recycling, occupational safety issues should be focused on with regard to the processing of recyclates (dusts, volatile harmful substances). This should take into account the establishment of limit values of substances relevant to occupational safety and the standardization of test methods and measurement techniques.

Research projects should investigate the extent to which separate occupational safety regulations are necessary for the processing of recycled materials or for chemical recycling. This must also take into account the fact that post-consumer recyclates may contain unknown harmful substances, and regrinds may contain higher levels of dust than virgin materials, for example. When evaluating dusts, the type of dust (microplastics, metal dusts) can be considered. If research activities show the need for a distinction, appropriate limits should be regulated by standards and laws.

Repurpose

Need 5.6: Review and update of existing standards regarding realistic environmental conditions in the evaluation of the biodegradability of plastics

In the area of biodegradable plastics, a review of the standards with regard to their practical relevance is recommended, since even materials that can be composted according to current standards often have to be sorted out at great expense. It is recommended that the environmental conditions of degradation (industrial and home composting, sediment, sea; but also temperature and humidity) be more focused in the assessment so that the standards also reflect reality. Furthermore, operating parameters for the composting plants could be recommended and standardized to actually achieve degradation.

Recycle

Polymer recycling is the state of the art. Mechanical plastics recycling refers to methods in which the polymer structure is not or hardly changed and the plastics are retained as a material. Physical plastics recycling refers to methods in which plastic grades suitable for this purpose are recovered in a solvent-based process. In the process, the polymer structure is retained. Chemical and biological plastics recycling are methods by which polymeric waste changes its structure in order to be converted into substances (mainly monomers) that can be reused as raw materials (polymers) for the manufacture of products.

RECYCLABILITY

Need 5.7: Qualification of plastics for reuse after present end-of-life
In terms of waste management, waste is any material or object that its owner discards, wants to discard, or must discard. A distinction is made between waste for recycling and waste for disposal. Waste for recycling includes recyclables such as wood, paper, cardboard and metals that can be easily recycled. With regard to plastic products at the end of their service life, conventional waste management today is not differentiated enough to be able to feed all plastics produced into suitable recycling streams.

A usable plastic not only contains the polymer, but also qualifies for an application via aggregates, additives, reinforcing materials, stabilizers and much more. This results in an infinite number of formulation possibilities, making precise identification in recycling difficult. Although DIN EN ISO 1043 [191] offers some guidance, it is too complex to be applied in a practical way in sorting operations.

This is further complicated by substances that diffuse into the material during product application. These can affect the technical properties of the plastic and its recyclability. Environmental effects such as contact with sunlight, oxygen and water can chemically alter the polymers or even the additives through photolysis, oxidation or hydrolysis, or consume them. Knowing the end-of-life quality of the plastic and the end-of-waste classification is fundamental information for any downstream recycling that may be considered. In particular, the focus is also on the legal conformity of the substances contained in the material, if, for example, currently banned plasticizers (e.g. diethylhexyl phthalate (DEHP)) or heavy metals (e.g. chromium VI) would re-enter the material cycle in the case of recycling very durable products, for example. Toleranced limits and exclusion criteria must be defined for this purpose.

Need 5.8: Assessment of the reusability of plastics
The objective of this need is to identify potential applications for sorted and reprocessed recyclates. On the basis of test methods, some of which have yet to be developed and standardized, and for which the requirements are described in more detail in the section on quality, materials are to be qualified so that their reusability can be assessed. The assessment of reusability must be broken down according to application areas such as packaging, automotive, etc., and must take legislative provisions into account. EN 15347 [190] covers the characterization of plastic waste, but does not address the characterization of recyclates; this is done for some materials in other parts of the EN 1534X series [187], [189], [190].

A superordinate standard for determining reusability should serve to provide potential manufacturing companies and customers with guidance on reusability for specific areas of application on the basis of the characteristic values determined and the data sheets produced, and thus to return recyclates to the cycle in a more targeted manner.

Need 5.9: Standardized information on additives for the recycling of plastics
Polymers are only used as pure substances in exceptional cases. Additives, as the name suggests, are added to the polymers. They have different functions and can, for example, help to make a recyclate reusable and reprocessable. Additives also have an influence on recyclability, especially if they are substances that are no longer permitted under substance law. For brevity, only a few important additive classes are described here. They range from fillers such as talc, carbon black or chalk, to colourants and processing aids to influence flow behaviour or demoulding, stabilizers to adjust ageing resistance, and reinforcing agents and crosslinkers to change the mechanical properties. Residual amounts of monomers, catalyst residues or other synthesis or degradation products from polymer production and processing may also be present

in plastic materials, but are not intentionally added functional additives. The plastic can be adapted and optimized to the application by selecting suitable additives. Therefore, when considering their recyclability, plastics should not only be considered as a mixture of polymer and other ingredients at the end-of-life scenario, but already at the design stage of the application as well as the synthesis of the polymer or the compounding and shaping of the plastic. Furthermore, it should also be considered that further additives are purposefully added to the plastic in the respective recycling process in order to improve its quality, stability and long-term serviceability for renewed use. These can be, for example, crosslinkers, stabilizers, fillers or other substances and materials.

The selection and combination of additives in the plastic can be decisive for subsequent recycling, e.g. in terms of whether mechanical or feedstock recycling is possible or whether energy recovery is the only economically viable option, e.g. in order to eliminate toxic substances that are no longer marketable. The accessibility of information on the additives contained in a plastic alone plays a key role in assessing its recyclability. The previously mentioned DIN EN ISO 1043 [191], describes in Parts 2 to 4 the abbreviations to be used for fillers/reinforcements, plasticizers and flame retardants, but for the multitude of other functional additives or additive combinations there is a lack of standardized information. There is a considerable need for standardization here. Furthermore, the integration of additives used in the manufacturing chain should be standardized in the digital product passport so that additives are identified transparently and, if possible, with recyclability and recycling recommendation at the end of the product life.

When implementing this Standardization Roadmap, it is strongly advised not to disproportionately restrict recycling by specifying quantitative, concrete material-specific characteristic values. For the determination of detailed limit values of a product, sufficient proven methods are available in the customer-supplier relationship, e.g. via delivery specifications and certificates of analysis, which sufficiently describe the properties and quality of a product. On the other hand, standardization can be a valuable aid, e.g. in determining the depth of information, especially for small and regional operators of recycling plants, see for example the approach of DIN SPEC 91446:2021-12 [49].

SORTING

Need 5.10: Uniform design of data sheets for the description of sorted materials

Especially in the case of plastics, the respective recycling plant must be specialized for the type of plastic and the respective application. For example, recycling film made of polyethylene is a different process than recycling hollow bodies which are also made of polyethylene. If the recyclables have a composition that is as constant as possible (sorting), a process can be optimally developed for this stream of recyclables. If a recyclable material is already collected separately, such as deposit bottles or logistics film, this first large-scale sorting step is not necessary, and a meaningful data sheet on the quality of the material should also be available. The data sequence and data depth in the specification of recyclable material qualities and, if necessary, the measurement methods (based on DIN EN 15347 [190], DIN SPEC 91446 [49]) should be developed in a standard.

Need 5.11: Harmonization of take-back and collection systems for commercial sectors and products

In the case of voluntary take-back and collection systems from the commercial sector, such as for building products, harmonization is desirable in order to increase the amount of material collected and also to minimize the logistical effort. Standardization of sorting grades and separation instructions in the commercial sector at the product level will encourage the rise of closed-loop products and material suitable for use within the same industry. This can be supported by standardization of design 4 sorting and recycling on an industry-specific basis, if necessary. If harmonization succeeds here, more uniform waste management structures can be created for the respective product categories, e.g. for waste electrical and electronic equipment (WEEE) [135], the automotive or the construction industry.

Need 5.12: Technical guideline for the definition of open and closed loop systems

To date, there is no uniform definition of open-loop and closed-loop systems for products or materials, and thus no uniform use of the terms. This also prevents a uniform understanding of whether the material can be returned to the same cycle. Another need for research and standardization activities is to develop a guide on what is considered open and closed loop, as these terms are interpreted very differently in practice. This also prevents a uniform understanding of whether the material can be meaningfully returned to the same cycle. Therefore, it is necessary to define the terms and establish a measurement procedure.

DIGITAL PRODUCT PASSPORT, TRACEABILITY

Need 5.13: Addition of recycling-oriented information in the digital product passport for plastics
A product passport can help to increase the recycling effectiveness of plastics, e.g. to show the presence of certain substances that have an influence on the suitability for certain applications (see Need 1.8). Likewise, it can increase the acceptance of recycled materials in product development. The material passport should clearly state the necessary information on proportions of all relevant components, but should be limited to the necessary information. A level of information must be found that ensures the benefits to the recycling industry, but protects the business base of the manufacturing companies. One possibility is a division into "required data" (mandatory to be provided) and additional "optional data", which can improve the communication of the economic actors in the long term. The following information is relevant for the sorting, preparation and processing of recyclables:

→ Type of plastic and application (e.g. processing extrusion/injection moulding, or suitability food/non-food)
→ Intentionally added additives and fillers
→ Substances likely to be present due to migration from adjacent materials during use, e.g., packaging of dangerous goods
→ Contained substances through use of recyclate in product/packaging manufacture (multi-cycle)

Sorting requires access to the data at maximum speed. For this purpose, the data interface, data formats (sequence, semantics, units), update cycles, etc. must be standardized. Access for all participants in the value chain (data interface and ensuring interoperability of databases) or the access structure (read/write), data linkage (e.g. batch to end product) and data security must also be defined. Here, industry standards and existing guidelines can be a starting point.

Special attention must also be paid to very durable products made of plastics, because legal requirements change periodically within the EU as laws, specifications, standards, etc. are revised. As a result, these plastics may then no longer be recyclable or the recyclate obtained in the recycling process may no longer be used in new products.

Need 5.14: Uniform documentation requirement for the traceability of plastics
In order to ensure the traceability of recycled plastics, all participants in the value-added cycle from collection of the recyclable material through sorting and processing to the person placing it on the market should be included in the documentation. This information is then used for quality assessment and designation of the recyclate content, among other things. The respective information to be documented (incl. definitions of terms for uniform interpretation), their data depth and measurement methods are to be standardized. These can be defined depending on the process step (e.g. origin in the case of collection, quality properties or contaminant assessment in the case of treatment methods). Additionally, data may be requested that is necessary for the digital product passport, a sustainability rating, or other compliance. A starting point here can be DIN EN 15343 [187].

The traceability of the batch designation or allocation methodology must be defined as the allocation between documentation and material. If the batch designation and size is changed or divided in the course of processing, this must be recorded in the documentation in a traceable manner without gaps. The location for storage and the storage period of this digital documentation must be defined, and particular attention must be paid to reconciling the requirements for a digital product passport and the additional requirements for traceability.

Need 5.15: Uniform calculation rules for determining the output rate in recycling processes
Depending on the quality of the recyclable material processed and the process structure selected, a specific output is expected for each recycling infrastructure for its target product. However, side streams can in turn end up in recycling plants specialized for this purpose and complement the overall recycling from the point of view of the recyclable material. For example, in a recycling plant for beverage bottles, the focus is on the PET, while the sleeve and caps go to specialized plants for each. It is therefore necessary to take into account the cascade of the various processes and their specific yields in the calculation when determining an overall recovery rate. Discharged contaminants, if they are not further recycled, and portions used for energy purposes should not be added to a recovery quota. In addition, the removal or fate of contaminants from the respective recycling processes must also be considered in the life cycle assessment methods.

If methods are used in which the material is mixed with other material flows and it is not recognizable on the product from which source the material originates (e.g. envisaged in chemical processing), the calculation method for the output rate must be specified. If the dilution of the recycled raw material, e.g. with virgin material, has an influence on the processability of the material (e.g., to be expected with strong dilutions) and on the output rate of the process, this must be taken into account in the calculation method.

If intermediate products are produced (monomers, oils, gases, solids), the yield should be determined on the basis of the resulting quantity of plastic from the subsequent process steps. If the substances are not used for the production of the original plastic application (e.g., solids or gases unsuitable for plastic production), they should be excluded from the calculation in the sense of the plastics Circular Economy.

Need 5.16: Rules for the calculation of the recyclate content
If only recyclables are processed in a recycling plant and no other materials are added in the manufacture of the product, the recyclate content for the recycled raw material produced is 100 %. If auxiliary materials are required for processing (water, washing substances, solvents, catalysts, etc.), it must be ensured that these are completely removed or are not included in the collection of the recycling raw material. If dilution of the recycled raw material is required for technical or other reasons, the mass fraction of the recyclate used currently determines the recyclate content. A starting point here can be DIN SPEC 91446 [49].

At present, however, standards (e.g. DIN EN 15343 [187]) only take into account recycling processes with segregated value chains, or value chains in which the exact composition of the products is known at all times. Not all new recycling technologies can meet these requirements for calculating recyclate content. Therefore, there is a need to revise and expand the calculation methods of recycled content in standards that take into account the different technologies (mechanical, physical, chemical, biological). For this purpose, a universal formula for the calculation of recyclate content, applicable to all recycling technologies, should be developed and specific rules for the different models of traceability in the supply chain should be added.

When designing such calculation methods deviating from the physical basis (free allocation), e.g., as a transitional solution for the set-up phase of a chemical recycling plant, the following criteria shall be defined: allowed dilution rate, binding in time, binding in place and allocation to different unavoidable material streams (products).

MECHANICAL RECYCLING

Need 5.17: Delimitation of recycling technologies/ methods for plastics and uniform life cycle assessment
Mechanical recycling encompasses a variety of methods and technologies, and some processing steps have been technologically combined in the past, thus also crossing the boundaries with other recycling methods. In principle, it would be important to clearly delineate the individual methods from one another in advance. This requires a clear nomenclature, especially in the direction of chemical and physical recycling and towards a uniform assessment.

In order to qualify mechanical recycling and to be able to define its state of development, it would be desirable to list the technologies and methods in a status report, for example in the form of a “technical report”. For this purpose, process steps of mechanical recycling (such as comminution, density separation, infrared/near-infrared (IR/NIR) sorting, compounding, volatile organic compounds (VOC) extraction, and many more) should be broken down and corresponding technologies described.

In addition, the limitations, advantages and disadvantages of the technologies for collection and sorting in preparation for mechanical recycling should be described. The important area of sorting and separation technologies should be explicitly described and evaluated, and the status quo should also be highlighted here. It would be useful if whole processing steps such as washing, melt filtration or sorting of plastic waste are described with their possibilities and weaknesses. This need is directed at standardization and research, but also at the processing industry.

Need 5.18: Systematization of markers and process requirements for destruction in the second recycling process and quantification of the environmental impacts
Incorporating markers into polymers not only helps protect against plagiarism, but also shows great potential in separating and sorting in the subsequent recycling stream. The marked plastic parts are sorted out of the heterogeneous waste stream with a high separation quality and can thus be further processed according to type. Marker combinations could be used to store important information on composition and origin, right through to digital product passports.

Currently used markers are designed for longevity; they remain in the material beyond the recycling process. This concept can certainly offer advantages, since the history of the material remains rudimentarily stored. However, a marker that has not been previously separated from a recycling stream could cause problems in further processing or in the next upcoming separation step. Standardization (in conjunction with research) could be an important tool for wanting to have markers that are completely removable following sorting during the recycling process, and without negatively affecting further application. Furthermore, it must be considered which environmental influences markers have during mechanical recycling, such as contamination of the wash water.

Of course, in this case a minimum of information about the marker is needed, as well as a systematization of the different marker types; also an application-specific declaration would help a lot here.

Need 5.19: Requirements for a paint system in terms of design 4 recycling and sustainable paint stripping processes

Paints and varnishes not only increase the value of an application, but also the effort to recycle and also deteriorate the quality of the recyclate. Therefore, knowledge of the coating system (pretreatment/carrier/coating) is of immense importance for all recycling processes. There is a great need for research in simple and cost-effective paint stripping without disruptive degradation products.

In principle, however, it would make more sense to, as early as the design 4 recycling stage, use a coating system that can be easily removed again or that has little or no influence on the process and on the quality of the recycled product. For this purpose, colour and carrier systems should be researched and defined. The paint stripping processes suitable for these systems should be developed and standardized already during the development of the systems.

Need 5.20: Systematics of combinations of organic and inorganic pigments in plastics for optimal recycling

Unlike paint systems, colourants are specifically designed for individual polymers or polymer groups. These appear to have little impact on the mechanical recycling process. However, there are combinations of organic and inorganic pigments that stand in the way of a high quality recyclate. Exceeding legal limits (such as for heavy metals) in a new application is also a risk. Therefore, knowledge of the type of pigment and its concentration is also extremely important here.

Problematic mixtures should be researched and a system should be developed to determine which combinations are mutually exclusive and which combinations, based on the application, may be permissible. There is not only a need for research here, but also for standardization.

Need 5.21: Determination of input streams with regard to foreign polymers and fillers and reinforcing materials

The topic of the influence of foreign polymers and fibres contained in recycled materials is in the early stages of research and commercialization and has so far only insufficiently reached standardization (see DIN CEN/TS 17627 “Determination of solid contaminants content ” [187]). Intensive basic research is currently underway to be able to assess the need for standards. Topics such as the process definition for the comminution of multi-material systems and their separation down to the pure primary material, or the determination of the length of reinforcing fibres and material properties contained in the recyclate using, for example, optical methods could be considered.

Due to the application- and property-related increased use of plastic composites with or without fibre reinforcement without considering basic principles of design 4 recycling in the product development phase, this topic is becoming more and more important. This is due to successes in recycling less complex materials, increasing pressure from politicians, but also the market environment (rising demand for recyclates) and, last but not least, growing awareness of the problem in industry and society.

A fundamental issue for standardization in this context is the definition of target component-specific methods in order to take the widely differing materials and products into account on a more individual basis. In addition to the most fibre-friendly treatment possible in the individual process steps, it is also necessary to determine and track the shortening of the fibre lengths in the polymer during mechanical recycling in order to specifically document the property changes based on this information.

Need 5.22: Mechanical recycling in preparation for further depolymerization or dissolution of the target fraction

Before polymers can be fed into a depolymerization process, interfering materials such as metals, polyolefins, PVC, polymers with brominated flame retardants, paper, etc. must be separated from the polymer to be depolymerized. The output quality is to be defined analogously to DIN SPEC 91446 [49], taking into account the standardization of the data sheets and criteria, in order to establish comparability of the input stream for the chemical recycling to be defined. There is a need for further research in this area, as depolymerization has not been economically viable to date. Furthermore, the quantity of the "pure" material stream as input is too low. In the future, better pre-sorting is necessary, and quality requirements for the depolymerization process have to be defined.

CHEMICAL AND PHYSICAL RECYCLING

The standardization needs can be separated, as shown in Figure 27, according to a process logic following the material flow. First, standardization needs are formulated that relate to plastic waste as a feedstock for the recycling methods, i.e., to processes upstream of the recycling methods. This is followed by needs for the chemical and physical conversion and recycling processes themselves, as well as standardization needs for products of the recycling methods and their further processing, i.e., processes downstream of the recycling method. Figure 27 illustrates the differentiation of recycling methods.

Need 5.23: Upstream processes – Quality-related standardization of input streams

As with mechanical recycling, a classification and quality description of plastic waste is also useful for chemical and physical recycling and should be standardized at national, European and international level. Analogous to mechanical recycling, quality requirements must also be met for physical and chemical recycling so that the processes are not negatively affected. For example, chemical recycling processes such as pyrolysis and gasification are affected by halogens such as chlorine or fluorine, which are, for example, chemical building blocks of the polymers PVC or polytetrafluoroethylene (PTFE). In physical recycling, the target polymer must be present in the input material in as high a concentration as possible for economical operation. The sorting and purification/preconditioning of recyclable plastic waste plays an important role here, as does the detection of interfering materials (classification, online monitoring of waste). This makes it possible to optimize subsequent recycling. The challenge is to map the diverse input stream requirements of the various recycling methods. The definition of input stream quality should be broken down for all recycling processes. There is still potential for standardization support here.

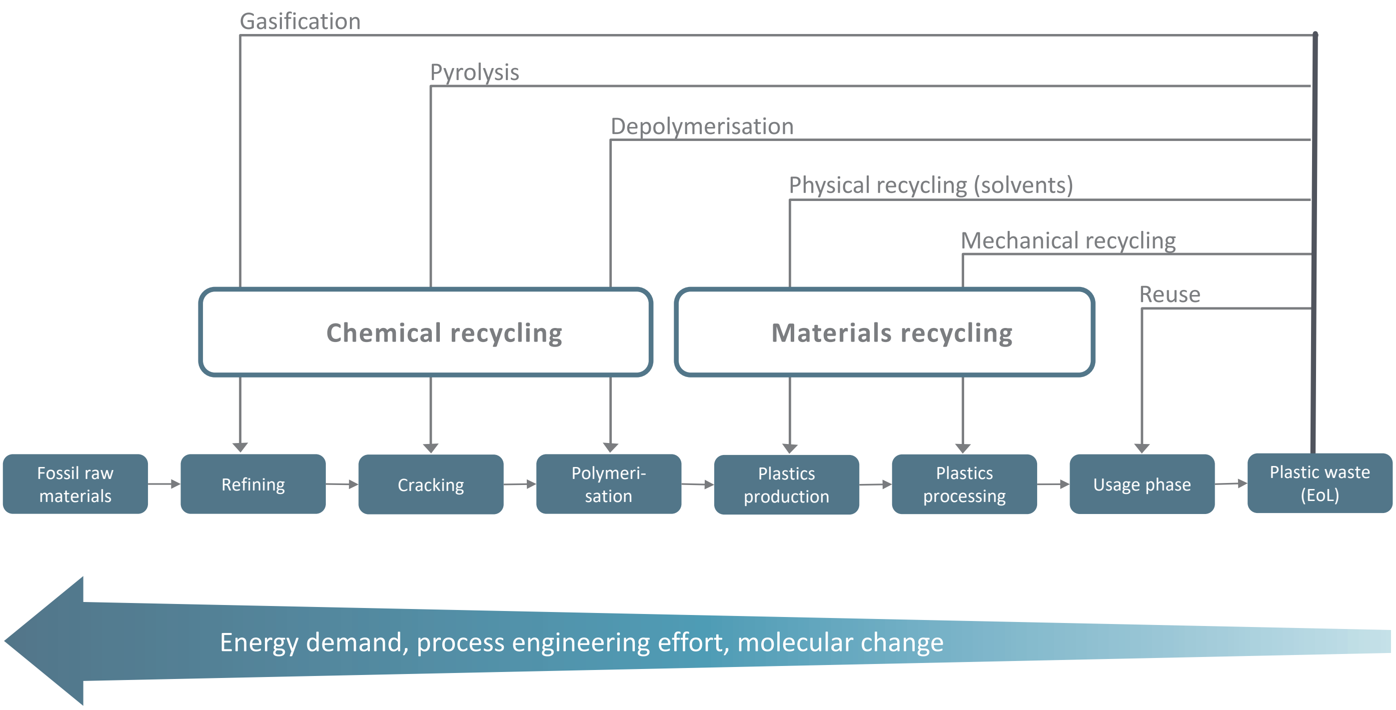


Figure 27: Overview of standardization needs in chemical and physical recycling (Source: DIN)

Need 5.24: Conversion and recycling processes – Description of chemical and physical conversion and recycling processes (Technical reports to illustrate the state of the art)
Despite existing scientific papers and increasing patent applications, there is currently a lack of technical reports that disclose the state of the art in the new recycling technologies and accelerate large-scale implementation of the technologies in conjunction with waste management. The presentation of the emerging technologies in the field of chemical and physical recycling as well as clear definitions of the various methods are prerequisites for establishing a general technical understanding and form the basis for further standardization projects. For example, a description of the state of the art of the different methods, and input and output streams is a prerequisite to define quality requirements for plastic waste. The development of general definitions, methods and calculation bases for chemical and physical recycling is fundamental work that has not yet been done. This gap has already been identified and a revision of ISO 15270:2008 [200] is being planned at the international level to address this need. The standard is to be converted/extended into a series of standards in the process. This series of standards, which will describe mechanical, chemical, physical, and organic recycling, will help generate a common understanding of existing and emerging recycling technologies and establish innovative technologies in waste recovery systems internationally. National preparatory work should, if possible, be included at the international level.

Need 5.25: Downstream processes – Quality-related standardization of chemical products from physical and chemical recycling
The Circular Economy of plastics can be strengthened by defining classes or categories into which products from chemical or physical recycling are classified according to their quality. In chemical or physical recycling, plastic waste is converted into products or intermediate products that are the raw material for processes to produce new chemical products, including plastics. So far, no quality classes have been defined into which the (intermediate) products could be classified according to the purity of the target substance and/or the proportion of interfering or contaminating substances. Such quality classes can act as transparent, generally accepted and thus binding interfaces between the recycling and processing industries. This would offer downstream processing companies the opportunity to see at a glance whether an (intermediate) product from recycling is suitable as a raw material in their production processes. At the same time, recycling companies would know exactly which qualities they have to produce in order to find buyers. The classification into quality classes would make products of different recycling companies comparable and tradable, so that markets for the different quality classes can develop. Therefore, quality classes should be established for the products of each chemical and physical recycling method, and minimum values for target substances and maximum values for interfering or contaminating substances should be established for each class. Standardization can provide support here by defining different quality classes for the different products of chemical or physical recycling.

For a future recycling of recyclates in cosmetic, medical and food applications, quality classes that allow the use of recyclates from physical (and mechanical) recycling are lacking so far. As the current legislation represents an almost insurmountable hurdle here, an adjustment of the legislation is necessary (e.g., allowing the “free-riding” of materials instead of a complete traceability of the origin of the material). Corresponding standards must then be defined downstream. This is the only way to integrate materials from physical (and mechanical) recycling processes into a Circular Economy in the application areas of cosmetics, medicine and food.

In the characterization of recyclates from physical (and mechanical) recycling, we see a need for research and also standardization, especially in the differentiation of various PE types (e.g., linear low-density polyethylene (LLDPE)) in the recyclate (based on DIN EN ISO 11357-3 [192]; DIN EN 15344 [189]). Knowledge of the composition of recyclates is essential for replacing virgin materials with recyclates.

QUALITY

Need 5.26: Test standard for the determination of NIAS (non-intentionally added substances) in recyclates
In the field of recyclates, there is currently a lack of standards governing the testing of NIAS as interfering substances. Therefore, the analysis methods and results of different testing laboratories sometimes differ greatly. At this point, both the analysis methods (analysis-specific sample preparation and processing and instrumental requirements for the equipment) and the substances to be analysed and their identification, including limit values, must be regulated via pollutant lists, which can be material-specific and/or application-specific. In addition to the need for standardization, there is also a need for research in this area.

Need 5.27: Strategies for sampling, homogenization, and retained samples for all recycling methods and process steps, and for evaluating batch variations

For meaningful material qualities, sampling and homogenization play a decisive role. CEN/TS 16010 [185] and CEN/TS 16011 [186] and some other standards already provide procedures for this. In practice, however, these technical guidelines are often little used because the sampling effort is too high from an economic point of view. Therefore, it is recommended that they be revised with cost-effectiveness in mind. In addition, procedures of different standards should be standardized, e.g., the inclusion of the simplified procedure of DIN SPEC 91466 [49] in CEN/TS 16010 [185], and a system for retained samples, including their retention periods, should be implemented. The type of sample packaging and storage should also be taken into account, as this is crucial for the analysis of volatile components in particular. Standardization could be supported at this point by research projects in order to obtain comparable statements with fewer samples or characteristic values.

To increase the comparability of materials/substances and the significance of test results, the definition of batches as well as batch variations is an important step that should therefore be considered in upcoming research and standardization projects.

Need 5.28: Analysis of persistent contaminants and their accumulation in recycled materials

Within the framework of research and subsequent standardization activities, analytical methods for the uniform detection of persistent contaminants and their accumulation in plastic recyclates should be developed in the future. For the classification of recyclates, the input stream as well as the subsequent application of the materials should be taken into account. A listing of contaminants (specified by polymer type, input stream, etc.) can help to standardize analytical screening procedures (see also Need 4.28 in Chapter 2.4).

Need 5.29: Standardization of the indication of quality specifications for recyclates (data sheets)

The EN 1534X series [187], [189], [190] and DIN SPEC 91446 [49] recommend an initial approach for the use of uniform data sheets and the specification of material properties. For better comparability of materials, the EN 1534X series [187], [189], [190] should be extended to other types of plastics that are technically recyclable and used in sufficient tonnages, such as engineering plastics like polyamides (PA), polybutylene terephthalate (PBT) or polycarbonates (PC). This should include information on additives and contaminants remaining in the material.

Need 5.30: Standardization of testing standards for bulk density

Different procedures are used for determining bulk densities, e.g. in the EN 1534X series [187], [189], [190] and DIN EN ISO 60 [210]. It is recommended that these be harmonized.

Need 5.31: Test standard for determining odour

The odour of a recyclate is a critical issue for almost all applications. Therefore, standardization for uniform evaluation of odour for recyclates is recommended. It is conceivable that this could be based on VDA Standard 270 [211] for automotive interiors.

Need 5.32: Test standard for determining volatile organic compounds (VOC)

In order to minimize risks from emissions from components, these are often determined for different applications, e.g. in automobiles or for interior measurements in the construction sector, and checked against lists of hazardous substances. In order to be able to detect these substances as early as possible in the process, a uniform test standard for VOCs from recyclates should be developed, whereby it is possible to follow common standards in order to minimize the effort involved. In this context, limit values of toxicologically relevant individual substances and/or groups (aromatics, terpenes, nitrosamines, etc.) should also be defined.

For the analyses and limit values, it is imperative that the target application be taken into account, as this can lead to very different relevancies for contaminants. For food contact use, this will be considered in the future in the revised Regulation 282/2008 [197].

Need 5.33: Promotion of research on the correlation of recyclate and product properties and screening methods

Since the recycling market is both time- and cost-driven in terms of testing, funding for research on correlation methods of test results of recyclates and products from recyclates is recommended, as is funding for research on screening methods Both can provide foundations for upcoming standards that expand the use of recyclates.

Need 3.34: Promotion of research on the introduction of contaminants into recyclates
Research activities should be promoted for the analysis of contaminant input into recyclates, both during the previous life cycle and during the recycling process itself, as this knowledge can lead to standardized testing. Different recycling processes (mechanical, chemical, physical, bioenzymatic) should be considered. In addition, the waste stream from which the input material originates must be taken into account in this context. For the evaluation of the relevance of the possible contaminants, the target industry should also be taken into account.

Need 5.35: Design FROM recycling guideline
A further need for research and standardization lies in the development of a guideline or recommended action for design, construction and processing of products in all sectors that are to be manufactured from recyclates or with the highest possible recyclate content from the outset. The guideline should serve as a recommendation as to how possible material variations can already be well compensated for by a suitable design or process parameters. This need is distinguished from the widespread design 4 recycling or circularity in that it is not a matter of designing a product to be recyclable, but of designing a product so that it can be manufactured from recyclates in a simple, process- and application-stable manner, as well as economically.

Need 5.36: Technical guide to the classification of defect groups and types of product/processing defects specifically for recyclates
There is a need for the development of a technical guide for the classification of defect groups and defect types for the processing and application of recyclates and products made from recyclates, since apart from immediately apparent surface defects, polymers are also damaged without obvious defects and thus may no longer fulfil the promised quality and function in the application. The guide should also include typical analytical procedures to detect the defects. The structure could be analogous to VDI 3822 on damage analysis on plastics [205].

Need 5.37: Occupational safety regulation for the processing of recyclates
Research projects should investigate the extent to which separate occupational safety regulations are necessary for the processing of recycled materials. This should also take into account the fact that post-consumer recyclates may contain unknown contaminants, and regrinds may contain higher levels of dust than virgin materials, for example. If research activities show the need for a distinction, appropriate limits should be regulated by standards and laws.

Need 5.38: Development of a test method for evaluating the degree of degradation and guideline for the addition of additives
Multiple processing of materials leads to degradation of the polymer chains and also to degradation of additives, e.g. process stabilizers. This greatly depends on the process parameters. Through research and the standards or guidelines based on it, test methods should be developed that evaluate the material in terms of its condition and possible degradation products that could be contaminants. This standard or guideline should assist in assessing the extent to which virgin material or new additives should be added to restore the material to its target properties or to determine that the material is no longer suitable for these uses, e.g., due to contaminants or crosslinking.

2.6 Textiles

2.6.1 Status quo

European textile consumption is the fourth largest cause of environmental pollution and climate change after food production, housing and mobility [212]. Against this backdrop, the EU›s Circular Economy Action Plan 2020 [4] placed a focus on the textile sector. A transformation of the linear business model into circular production, circular design and a shift towards durable products, reuse and recycling is necessary to minimize impacts on the environment and climate change.

Textiles are very diverse and often consist of different fibre blends and other, non-textile components; depending on their area of application, they have to fulfil different functions. If we compare, for example, the health sector, the automotive sector or the construction sector, textiles have to meet completely different requirements in each case than in the clothing or home textiles sector.

Today, Germany produces (innovative) technical textiles in particular, as well as high-quality apparel textiles. According to the concept of the “Techtextil” trade fair, technical textiles are divided into the following areas: Agrotech, Buildtech, Clothtech, Geotech, Hometech, Indutech, Medtech, Mobiltech, Ecotech, Packtech, Protech and Sporttech. Technical textiles account for around 30 % of sales and, like clothing, are exported on a large scale [213].

European textile consumption is among the top three pressures on water and land resources and among the top five pressures in terms of raw material use and greenhouse gas emissions. In the fashion industry in particular, consumption has more than doubled since 2000; wear time has halved on average [215]. The fast fashion industry produces new trends at ever shorter intervals. Buying fashion today no longer has anything to do with the need to have something to wear; rather, it is about expressing an attitude to life and the purchase is strongly influenced by the social environment as well as (social) media [216]. In a European country comparison, Germany ranks second in the consumption of new textiles [217]. Every year, around 1,5 million tonnes of clothing, footwear and home textiles come onto the market in Germany [218]. It is estimated that about 40 % of clothing is rarely to almost never worn [219]. More than 90 % of German consumption is imported; the main producing countries are China, Bangladesh and Turkey [221].

Against the background of production figures and consumption in Germany and the EU, the experts decided to limit themselves in principle to clothing and home textiles (excluding mattresses and carpets) when developing standardization needs. The clothing sector also includes medical clothing and workwear, including clothing for personal protective equipment. Other products made of textile materials, such as fibre composites, construction textiles and geotextiles, are classified differently in terms of use and type and duration of use. It is therefore suggested that these product groups are also to be taken into account in any further development of the Standardization Roadmap Circular Economy.

The EU Chemicals Regulation (Regulation (EC) No. 1907/2006, REACH Regulation) [73] plays a major role in particular for the production or import of textiles. During the manufacturing process and further processing (dyeing, finishing, etc.) more than 7000 chemicals are used [222], which remain in the textile. The German Product Safety Act (ProdSG, 2021) [220] with regulations on safety requirements for technical work equipment and consumer products must also be taken into account. In addition, for safety-related products such as personal protective equipment, there is the European PPE Regulation (EU 2016/425) [232] and for medical devices, there is the European Medical Devices Regulation (MDR, EU 2017/745) [269]. For textile products, the EU Textile Labelling Regulation (Regulation EU No. 1007/2011) [238] must also be observed. This is implemented in Germany with the Textile Labelling Act of 2016 [236]. In contrast to other countries such as Austria, care labelling of textiles is not mandatory in Germany.

For the waste management of textile waste from households or other source areas such as production, cleaning companies, hotels, gastronomy, administration or trade, there is no special legal regulation so far. The Commercial Waste Ordinance (GewAbfV) [233] already provides for the separate collection of textiles from other sources. From 01.01.2025, due to the amendment of the German recycling act, the Kreislaufwirtschaftsgesetz (KrWG) in 2020 [176], textile waste from households must also be collected separately.

With the publication of the EU strategy for sustainable and circular textiles (EU Textile Strategy) [215] in March 2022, the EU Commission shares its vision for sustainable and recyclable textiles in 2030. According to this vision, only textile products that are durable, recyclable, largely made of recycled fibres, do not contain hazardous substances, and are produced in compliance with social rights and in the spirit of environmental protection will be placed on the EU market. In a competitive, resilient and innovative textile sector, manufacturers take responsibility for their products along the entire value chain – right through to disposal. Economically viable reuse and repair services are still available. The circular ecosystem has sufficient capacity for innovative fibre-to-fibre recycling, whereas incineration and landfilling of textiles are minimized. In total, there are nine key measures to bring about the transformation of the textile sector.

The Sustainable Product Initiative (SPI) [225] was also published at the same time, identifying key measures for circular and sustainable products, including textiles. The SPI proposes to replace the Ecodesign Directive (2009/125/EC) [21] with a regulation. Requirements are to be made product group-specific in delegated acts. The EU textile strategy [215] refers to the development of the Ecodesign Regulation and sees this as the starting point for anchoring requirements for textiles. The revision of the Ecodesign Directive thus imposes extended requirements on the manufacture of products, which also cover textiles in the EU textile strategy [215]. Altogether, it can be said that significant changes to the legal framework will be forthcoming in the next three years. These changes must be taken into account in the standardization work. Based on the publications, it can be assumed that the following EU provisions for textiles in particular will be (further) developed.

- → Ecodesign requirements (longevity, repairability, recyclability)
- → Minimum use of recycled fibres/recyclates
- → Digital product passport (DPP) /digital label
- → Environmental fee scale for extended producer responsibility for textiles
- → Introduction of a transparency obligation for the publication of destroyed and disposed textiles
- → Goals for the reuse and recycling of textiles
- → Development of end-of-waste criteria for textile waste
- → Development of EU criteria that distinguish textile waste from certain used textile goods

In Germany, there is as yet no strategy for the sustainable use of textiles. However, with regard to the publication of the EU-wide Textile Strategy [215] and Sustainable Products Initiative [223] in March 2022, the German government has indicated that it supports the initiatives and is working on the introduction of extended producer responsibility for textiles [198].

Evaluation of standards research
Across all seven key topics, 2101 standards were identified that can be assigned to the Circular Economy topic area. Figure 28 shows the distribution of standards for textiles among R-strategies as well as the carbon footprint, DPP, and general standards that feed into several of the above aspects. In total, 160 standards could be assigned to the R-strategies as presented in Figure 28. Standards already exist today that can be assigned to the R-strategies "recycle", "rethink" and "reduce" – especially in the textile laundry care area.

Textile materials are used in numerous, very different products (see Figure 29). It can be seen that standards already exist today for the product groups of home textiles and of textiles that take into account individual aspects of the Circular Economy. The standards search also includes standards on

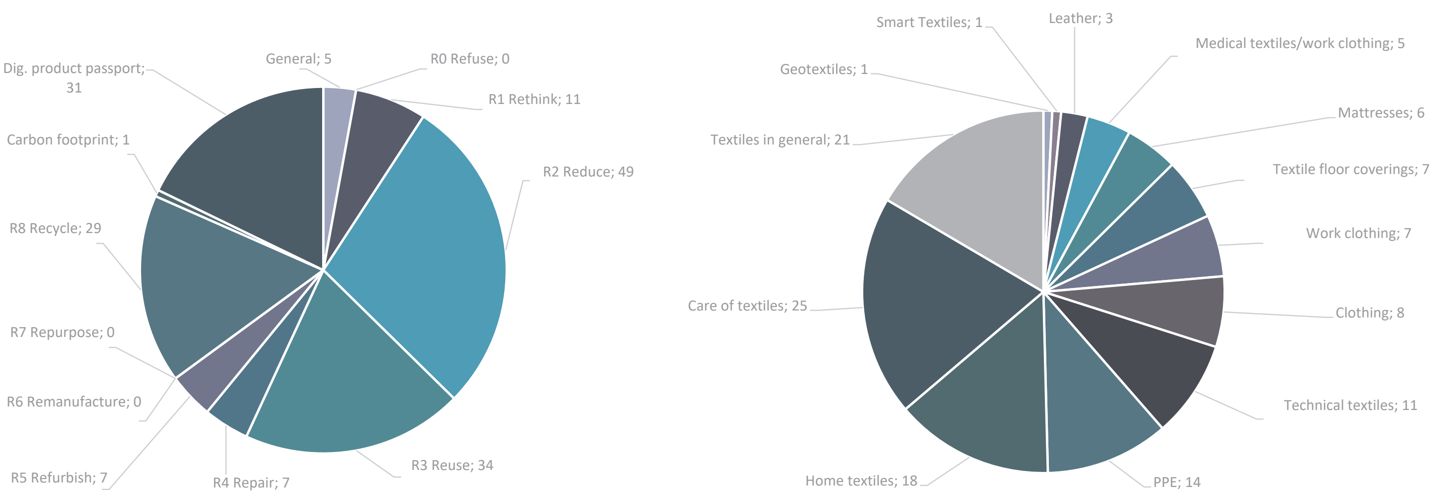


Figure 28: Distribution of standards among R-strategies, carbon footprint, DPP, and general, and distribution among product groups (Source: DIN)

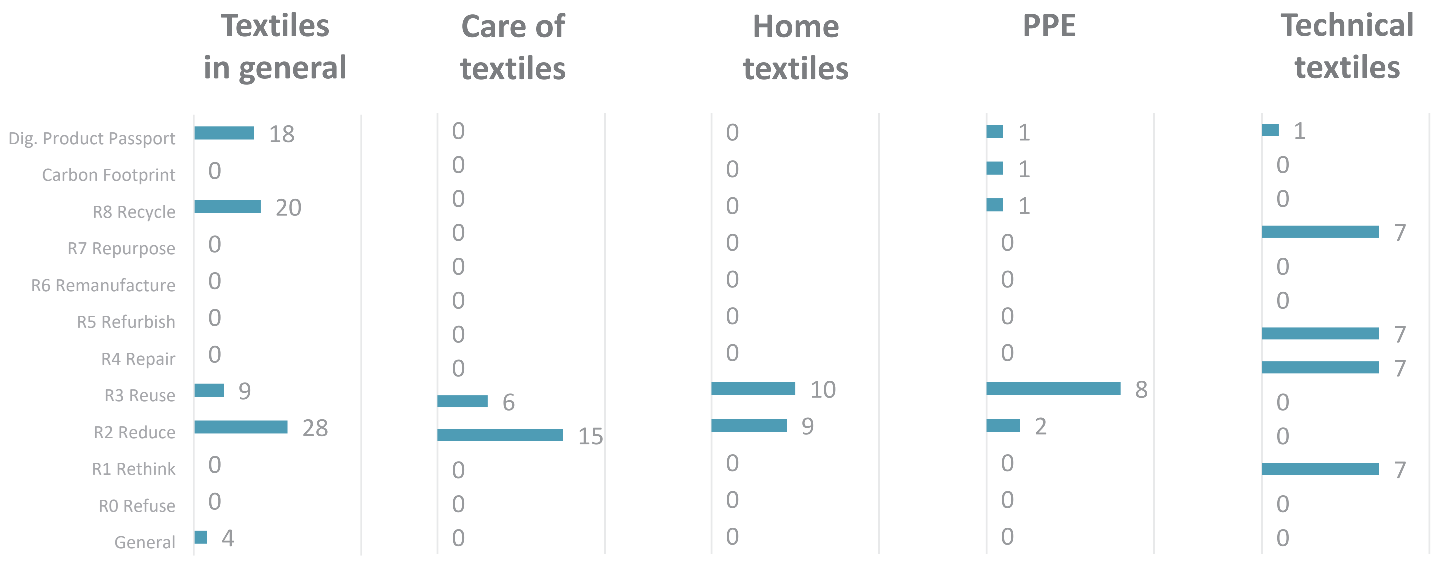


Figure 29: Distribution of the different R-strategies and the carbon footprint, the DPP as well as general standards among selected product groups (Source: DIN)

textile groups (e.g. geotextiles) that have been excluded from the current Standardization Roadmap.

Figure 29 shows the product groups with the most existing standards in the field of Circular Economy. It can be seen that there is no general distribution of R-strategies and systematics between the different product groups, and that there are hardly any standards today on the terms carbon footprint, “repurpose”, “remanufacture”, “refurbish” and “refuse”.

It is clearly evident that there is still no consistent product group-specific standardization on Circular Economy for textiles today. Many gaps are apparent in the standardization landscape for specific product groups. Due to the heterogeneity of the textile product groups, it must be examined to what extent the standards that have been identified generally for textiles can be applied specifically to the various product groups or must be adapted.

2.6.2 Requirements and challenges

The effectiveness of Circular Economy standards depends on the policy framework.
The absolute reduction of resource consumption and, consequently, the reduction of environmental impacts can be achieved in particular by extending the lifetime of textiles and assuring repeated use. In addition to the technical aspects, there are two other factors that influence the duration of product use: consumer behaviour and business models.

Circular business models support the life extension and product use of textiles. These models are already successfully established in the field of workwear or commercially used textiles. Textile service companies (cleaning, repair, etc.) see themselves as service providers and sell their service as a “product as a service”. The goal must be to establish these business models in the private sector as well. Furthermore, it must be a matter of course in the future to wear second-hand fashion. However, the successful development of these business models cannot compete with cheap fashion. That is why a fundamental rethink is needed in the consumption of clothing. Standardization (alone) cannot achieve this. Instead, political and legislative measures are needed, such as comprehensive consumer education and communication, as well as transparency, requirements to include environmental costs, and demands for compliance with social rights in developing countries.

Standards are often very technical and often not “readable” for end users. It is important to keep this in mind. It is important to inform private consumers comprehensively and understandably with regard to technical specifications, as well as about the interrelationships and interactions with and within the Circular Economy. Against this background, the labelling of textiles and the dissemination of information is of essential importance not only within the textile value chain.

It should also be mentioned at this point that the aforementioned EU packages of measures will to a large extent form the basis for standardization work in the area of the Circular Economy. However, as of today, there is still no concrete formulation of the legal requirements. Since the implementation of the future provisions of the Ecodesign Regulation [21] in particular will dictate the standardization work in detail, it is proposed against this background that the relevant requirements should not be addressed until it is clear how the statutory minimum requirements are defined. Before further standardization projects are launched on the basis of the needs listed here, it is essential to check the status quo of ongoing projects, for example with the European working group CEN/TC 248/WG 39 “Circular Economy for textile products and the textile value chain” or with the international working group ISO/TC 38/WG 35 “Environmental Aspects” on the draft standard DIN EN ISO 5157 [226].

Today, only a small share of the market for textile products, especially clothing textiles, is manufactured in Germany and in Europe. Therefore, in addition to national standards, European and international standards must be developed for textile products in order to establish the recyclability of textiles.

Not all textiles are created equal
During the discussion on the individual standardization needs, it became clear that the individual measures for circularity can vary greatly depending on the product group and that this must be taken into account. In particular, this point was discussed on the issue of longevity of textiles versus recyclability; the different approaches became very clear in terms of the use of materials, the construction of textiles, but also in terms of handling during the use phase, for example in the area of today’s rapidly changing fashion trends, which may be in competition with a long-lasting design.

2.6.3 Standardization needs

The identified standardization needs refer to one or more R-strategies and are listed below by R-strategy. Needs with multiple assignments were assigned to the most relevant R-strategy or general standardization needs and R-strategies with no need assignment were not listed. General needs include the topic of labelling as well as the DPP.

Refuse

The rejection of a product is sustainable if the rejection means that the product is not produced in the first place. However, this is an individual decision of the consumer and often an economic decision

Need 6.1: Prioritization of reusable products in product standards over single-use products
In some areas of use (e.g. protective masks and gowns, surgical textiles, hand drying), reusable textiles are an alternative to single-use products on the market. Single-use products are often chosen for economic reasons, as they are cheaper to procure than reusable products, which, due to multiple use, are ultimately economically more favourable over the entire life of the product and make more sense in terms of sustainability. Reusable products should be preferred in the sense of the Circular Economy and single-use products should only be used if this is necessary for safety reasons (e.g. health impact, environmental impact). Product standards in such application areas can help to promote existing and new business models for textile reusable products in use areas.

Need 6.2: “On demand” production
Completely demand-driven production leads to a reduction of the required product quantities and only to the production of textiles that are actually used. This avoids overproduction.

Reduce (by Design)

Reduce by design leads to the design of products and services that consume fewer materials per unit of production and/or during their use. “Reduce by design” influences all phases of the life cycle of a product or service. About 80 % of the environmental impact of a product is determined already in the design phase [227]. The design defines functionality, material, construction and finishing. This influences longevity as well as separability and recyclability. Today, information is not readily available, but must be collected, linked, and evaluated from the various fields (see also Need 1.33). The activities of the EU Commission are to be taken into account here.

Need 6.3: Data basis on maintainability, separability and recyclability for material selection/use – material index
Most textile products are made of a mix of materials. Basically, the more different types of fibres are combined, the lower the separability and recyclability of these textiles and the

care is negatively affected. A database on the separability and recyclability of fibre combinations of all kinds can be helpful here. A standard can, for example, specify which fibre combinations exhibit both high separability and recyclability and easy processing (washing, care, repair) according to the current state of the art. Such a standard can also list new types of fibres that have certain properties as monomaterials – which today are usually only available in material combinations. In this context, the different recycling processes depending on the fibre combination can also be mentioned, so that responsible product designers can also take this aspect into account when making their design decision. If, for example, the product designer is aiming to produce a textile that is to be recycled in a closed loop, the standard can be used to provide an overview of which fibre combinations are suitable for this. An extension to the aspects of joining techniques as well as components and accessories is possible.

Need 6.4: Extension of chemical management to include closed-loop aspects – Chemical index

Chemicals used in the manufacture of textiles and products must comply with the Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) regulations [73] currently in force in the EU. Companies importing products to the European Economic Area are required to exclude substances listed in a Restricted Substances List (RSL) [228] drawn up for this purpose. Up to now, the assessment has mainly considered environmental compatibility, safety, health, etc., but has not looked at the recyclability for the finished product, including the chemicals. The current regulations for chemicals need to be comprehensively expanded to include aspects of the Circular Economy (see also Note to Policy-makers: use of recyclates and compatibility with application-related limits for harmful substances).

Note to policy-makers: So far, REACH does not cover the aspects of the Circular Economy. Chemicals used in a product can accumulate in recycled products through repeated recycling processes and lead to environmental and health hazards, which must be avoided. The RSL for REACH should be expanded to include recyclers' raw material requirements so that there are automatically no chemicals in circulation that could interfere with the recycling process.

Need 6.5: Clustering of product groups

Before criteria and parameters can be established to define the topic of longevity, a meaningful clustering of textiles must take place Work clothing that is exposed to heavy mechanical stresses and considerable dirt and/or serves specific protective purposes must meet different criteria than everyday clothing, which is generally only exposed to low levels of stress (see also Need 1.1).

The following points, among others, should be considered: Type of fibre, type of textile fabric (knitted fabric, woven fabric, etc.) and weight per unit area, finishing of the textile, type of finishing (sewing, welding, etc.), ingredients and accessories (buttons, zippers, etc.), area of application (e.g. everyday, haute couture, home textiles, work clothing, PPE, footwear …) and processing parameters (washing, cleaning, drying).

Need 6.6: Definition of longevity for product groups (longevity index)

Longevity as a sustainability criterion for textiles depends on numerous factors, e.g. production, area of application, service life, durability, and many more, as well as the business models used. Textiles in rental and leasing systems today are already designed to last and withstand intensive care. Here, longevity is a decisive, sustainable as well as an economic criterion. Textiles in the classic B2C sector, on the other hand, are today often only used for a short time.

A longevity index could be used to evaluate products for their longevity and provide customer transparency for purchasing decisions and potentially regulatory requirements.

Need for research: Further insights in the area of influences on longevity through material selection (Which materials, fibres, threads, construction, sewing ingredients influence longevity?), chemicals (finishing) (how environmentally friendly are the chemicals used/how harmful are they?), business models, product attributes and services that contribute to emotional longevity, and care (which care has a positive impact on the life cycle?) are needed. Furthermore, "emotional longevity" is an aspect that is hardly considered today. Methods for determining individual properties that are necessary for statements on longevity already exist (such as abrasion resistance of a textile DIN EN ISO 12947 [229], DIN EN ISO 9073-4 [230], tensile strength and tear resistance DIN EN ISO 13937 [231] and DIN EN ISO 13934-1 [234] and others). But so far, there are generally no pass/fail criteria that must be met for a product to be considered to have a long life. Also, so far, soiling and its effects are not taken into account. The various influences can complement each other positively or have a negative impact on each other. Due to insufficient data, a weighting of different parameters is lacking so far, so that an easily understandable index could be created to make purchasing decisions more transparent.

Longevity can influence recyclability, but there is also still a large gap in data here.

Need 6.7: Guidelines for design 4 recycling
The EU textile strategy [215] calls for textiles to be fundamentally recyclable. Design guidelines that consider recycling of the product at the product development stage can help answer the following questions at the material selection stage: Which textile materials and components result in the desired property profile? In what way are the possible materials recyclable? Can the materials be recycled in a closed-loop or open-loop process? Defined recycling requirements and standards are needed that can be incorporated into a recycling index so that the recyclability of a product is involved directly in the design phase. Guidelines would provide essential support to designers to realize a circular design and thus a circular product, and could also be motivation to create a more recyclable product. To address these multiple challenges, transparent processes are needed, starting with collection and sorting for the recycling process and ending with product labelling via the DPP.

Note to policy-makers: One hurdle for the realization of the requirements for the Circular Economy is that the know-how for the Circular Economy has not yet been taught in the training of textile professionals. Changes and investments in training and skilled workers who can map textile and, based on this, environmental issues in combination with economic issues are necessary.

Need for research: Expand research into the application of textile fibres and fabric constructions that improve design qualities to enhance, recycle and reduce materials available in the marketplace while making information more digitally transparent and enabling more efficient use of materials using overarching software.

Need 6.8: Definition of quality requirements and standardized test procedures for a quality index
Materials, components and sewing ingredients not only determine the structure of the value and supply chain, but they also offer the possibility of keeping textile products in use for longer, increasing their service life while making them easier to repair. In order to increase the longevity and thus the quality of garments, the various stakeholders (brands, manufacturing companies, labels, etc.) have so far defined quality requirements for their applications [235].

Quality requirements can be investigated with test standards that specify the test methods; to date, there are no generally applicable minimum requirements for properties. Quality requirements assessed and compared against a set minimum value could help define the closed-loop quality of a textile product, set specific targets, and thus prevent low-quality textile products from entering the market.

Due to the diversity of products, the minimum requirements for the individual quality standards of the circular total quality index must be adapted for each product group and/or function of the product (see also Need 1.2).

Need 6.9: Evaluation criteria of longevity in relation to other sustainability criteria
A product made from a durable synthetic fibre (e.g., petroleum-based) is not necessarily the more sustainable product (keyword resource crisis and microplastics due to abrasion). Longevity must always be set in relation to other sustainability criteria, such as recyclability, biodegradability, carbon footprint, and evaluated accordingly.

Need for research: Longevity can affect the separability and recyclability of textiles. To date, there have been no systematic studies in this area showing the relationships between longevity and recycling and the quality of the recycled material.

Reduce

In general, “reduce” is about reducing the (consumption) resources used to manufacture and supply the required semi-finished products and textile products. This includes raw materials (here: polymers, fibres, chemicals, ingredients, etc.) and energy (incl. water). Material and energy sources are either fossil, non-renewable or renewable resources. Mineral fibres or metallic raw materials are not explicitly considered in the following, nor are auxiliary and operating materials.

Material efficiency involves, among other things, the use of virgin materials, recyclates and appropriate blends, always while maintaining the required product functionality and quality. Energy efficiency is predominantly about optimizing manufacturing or production processes.

Raw materials are essentially fibres that are typically processed into yarns in a spinning mill. Very often a wide variety of fibres are mixed in the process. Furthermore, polymers are involved (in the form of granules or similar). These are typically extruded into (continuous) filaments (and thus into continuous man-made fibres) in the primary spinning mill or used directly for nonwovens production.

Both fibres and polymers can be virgin raw material or recycled raw material. Recycled raw material comes either from the textile cycle or from other cycles (such as r-PET from PET bottles). Another characterizing feature is renewability: Natural fibres are typically renewable, while synthetic fibres, which are made from petroleum, are not. Regenerated cellulose fibres (such as viscose) are made from cellulose (e.g. from wood) and are thus of renewable origin.

Furthermore, scraps and waste from semi-finished products can flow directly back into the cycle, such as yarn scraps directly back into the spinning mill or textile process waste for use in other textile products.

Basically, the manufacturing processes considered here include (1) fibre production and processing, (2) thread/yarn production and finishing, (3) fabric production and (4) finishing, and (5) garment production and finishing. Polymer production and logistics processes are currently not explicitly taken into account.

For closed-loop considerations, the downstream "processing stages" – i.e., after product use, collection and sorting, disassembly, mechanical recycling, and chemical/biological/thermal recycling – must also be considered from a material and energy efficiency perspective.

An important definition is that of the functional unit (kg of yarn, m^2 of fabric, garments, etc.)

Another important aspect is data quality or data accuracy: Is the data measured, real individual data from which an actual report can be created (report, ex-post), or is it extrapolated, (more or less) estimated, averaged, assumed, simulated or similar realistic data taken from the literature that can/should be used for scenarios and for decision support in design and process design/planning, i.e., ex-ante? Such ex-ante information is also important for (textile) mechanical engineering in order to optimize machines and plants in terms of material and, above all, energy efficiency.

Need 6.10: Methods for determining and identifying recyclate content and sources in semi-finished products and products at batch level, etc.
Standardized formats are required for specifying the recycled material content and source in order to provide comparable information on the content. It may be useful to show the sources of the recycled content as well. This requires standardized designations for process stages. It would be useful to establish methods for determining the recycled content. This can answer questions such as: How much (in quantity %) recyclate is in this material/product? What type of recyclate (such as rPET? r-fibre)? Are they recyclates from production waste and residues or overproduction ("pre-consumer waste") or utilization waste ("post-consumer waste")?

For recyclates to be used, there must be collection and "manufacturing" of sufficient or large quantities of recyclates. For this purpose, factories with corresponding plants and machines must be built and the necessary (logistics) infrastructure must be established (keyword "recycling hubs" by EURATEX [237]).

Note to policy-makers: According to the European Textile Labelling Regulation [238] and the German Textile Labelling Act [239], only the indication of the fibre materials is required so far. This hinders the use of recycled materials. Therefore, labelling of the recycled content would be necessary. Additions to the labelling, such as showing the amount and source of recycled material, the percentage of renewable raw material, and notes/references for reuse and recycling, would be useful.

Need for research: Systematic knowledge is required as to which recyclate quality and which blending ratios can be used to achieve which yarn or thread qualities. Furthermore, it must be investigated whether previous fibre parameters are also applicable and sufficient for recycled fibres.

Need 6.11: Measurement or determination of consumption data and product components
Life cycle assessment (LCA) is a way of recording and evaluating the environmental impact of products, for example, over their entire life cycle. For this purpose, a cross-media consideration of all potential harmful effects on the environment and all material streams associated with the product under consideration is carried out. All stages from raw material extraction to production, application and use, waste treatment, recycling and final disposal should be considered. The aim is a holistic presentation of the ecological impact.

The procedure for preparing a life cycle assessment and the requirements for a life cycle assessment are defined by the standards DIN EN ISO 14040 [80] and DIN EN ISO 14044 [81].

Currently, the use phase and, in part, the end-of-life (EoL) phase can only be codified inadequately. What is meant by this is that it is a challenge to describe usage behaviour or even the different cycle management options in data models. If, for example, one wants to make statements at the "beginning of its life" about the environmental impact of a product which arises during its use and EoL, suitable methods are lacking here.

Information on LCA analyses is often not clearly communicated, so that in case of doubt, "false" expectations are created. Especially the comparability of LCA results is often misjudged here – if LCA results are based on different methods and approaches, the results are not comparable! However, it should not be underestimated that environmental assessments (LCA, HotSpot Analysis, etc.) can very well be helpful as internal decision support for improvements or changes in product design, e.g. in development teams within a company. Existing standards should be reviewed to see if requirements for better communication can be incorporated.

The core question is how material and energy consumption data, as well as product components are measured or determined.

Need for research: Development of a simplified LCA "LCAlight" or a corresponding standard to achieve easier handling for SMEs already during product development. Development of methods to calculate/determine ex-ante values of material and CO_2 quantities (extrapolation, estimation, screening, simulation, scenarios), including for decision support during product design and process planning.

Need 6.12: Calculation methodology and data management

A standardized method, or at least a standardized management system, is required to calculate or prepare the information for the above labelling requirement (see also Need 6.10) on the basis of measured or determined data (see also Need 6.9). At present, planned and actual information on material quantity and CO_2 flows for the above process stages is generally non-existent, inconsistent or impossible to communicate because it is not available. Likewise, the designation or allocation of recyclate quantities from the preliminary materials in the products is unclear. The manufacturing processes are partly carried out with obsolete technologies or machines and equipment. This results in leftover and waste materials and chemicals, as well as inefficiencies in energy and water demand.

One approach would be to align/add material flow cost accounting (MFCA, according to DIN EN ISO 14051 [291]) for integrated modelling, analysis and simulation of material, energy, CO_2 and cost flows in the textile cycle. Thus, a standardized methodology can be created to determine the quantity flow and the CO_2 flow along the textile value chain (and thus across companies) and to make it communicable, both ex-post ("protocol", "report", "actual") and ex-ante ("simulation", "estimation", "scenario").

A second approach would be to supplement the DIN EN ISO 14001 [240] environmental management system with corresponding explanations on the acquisition and handling of data and information for aspects of the Circular Economy – where not already available. Possible aspects are data quality (origin, accuracy, completeness, currency) and appropriate procedures and processes to ensure data quality. The same applies to measurement and test methods, as well as calculation methods (such as the allocation of energy demand to product batch).

Need 6.13: Development of an indicator methodology for products as well as for companies (keyword: traffic light system) with regard to the Circular Economy (closed loop indicators)

How good (or bad) is the textile from a quantity perspective in the cycle as well as complementary from a CO_2 perspective?

One of numerous approaches from science, business and politics is the Material Circularity Indicator (MCI) [241], co-developed by the EllenMacArthur Foundation. This value is determined for a product by entering information such as the proportion of recycled material, reuse or service life ratio using a key figure between 0 and 1. A preparation for the (textile) Circular Economy is currently the subject of research activities of the DITF [242]. The MCI may also require an adapted LCA methodology. Furthermore, assessments are required for the closed-loop capability or closed-loop characteristics of (individual) companies. The starting point here could be the numerous templates for company sustainability reports.

Need for research: Preparation and adaptation of the Material Circularity Indicator (MCI) to textile cycles.

Reuse

Reuse considers the life cycle phase of textiles after the initial sale up to the point at which the product is to be turned into the end-of-life (= utilization phase). In this phase, the aim is to enable the product to be used for as long as possible, so that repeated use and the resulting reduction in newly produced products enable a reduction in resource consumption.

A basic condition for a long product life is good initial quality. In this respect, product design (see section on "reduce by design") also plays an essential role for "reuse", as does the existence of appropriate business models in the use phase (see also Need 1.30).

During the utilization phase, textiles become soiled or can be damaged and therefore need to be processed before being used again. This is done by consumers or service providers with professional preparation and care of textiles (e.g. dry cleaners, ironing and mangling shops) as well as other service companies in the field of dyeing, re-impregnation of textiles with existing or new business models. In some areas of use (e.g. protective masks and gowns, surgical textiles, hand drying), reusable textiles are an alternative to single-use products on the market. Reusable products can be strengthened with product standards in such areas of application and strengthen already existing business models for textile multiple products in these areas of use.

Incorrect care can lead to a reduction in the lifetime of the textile. Gentle washing and cleaning processes can help maintain quality and prolong life. Additives in the processes can help to maintain functions or even to regain functions (e.g. avivages, finishes, re-impregnations, flame retardants, chemical protectors, UV protectors, stain protectors).

Need 6.14: Extension of textile care labelling
Private clothing worn by consumers as well as service providers who care for clothing such as everyday clothing from nursing homes are informed about the appropriate care (such as washing, cleaning and drying processes) via labels on the textile and by means of the care symbols according to DIN EN ISO 3758 [243]. So far, there is a lack of data on the number of washing cycles with which a textile can be washed without loss of quality. Product- and material-related tips for gentle care would help to extend the utilization phase [244].

Note to policy-makers: One obstacle is that textile care labelling has so far been voluntary and therefore sometimes lacks important information for consumers and service providers. Therefore, a mandatory requirement would help to ensure that all information is always available.

Need 6.15: Additional standards for various care and reprocessing procedures
Workwear can be reprocessed according to procedures for professional reprocessing (see DIN EN ISO 15797 [245]). Textile manufacturers for leasing and rental services test the quality of textiles before launching them on the market, using a realistic number of washing cycles and washing conditions. Subsequently, material tests (e.g. tensile strength, colour change, dimensional stability, etc.) are carried out, which can provide information on the quality of the washed textiles. Such extensive testing is not common for garment textiles. For workwear and protective clothing, DIN EN ISO 30023 [246] provides a system of graphic symbols covering the marking of workwear and protective clothing with information relating to suitability for professional industrial laundering in accordance with DIN EN ISO 15797 [245]. In the field of professional cleaning, there are also various test methods for evaluating dry cleaning and wet cleaning (see DIN EN ISO 3175 (all parts) [247]), in which particular emphasis is placed on the life cycle extension measures of textiles.

For privately used textiles, further product information (in addition to the above-mentioned textile care label codes) can help to optimally reprocess the products. Irrespective of this, possible (negative) interactions during care should already be taken into account in the design phase and in the selection of the various materials of the product (see section "reduce by design") and this information should be included in the DPP.

There is a need for standards for environmentally friendly washing and cleaning processes, for environmentally friendly (stain) solvents or even finishing chemicals, and for re-dyeing of textiles for the textile product groups.

Need 6.16: Promotion of rental and leasing systems
Rental or leasing systems are based on the "purchase of services". The ownership of textiles remains with the producer or the rental company, which, as part of their services to the customer, ensure the functionality and quality of textiles and clothing for the agreed warranty period. Rental systems include: rental, pay-per-use and product-as-a-service (see also Need 1.30). These systems can be applied to business customers and individual customers.

Leasing textiles are characterized in particular by high durability, consistency of fit and colour fastness, but also maintainability, because the frequency of use cycles is crucial for economic success. There are a large number of individual test standards for these product properties (see Chapter 1.6.2), which today are mostly only applied to new products or the starting material, and in some cases after ageing or a certain number of washing cycles.

In the field of workwear and commercially used textiles, business models in the rental service or leasing have been established for several years. For these business models in the B2B sector, there are already existing methods and standards in some product areas (see Chapter 1.6.2), but these need to be significantly expanded in order to extend the service life of many textiles, especially for privately used clothing.

Need 6.17: Specifications for the description/labelling of textiles for the second-hand market
However, a change of ownership can also contribute to the extension of the usage cycle if the initial purchaser no longer wishes to own/use the textile. Approaches for corresponding business models already exist for this as well.

Second-hand use involves a transfer of ownership of textiles, and the products are resold. Compared to the rental models, this business model could be used in particular in the private sector for “normal everyday clothing”. The purchase should be combined with an examination of the current quality of the second-hand textiles before resale. Buyers and resellers of these products sometimes lack information about source materials and condition of use of second-hand goods. Here, the DPP (see Chapter 3.3) and, if applicable, standards for a condition assessment of the product (see Need 6.8), manufacturer information on the number of possible washing/cleaning cycles could help to promote and enable secondary use.

Need 6.18: Non-destructive methods for condition assessment of used textiles
Systematic quality assurance could increase consumer confidence in the purchase of used textiles and thus be a means of significantly expanding the scope of this market. Quality properties are partly determined with destructive tests; here there is a need for non-destructive methods for the quality assessment of used textiles [248], [249], [250]. Even though the systematic introduction of quality assurance measures for second-hand textiles will lead to additional costs, these can be compensated by a substantial expansion of the second-hand market (see Need 1.2).

Need for research: Development of non-destructive test methods is necessary to make an objective condition assessment and quality assessment of used textiles.

Repair

It is imperative to increase and support the repairability of textiles as part of the shift to the Circular Economy, because this contributes significantly to extending the life of textiles and thus saving resources. This requires an expansion of repair services. Standardization can support this process:

Need 6.19: Define standardized product information about spare parts
Repairability requires the production and distribution of spare parts (new or discarded products) and the provision of information on their availability (including on digital platforms).

Currently, only a few textile manufacturers produce spare parts in addition to the ready-made product and also sell them separately. This business area is of core importance for textile repair and alteration services. One particular problem is that it is often not clear where which spare parts can be found or which textile materials were used in the original product, so that appropriate fabrics could then be identified for repairs.

Need 6.20: Definition of repair or spare part requirements as well as standards that can be included in a repair index (repair index)
Consumers who own a valuable garment usually want to keep it as long as possible and would most likely be willing to repair it in case of a (minor) defect. This, in turn, would increase demand for repair services. Retailers could offer repairs and other services in their stores and partner with providers of repairs and remodelling in local communities. Several brands already offer in-store repairs and incentivize users to keep their garments in good condition, especially outdoor clothing brands.

Note to policy-makers a: Extend “right to repair” [251] to textiles and advance its practical implementation (see Need 1.35). Even if standards on repair requirements were available, implementation is hampered by the voluntary nature of the standards application, as all activities to expand repairability are an additional cost.

To be able to repair textiles, spare parts must be made available and this is rarely the case today. Manufacturers could make spare parts available for a minimum number of years after the product is sold, or provide information on where consumers can obtain appropriate spare parts. Even if standards were available for repair, implementation is hindered by the voluntary nature of standards application.

Note to policy-makers b: Obligation of the garment manufacturers to stock spare parts, to make them available or to inform about suitable sources of supply.

Note to policy-makers c: In addition to reducing the cost of repair and alteration services for consumers and the "right to repair" for textiles (see Note to Policy a), there is a need to strengthen the craft as an attractive profession (see also Need 1.36) and to expand training opportunities for textiles (see also Need 1.37).

Need 6.21: Identification of repairability
Standards must be drawn up that specify, for example, how a textile product must be marked so that it can be repaired in the best possible way. The question of what types of repairs are appropriate can also be addressed. Likewise, product (group)-specific standards can specify how a product should be designed to ensure the best possible repairability (design 4 repair).

Recycle

Material recycling is preceded by collection and sorting as necessary process steps.

COLLECTION OF USED TEXTILES

High material utilization requires well-developed and easy-to-use collection systems. For all used textiles that are not collected by type, sorting is also necessary in order to reuse or recycle the collected materials. A distinction must be made here in the private sector, for which an almost nationwide depot container collection system for used textiles (as a collection mixture) is available in Germany today. There are a wide variety of collection systems and solutions for used textiles from other sources, such as industry, commerce, trade and administration [252].

In the process of disposal of used textiles, collection represents an important area. The focus is on collections via depot containers, as more than ¾ of the used textiles in public collections are collected via depot containers [252]. The focus of the collection of used textiles is on safety for the "end consumer" who disposes of the goods in depot containers, prevention of "littering" of stand locations, "information and transparency", protection against wetness, and "material-friendly removal" of used textiles from depot containers so that the highest possible proportion of used textiles can be used for preparation for reuse.

Need 6.22: Requirements for the condition and environment (location) of depot containers
Through standardization, requirements for the condition of the containers and the environment (locations) of the containers should be defined. The goal is to minimize the risk of accidents, littering and robbery. The depot containers must also be protected against the weather and be theft-proof, as well as meeting all safety-related aspects.

Existing working group: CEN/TC 183/WG 1 "Waste containers" [254].

Need 6.23: Uniform marking of collection containers
Standardization of uniform marking is intended to provide citizens with the information necessary for the use and transparency of the collection system and for its acceptance. Important information is especially markings from which it is immediately clear who the collector is (complete contact details of the actual collector incl. the collector's direct telephone contacts; this is also important, for example, in order to be able to contact the collector directly in an emergency). In addition, it must be clearly indicated which used textiles may be placed in the container and in what form (e.g. "clean and packed in bags"). Such marking helps determine that the collection is legal.

Need 6.24: Requirements for the process of removal of the collected goods from the depot containers
The used textiles should be collected in such a way that the highest possible proportion can be prepared for reuse. The initial screening and "material-friendly" removal are of central importance for the entire recycling process, because cross-contamination of the collected material by foreign matter and impurities can be avoided during the subsequent transport to the sorting plant. Requirements for the process are important, for example, by separating waste and other things that can lead to soiling of the used textiles. When taking over the collected goods at the collection point or when emptying the containers, an initial inspection should already be carried out. Obvious foreign matter and impurities are to be removed.

Need 6.25: Standardization/product specification according to sorted collection of textile waste from other sources
Used textiles of commercial or other origins often accumulate only in small quantities, but are sorted by type. Thus, high-quality recovery is possible if the specification of the waste can be specifically defined and named. In this way, “pooling” for sales markets and marketing according to specific requirements is possible. Textile waste of other origins that is sorted by type includes post-consumer or pre-consumer waste as well as production waste (such as cuttings or selvedges).

Material pools can be formed by drawing up product specifications. This can create or expand sales markets for various types of textile waste collected by sorting. Standardization may involve, for example, references to material fraction, textile composition/components, origin, purity and delivery form (see also Need 5.11).

SORTING OF USED TEXTILES

For all used textiles that are not collected by type, sorting is required that meets certain quality criteria and product specifications as well as the waste hierarchy.

At the same time, the process of sorting can be very different. While in some plants very differentiated sorting is carried out, in other plants only a rough and superficial pre-sorting takes place. Compliance with the waste hierarchy can only be achieved through a process that prepares used textiles for reuse and sorts used textiles that are no longer wearable and marketable into fractions for existing recycling processes.

Need 6.26: Establishment of regulations and criteria for used textile sorting plants
Standardization of regulations and criteria for used textile sorting plants serve as a preparation for the certification of plants according to uniform assessment standards.

Need 6.27: Product specification after sorting of mixed collected used textiles
After the sorting of mixed collected used textiles, there are very many different textile products, but also textile waste continues to be available for further marketing. Standardization is intended to establish a data quality level to define a commodity and, moreover, to exchange information. The main objective here is to ensure that as high a proportion as possible can be prepared for reuse and marketed, and that the remaining quantities are recycled at a high beneficial level (see also Need 5.10). This is achieved through transparency and security.

For used textiles prepared for reuse, quality assurance, wearability, purity and, as far as possible, differentiated and in-depth information about the products as well as the delivery form play an important role. At this point, reference is also made to the working document on the revision of the Waste Shipment Regulation [255], in which the EU Commission is to be authorized to develop criteria for distinguishing used goods and waste for certain wastes (including textiles).

For the sorted textiles that are not suitable for reuse, the market for the appropriate recycling methods in each case should be covered by standardization. In the context of standardization, therefore, purity, the tolerated proportion of impurities and substances, colours and delivery form are important in addition to the material fraction.

An example of a specification: DIN SPEC 91446, Classification of recycled plastics by Data Quality Levels for use and (digital) trading [49].

RECYCLING/RECYCLING METHODS

Transparency and origin of recyclates and fibres are to be observed according to the German Supply Chain Due Diligence Act (LkSG) [256] and are to prevent greenwashing. In order to map the heterogeneous recycling market for textiles, meaningful data and a uniform language are required. A uniform, standardized categorization of waste that can be further used as a secondary raw material is needed.

The preparation of information regarding the starting material is essential for further processing, but also for deciding through which recycling process (e.g. mechanical or chemical) the material is recovered for reuse as a raw material. While chemical recycling achieves a comparable output in terms of quality, mechanical recycling involves a downgrading of quality by shortening the fibres. At the same time, however, the consumption and use of resources for material preparation must also be taken into account.

Materials can be closed loop through the various recycling technologies or leave their own product loop (open loop). There may be economic or technical reasons for this, for example if the quality of the recyclate no longer permits its use in the closed loop. The aim, however, is for the loops to be largely self-sustaining through the materials already in circulation. A product entering the open loop, which could be continued in the closed loop, is to be avoided, provided that ecological and economic aspects are not in complete contradiction.

The availability of information on these topics, as well as education on possible recycling routes and the application options of recyclates and recycled fibres, are key to a high-quality holistic reprocessing system. A network should be established to facilitate access to this information. One example could be EURATEX's ReHubs initiative [237].

Need 6.28: Definition of permissible materials and verifiable information as "recycled content"
Various starting materials can be used for the use of recyclates and recycled fibres. From the textile value chain, this includes (cut) waste from production (post-industrial waste), as well as collection surpluses, faulty production, returns (pre-consumer waste) and used textiles (post-consumer waste), insofar as this waste can be reused or recycled.

It is important to create a demarcation and define from which material streams recyclates and recycled fibres can be termed "recycled content". A self-contained recirculation, such as roving/pre-yarns from the spinning process, which are directly recirculated in the same process and therefore reused, should be distinguished from this. This should prevent greenwashing.

Note: Recycled Claim Standard is an international voluntary standard for textiles with a minimum of 5 % recycled content.

Global Recycled Standard is also a voluntary standard for textiles with a minimum of 20 % recycled content [267].

Need 6.29: Establishment of criteria and definitions for the traceability of material streams
Determining the recycled content or the history of a recyclate or recycled fibre is not possible according to the current state of the art. Therefore, there is an increased need for transparency or traceability of the material streams to make a plausibility check possible. If recycled mechanically, the fibres are very shortened. But new, original fibre material is also shortened as it passes through the various processing steps to become yarn. In chemical recycling, the material to be recycled is transformed back into virgin fibre material through a transformation process. According to the EU Textile Strategy [215], textile products should be recyclable and contain recycled material in equal measure from 2030 onwards, in addition to other aspects. This means that market participants will strive to meet this requirement. Similarly, textiles with recycled fibre content will become more attractive compared to today. In order to close the loophole for greenwashing, the control and transparency of material streams (input = output) is of great importance.

Where the materials come from and traceability within the supply chain should also be considered in this context, with reference to the requirements of the LkSG [256]. Here we also make reference to the DPP, where the information about the origin of the material can be integrated.

USE OF RECYCLATES AND COMPATIBILITY WITH APPLICATION-RELATED CONTAMINANT LIMITS

On 01.06.2007 the REACH regulation [73] was issued by the European Union for the protection of humans, animals and the environment. Companies must identify and manage the risks of the substances and products they place on the market. REACH establishes procedures for collecting and evaluating information on the properties and hazards of substances. In the long term, the most hazardous substances are to be replaced by less hazardous ones. At the same time, however, it should be noted that this regulation does not prevent the use of recyclates and recycled fibres, which are often made from mixed, inhomogeneous waste. In any case, increased contaminant input through the use of recycled materials and recycled fibres should continue to be ruled out; at the same time, excessively high testing and verification requirements should not hinder their use.

Note to policy-makers: Adaptation of the legal framework with the aim of preventing the input of pollutants exceeding limit values, while at the same time not hindering the use of recyclates.

Need 6.30: Determination of the test criteria and the test time for the detection of the potential pollutant input
If recyclates or recycled fibres are produced from used textiles that were manufactured before the introduction of pollutant limits, or from textiles that are only subject to certain pollutant limits, these pollutants may appear as contaminants in the recyclate. Labels (such as OEKO-TEX [257], Green Button [258]) can provide information about past contaminant testing and limits, but it is not known if there was any contaminant input during the use phase. REACH does not include second-hand clothing so far. DIN CEN/TS 16010

[185] and DIN CEN/TS 16011 [186] provide useful guidance on general sampling methods for the testing of plastic waste as a raw material for recycling and recyclates. Reference is also made in this context to E DIN EN ISO 5157 [226], which is currently in preparation, in order to ensure compatibility with the terminology it contains.

Need 6.31: Standards and specifications for the evaluation of textile waste and its recyclates/recycled fibres
The availability of meaningful data, as well as consistent language regarding the generation and use of that data, is important for making waste accessible to a specific, designated recycling technology. Due to the dynamic development of the state of (machine) technology, the specification of this data must be flexible. Even today, required material parameters for different recycling technologies (e.g., mechanical tearing or chemical dissolution) can differ significantly. The tools of standardization should therefore serve to generate information, place it in context, and make it comparable (see also Need 5.9).

DIN SPEC 91446 [49] offers an approach that encompasses all the different types of polymers and is intended to facilitate consistent communication along the value chain, thus spurring the establishment of a Circular Economy for plastics.

The specification deals with quality levels and information that can be provided about the material in question. The more data available, the higher the level (max. level 4). The data are divided into information, properties and optional characteristics of the material. The information category includes details such as the type of material (PES, PP, PA, etc.), colour, recycling methods (which process), information on the use phase already passed or the shape and condition of the material. The properties category contains test data and by which test methodology they were obtained. Optional characteristics are further material properties that may be important for recycling. As this may differ depending on the recycling technology, this information is only optional, not mandatory, and has no influence on the classification into quality levels.

In the field of textiles, however, plastics are only some of the established fibre materials. Consequently, natural fibres do not fall within the scope of this specification. In addition, it is to be discussed whether the catalogue of the respective data for information, properties and optional characteristics for textiles should be further edited or expanded compared to the general plastics trade.

Note to policy-makers: So far, only the labelling of the material composition is mandatory for textiles and information on recycling is not required. This is an obstacle, because at the moment consumers do not receive any information about the recycling method, among other things. Appropriate labelling and information on recycled material in the textile and the recycling method used on the textile can support consumers in their purchasing decisions. In addition, this information can assist contributors to the processing and recycling industry to apply the optimal recycling method for each textile waste product. This also creates transparency for the textile supply chain. The information should be equally incorporated into the DPP.

Need 6.32: Tamper-proof material labelling and marking
Tamper-proof material labelling supports simplification in the separation and recycling process by enabling simple and reliable material identification, thus avoiding costly subsequent analysis.

Need for research: Develop appropriate marking methods for the different types of fibres.

General standardization needs
The general standardization needs described here, “Labelling – sustainability, circularity, and certification” and “Digital product passport (DPP),” impact several R-strategies.

LABELLING – SUSTAINABILITY, CIRCULARITY, AND CERTIFICATION

Sustainability and circularity are not synonyms, but complementary interacting systems that pursue common goals from different perspectives. In order to obtain quantitatively comprehensible foundations for decision-making, various Circular Economy frameworks were identified that take into account a number of specific indicators and metrics. These relate both to sustainability and Circular Economy goals and to key characteristics specific to the industry.

Need for research: The relationship between circularity and sustainability performance needs to be investigated.

While the proliferation of Circular Economy indicators has received much attention, there is still a lack of critical review of combinations of methods that specifically quantify the sustainability impacts of Circular Economy strategies [259]. This is an important prerequisite for creating clarity and a transparent basis on which to build label and certification systems.

Need 6.33: Standardized definitions of terms related to environmental statements
Environmental statements/declarations of conformity/voluntary sustainability seals that refer to environmental or social aspects are only permitted if the issuer is a recognized institute or independent organization, or if they are based on the EU Ecolabel, environmental labelling (DIN EN ISO 14021 [177], DIN EN ISO 14024 [260]) or specific EU legislation relevant to the statement, or if the statement has been independently validated by a third party. The terms sustainability and circularity are often unclear and need to be clearly defined – some labels do not make it clear which sustainability or circularity features the product has (see also Need 1.25). For this purpose, there is a necessary differentiation between sustainability and circularity features without the possibility of verification, with the possibility of verification but without a certificate, and/or with the possibility of verification with a certificate.

Note to policy-makers: Greenwashing is defined as all actions with which companies suggest an environmentally friendly image to the outside world, although they do not work or produce sustainably. Unlike the term “organic” in the food industry, statements such as “sustainable,” “climate-neutral” or “environmentally friendly” are not legally defined for textiles. There are no regulations on what requirements must be met when companies advertise using these terms. Greenwashing can occur through the use of terms that are not clearly defined. Lack of universally accepted definitions hinders sustainability disclosures. For this reason, legal requirements are necessary here to prevent misuse. DIN CEN/TS 16822 [214] and E DIN EN ISO 5157 [267], which is currently being developed, are initial starting points here.

Need 6.34: Establishment of overarching criteria for product labelling that define the Circular Economy framework
The main reason for introducing labelling is to inform consumers that a product has been manufactured in accordance with the vision and/or technological knowledge of the Circular Economy and that this product meets a set of selected Circular Economy criteria. There are already a number of labels. Most of these labels focus on pollutants, materials, production, sustainability and/or social issues. Information on quality of use, service life, repairability, reusability or recyclability is still lacking. A comprehensive and easy-to-understand Circular Economy labelling is lacking so far. The requirements for labelling for a Circular Economy should be defined along the value chain, especially in the design/product development and production phases. This requires transparency across all steps in production.

The following overarching criteria have been identified for holistic labelling: Circularity innovation (business model consideration, R-strategies), product design (eco-design), material use (grade purity), life cycle assessment (LCA), longevity, quality, chemicals, care, production location/site, social and environmental aspects in production, where and how to “dispose” of the textile at the end of its use [268].

Need 6.35: Definition of an overall index (composite index) with variables for Circular Economy labelling
An overall index could be a suitable tool to create a set of indices which are based on standards and are therefore measurable, allowing certification to be carried out. Due to the great diversity of different product groups in the textile industry, an overall index could be practical, as it could be adapted to the product group and/or function. A selection should be made from the overarching criteria of a Circular Economy label to define a set of variables that can be measured based on standards and that can provide clear, objective results. Criteria are, for example, suitable variables for the creation of an overall index (quality index, chemical index, care labelling, repair index, recycling index) [261].

DIGITAL PRODUCT PASSPORT (DPP)

Need 6.36: Information needs of different stakeholder groups
This need is described in the Chapter on the DPP.

Need 6.37: Information needs for different product groups
Requirements according to product group: Product groups such as home textiles, clothing, PPE, medical textiles, etc. have different properties and cannot all be described in the same report. Therefore, there is a need for product-specific reports. The appropriate data fields/parameters for the product group (e.g. fibre quality, ingredients and material mix) should be defined in these reports. The circularity.ID Open Data Standard [262], which is designed for clothing, could serve as the basis for this.

Need 6.38: Interoperability of product and event data, and metadata through a unified ontology/taxonomy
This need is described in the Chapter on the DPP (see Chapter 3.3). Specific standards and specifications that can be applied to the textile industry are listed below. The UNECE has already started to develop traceability standards with the project “Traceability for sustainable garment and footware” [263]. Other de facto standards that should be considered as

a basis are the “Materials, processes & product classification” of Textile Exchange [264], the “GTL Language” of Global Textile Scheme [265], the “circularity.ID Open Data Standard” of circular.fashion [262] and the “Web Vocabulary” of GS1 [266].

Need 6.39: Care instructions for washing machines
Optimal care can help to ensure that textiles can be used for a longer time. Digital and standardized care information on textiles could be read out automatically by intelligent washing machines and appropriate washing programs (domestic and industrial) can be selected (communication between textile and washing machine).

Need 6.40: Data carrier for textiles
In order for the data to be readable by all stakeholders along the value chain, identification numbers and data carriers on which the identification numbers are stored are required.

Standards are required for the data carriers, e.g., those with information on which data carriers are suitable for which area of application. For example, it is of little use when textile manufacturers use QR codes as data carriers if used textile sorting companies or recyclers do not want to use them in terms of process technology because it is not economically viable. Data carriers are therefore required that are machine-readable and, if possible, that can be read automatically in a used textiles sorting system (e.g. RFID). At the same time, optically readable data carriers (e.g. QR, data matrix, barcode) can also make sense, as they are cheaper, do not add any additional materials to the textile and thus do not need to be removed before recycling.

With regard to robustness, standards are required as to how many wash cycles (which wash programme) a data carrier must withstand, depending on the product group (e.g. underwear is washed more often than jackets). The placement of the data carrier can also be important, firstly to prevent consumers from removing them and secondly to ensure that used textile sorting companies can also find, read and, if necessary, remove them. The placement could also be integrated as a data field in the product description. It must also be defined how the identification numbers are stored on the data carriers (e.g., as an electronic product code).

Note to policy-makers: Policy-makers should issue guidelines so that all stakeholders along the textile value chain can adapt to appropriate means of identification and data carriers. Ideally, this should be implemented with technologies that have already been used on the markets for many years. Further, research and development can also help here to develop data carriers that can store unique identification numbers, are robust and machine-readable, and do not contain metals.

2.7 Construction and municipalities

2.7.1 Status quo

The construction sector has the largest demand for resources, it is the largest CO_2 emitter and also generates the largest share of global waste production [342]. The construction sector has a key role to play in achieving climate protection targets at German and European level [343]. The conclusion of the Paris Agreement of 2015 [270] and the binding climate protection targets agreed in December 2019 [3] have tightened the requirements for reducing greenhouse gases at both European and national level. The European Green Deal sees sustainable transformation in the most CO_2-intensive sectors in terms of climate protection, resource conservation, and digitalization as important approaches [2].

The EU Taxonomy Regulation, as a part of the European Green Deal, is a system for classifying sustainable financial products. In this context, pressure is exerted on real estate, as well as on those involved in the real estate industry through the fulfilment of sustainability requirements as well as their transparent disclosure. Among other things, this calls for a life-cycle-based CO_2 assessment of buildings and compliance with and disclosure of certain target values in the circularity of buildings. This is because the sustainable Circular Economy is a key means of conserving resources, including energy (grey energy), raw materials and CO_2 emissions, so that climate protection targets can be achieved. The EU taxonomy therefore specifically requires that percentages be demonstrated in the use of secondary raw materials and/or biotic raw materials. The reuse or continued use of individual components or entire component groups is lacking and must be included [271].

On the one hand, with the help of future standards and specifications, the use of resources must be reduced by extending the service life at all levels (building land, building, component, fastener, equipment, material), and the material/technological material cycle must be promoted with the aim of avoiding waste, reusing components with the highest possible quality and recycling building materials (recycling without downcycling). On the other hand, the existing, overriding challenges, such as the testing/certification/approval of "used" or already installed components/building materials, and the questions of warranty and liability, must be solved through standardization (see Figure 30).

The levels and components of consideration in the context of construction and municipalities are shown in Figure 31. Further, the Figure visually characterizes the terms (components, building components, material, etc.).

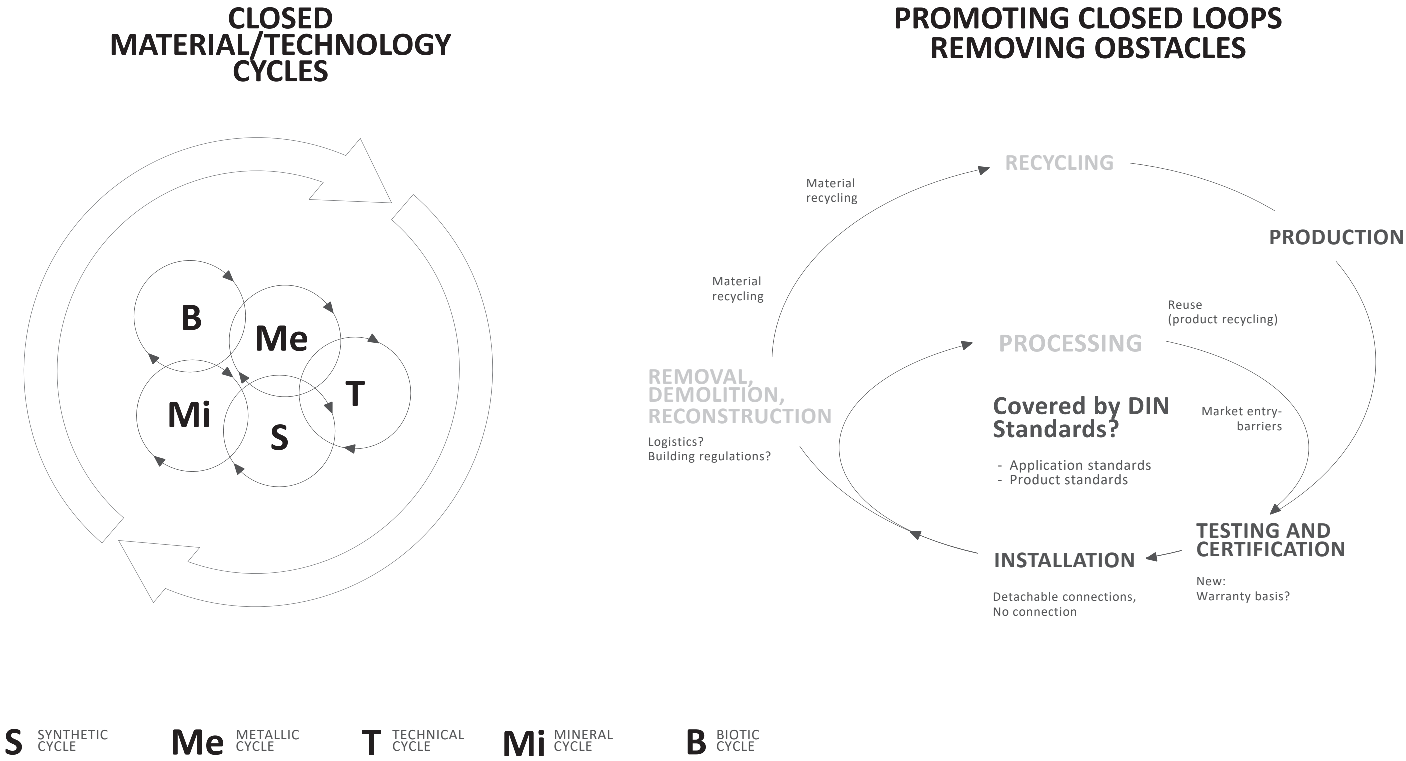


Figure 30: Circularity of the levels of consideration of building materials (Source: DIN)

Evaluation of standards research

In the key topic "Construction and municipalities", the standards research on the Circular Economy (see Chapter 1.6.2) of DIN, DKE and VDI was evaluated on the basis of the nine R-strategies. In addition, the topics carbon footprint and digital product passport were identified. Altogether 432 of 2066 standards and documents were relevant for the topic.

Interpretation

Overall, there are many relevant results for circular construction and municipalities. The majority of the standards are in the area of recycling, a classic area of the Circular Economy, or are generally applicable results. This is followed by standards on the digital product passport in the broader sense, and for recording a carbon footprint. Some, especially higher-value strategies, have little or no results in the set of standards.

Breakdown by product groups and R-strategies

No systematic approach to the Circular Economy is apparent in the existing body of standards; for example, there are hardly any standards on carbon footprint, "refuse", "repurpose", "remanufacture" and "refurbish". The "repair" and "reuse" strategies are represented in isolated product groups. Applications for other product groups are to be investigated. There are a large number of recycling standards in the construction sector, especially in shell construction and dismantling.

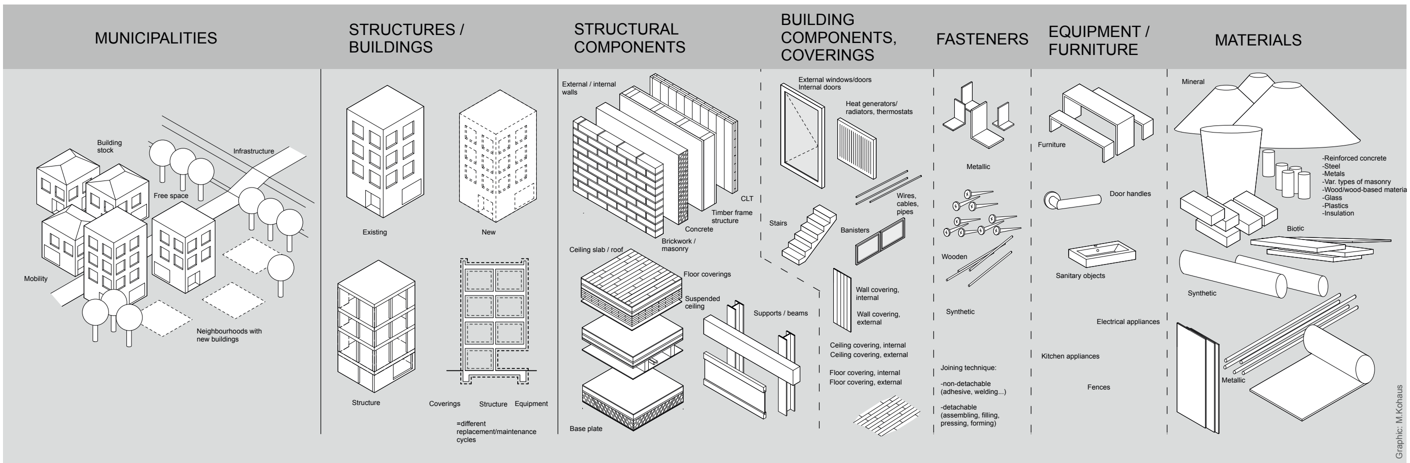


Figure 31: Levels and components of consideration in the context of construction and municipalities (Source: DIN)

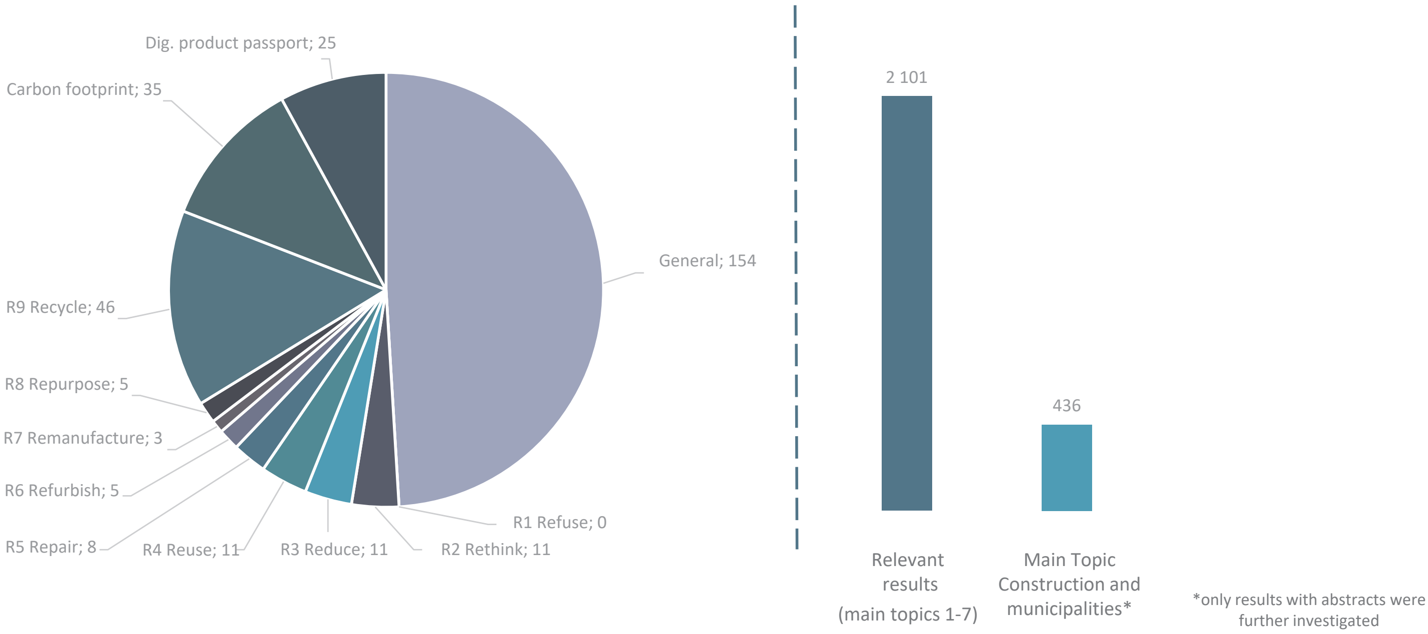


Figure 32: Categorization by R-strategies (Source: DIN)

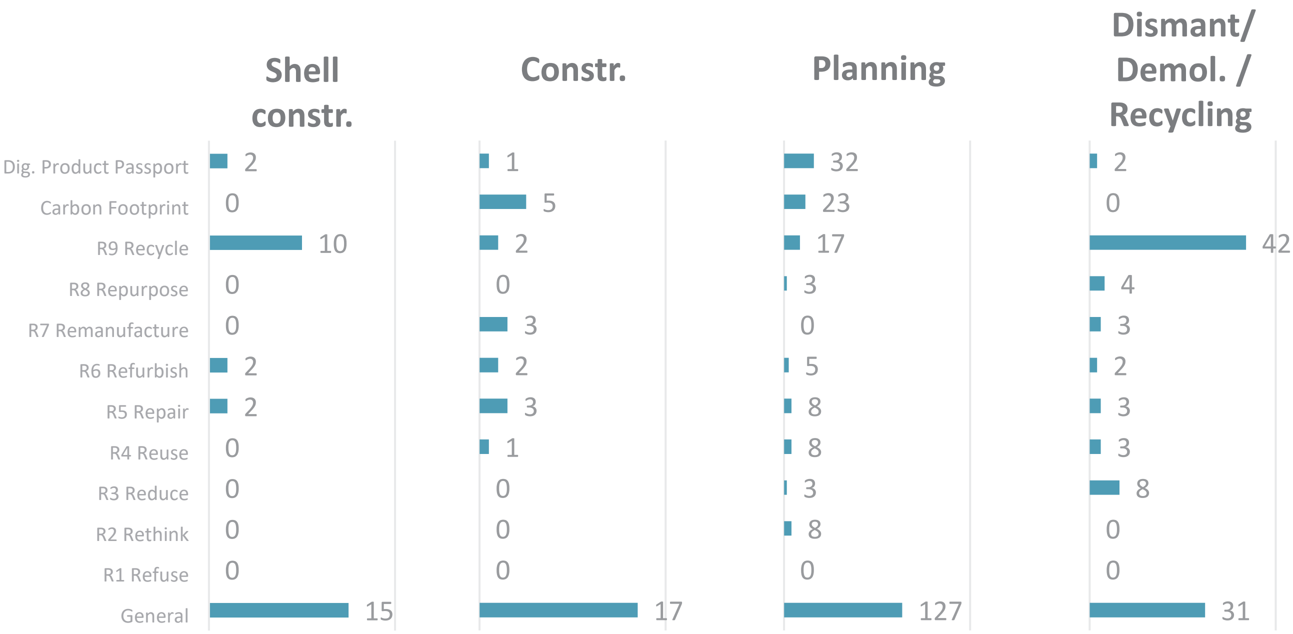


Figure 33: Breakdown according to R-strategies and product groups (Source: DIN)

It should be noted that no consistent process group-specific standardization is discernible in the area of the Circular Economy. Thus: There are many gaps in the standards landscape and a more detailed analysis for circular construction is needed.

2.7.2 Requirements and challenges

The requirements and challenges in the area of the key topic "Construction and municipalities" were developed in the four challenge areas of municipalities, building materials, buildings, and methods and tools, and are described below. The standardization needs identified are then listed in a structured manner according to the R-strategies.

Municipalities

In Germany, the municipalities are usually responsible for the tasks of providing public services and thus make decisions independently. Therefore, legal regulations and standards in the areas of services of general interest relevant to municipalities can only provide a framework. The municipalities themselves decide on the details. Large municipalities tend to have good knowledge of the various stakeholders needed for the Circular Economy and are usually involved in networks to initiate and drive the Circular Economy. Medium-sized and small municipalities often lack the human resources to deal intensively with these issues. The goals of the European Circular Economy are: Increase resource efficiency, stop biodiversity loss, de-pollute the environment and create jobs. The global issues of our time are also forcing local municipalities worldwide to set out on the path to becoming a "sustainable community." Cities and municipalities have mostly committed to the 17 UN Sustainable Development Goals [203]. The Circular Economy plays a central role in SDG 12 [203] "Sustainable production and consumption". Digitalization is a supporting instrument of the Circular Economy. The concept of a smart circular municipality focuses, among other things, on digitally supported circular concepts including building data modelling and digital systems in neighbourhoods (holistic digital transformation process (smart city)). From a technical and economic point of view, digitalization can help to make processes in the various municipal fields of action, such as energy, mobility, infrastructure, supply or buildings, more efficient and, above all, to think in a more integrated way. Initial steps can be tested in neighbourhoods. Through forward-looking neighbourhood planning (the neighbourhood of short distances), supported by digital neighbourhood systems, the transformation to a circular neighbourhood, which is CO_2-neutral, for example, by means of regenerative and integrated energy systems as well as intelligent mobility solutions, can succeed. A central theme of a circular municipality is sustainable (multifunctional) land and building management. Public relations work on sustainable consumption and participation in Circular Economy planning and projects should accompany the process. Know-how and personnel must be trained and available for the targeted Circular Economy. It can be said that the role of the municipality in the Circular Economy is very versatile – the municipalities are initiators, coordinators, implementers, financiers and companions of Circular Economy measures. The influence of municipalities on the Circular Economy through their statutory rights is far from exhausted. In addition to concrete needs for standardization, the following challenges and requirements in the context of municipalities were also discussed during the development of the Standardization Roadmap, but no concrete need for standardization could yet be formulated.

The collection and reuse of recyclable materials and products should already be reflected in the planning processes of urban neighbourhoods by considering optimized collection systems or spaces for sharing/repair in the planning. This leads to an increase in the quality of the residual material composition through optimized collection systems. In addition, repair services, e-charging, maintenance, cleaning, etc. can be integrated into mobility stations.

A recurring problem in many places is the quality assurance of knowledge. For this, the municipality needs digital evaluation tools. Digital platforms as an information and exchange platform with an evaluation matrix for corresponding content help to build up knowledge and experience quickly and extensively. The Circular Economy must be included as a criterion in planning processes in order to strengthen them in planning consideration processes. The Circular Economy must be incorporated into climate protection, energy and mobility concepts and into regional and urban planning.

Regional resource, circular and material flow concepts can be developed in regional nodes. In addition to identifying (secondary) raw material needs and potentials, and coordinating with circular business establishments, a common logistics, collection and sorting infrastructure can be established in the area of reuse. In addition, community guidelines and circular targets, including resource reduction targets, should be established. Municipalities must use formal and informal planning tools to promote the Circular Economy. Together with the regional nodes, these two plans are important for the implementation of the Circular Economy in municipalities and regions.

Waste incineration plants represent a major investment and are an important municipal infrastructure measure. Should waste volumes reduce drastically in the coming years, an exit scenario should exist at the regional level that provides for municipal compensation and promotes the use of alternative renewable energies in the heating sector. In parallel, the development of a new collection infrastructure for reusable and recyclable products, as well as infrastructure projects to prepare for reuse or material recycling, must be established at the municipal and regional levels. In this context, criteria for phase-out scenarios should be developed at the regional level and anchored in standards, and regional cooperation should be promoted.

The Circular Economy should be integrated as a building block in sustainable municipal procurement. For this purpose, a catalogue of criteria/guidelines for the qualitative assessment of circularity would be useful. Tendering itself should also be standardized in form and content. The Circular Economy should be a permanent fixture in all municipal plans. For a uniform application and assurance of the qualities, actors in the municipalities must be trained accordingly.

One tool to promote land recycling of unused or underutilized land and real estate can be digital land passports. They create transparency regarding the framework data of the land and show the development potential. In addition to information relevant to real estate, data relevant to contaminated sites, etc. is also recorded so that potential investors can access these sites as quickly as possible. In the new development of industrial parks/commercial areas, care should be taken to ensure that one company's residual materials are another's basic materials. Furthermore, reverse logistics and waste heat and thermal potentials can be coordinated.

The previous distribution of goods can be controlled in terms of time and space. If, in the future, products are reused, repaired and refurbished several times, neither the time of collection nor the transport route can be predicted and thus calculated. This means that a change is required in the way waste is recorded and collected compared to the previous method – reverse logistics. Since transports are also associated with emissions, these must be optimized. This makes clear the urgent need for new collection concepts. This will only succeed if material and substance streams are taken into account in municipal mobility concepts.

The current waste management concept will exist in addition to the transition to the Circular Economy. This applies in particular to the planning/maintenance and operation of infrastructure measures and to logistics. In this context, synergies must be leveraged and system alternatives examined within the framework of municipal/regional Circular Economy concepts.

Building materials
Construction and civil engineering (including operation of buildings) accounts for 70 % of all land change, 50 % of resource use and 40 % of energy consumption and greenhouse gas emissions [344]. Therefore, resource-efficient construction under the ecological aspect of saving resources is one of the major key topics. Sustainable solutions not only for reducing the need for resources, but also for closed material cycles, are thus increasingly coming into focus. The main objectives are to reduce the use of raw materials in new construction, to extend the service life of the building through sustainable use and upgrading of the existing building fabric, and to reuse the components and materials recovered during conversion and demolition. The challenge is that requirements or future standards to strengthen the Circular Economy are difficult to integrate into existing standard structures. Parallel standard structures lead to an increased effort and reduce the acceptance of the overall concept.

The European Construction Products Regulation EU 305/2011 laying down harmonized conditions for the marketing of construction products takes Circular Economy into account in Annex 1, No. 7 [272]. According to the Regulation, the essential characteristics of sustainability are reusability, recyclability, durability and use of recycled materials. In the future, the standardization task may consist of defining product characteristics that contribute to achieving these essential features. For these product characteristics, where the Regulation is relevant, test criteria as well as the designation in levels and classes according to Article 27 have to be established by a delegated act according to Article 60. These criteria are to be specified in the respective product standards in the future. This standardization task has not yet been undertaken for the essential characteristic of sustainability. There is therefore an immense need for standardization with regard to circular products, as all harmonized specifications could be affected. In this respect, each product standard offers its own possibilities and limits, which are determined not least by the other product characteristics that contribute to the fulfilment of the essential characteristics according to Annex Nos. 1-6 of EU 305/2011. These are mechanical strength and stability, safety in case of fire, health and environmental protection, accessibility and safety in use, protection against noise, and finally thermal insulation. The challenge is to define product properties that are meaningful for the intended application, with associated standardized test methods and evaluation levels.

Buildings
In terms of a resource-efficient and circular real estate economy, issues such as the reuse of the building stock are of high priority. The increasing scarcity of important resources for the construction industry, such as gravel, sand, wood, but also land, further underscores the relevance of reuse. The practical implementation of widespread reuse within the construction industry is failing due to unregulated provisions and the resulting challenges in generating information. The building passport can be seen as an auxiliary tool for recording and collecting information about the building stock or the individual building in its as-built form. The basic idea of the building passport is to collect and bundle all relevant information about the building and its components. This information can be used at a later point in time, for example at the end of the life cycle, to reuse and recycle individual materials, components or parts, or the entire building as such, and thus keep them in the cycle. In order to build more sustainably in the future, it is not enough to exclusively use resources efficiently and plan new buildings more sustainably. Instead, new construction must become the exception and more intensive work must be done on existing buildings. This must be energetically renovated, further used or converted. For new construction, existing buildings that can no longer be used can form the raw materials warehouse of the future. The recycling of components and materials increases resource efficiency and reduces the use of grey energy.

Methods and tools
Methods and tools for assessing the recyclability of buildings, components and building materials are the prerequisite for the politically desired implementation of the Circular Economy in the construction industry. They must be uniform and standardized. The tools must be readily usable in the planning process to provide robust and comparable results. They must be applicable throughout the entire life cycle of the structure. Furthermore, the methods and digital tools should be accessible to all participants in the construction value chain as cost-effectively and barrier-free as possible and should promote simple construction and serve to support planning. The accessibility and exchange of information on materials is a basic prerequisite for implementing the Circular Economy in construction. The methods and tools to be standardized will initially focus on materials and constructions for buildings. In addition to these aspects, existing tools should be supplemented or others developed in the future, for example to assess the circularity of land, water and energy. In addition, due to the diversity of the existing stock, the considerations within the scope of this Standardization Roadmap

initially focus on the standardization of methods and tools for new construction or additions to the existing stock. These must also be extended when working in existing buildings. Further consideration of the topic should take into account ISO 20887:2020 [273] and, in particular, develop guidance on how to implement the design principles stated therein.

2.7.3 Standardization needs

Some standardization needs can be assigned to multiple R-strategies. Requirements with possible multiple allocations were assigned to the most relevant R-strategy. Therefore, some R-strategies may not be listed in a separate section.

Refuse

BUILDING MATERIALS

Need 7.1: Formulation of standards and specifications that clearly describe the transition from waste to product (end-of-waste) and/or ensure minimum qualities with regard to suitability and warranty
Tenders should take into account as many reused components and quality-assured recycling building materials as simply as possible. Currently, these components or building materials are at a disadvantage compared to standard new products due to a lack of regulations, or due to additionally required analyses, test methods or special knowledge during installation. The disadvantage of recycling building materials must be done away with. Sentence 2 no. 3 of Section 45 of the German recycling act, the Kreislaufwirtschaftsgesetz (KrWG) [175], could be implemented much better in practice if standardized and binding declarations on these product properties were available, referring to harmonized standards according to Regulation EU 305/2011, taking into account Annex 1, no. 7 “Sustainable use of natural resources” [272]. To a certain extent, the acceptance of recycling building materials requires product-specific evaluation standards, which also take into account the rules of marketability of building products on the European internal market.

The prerequisite for this is the need for standardization described in Table 3. The four essential properties of sustainable building products were translated into testable properties and simple level and class systems were proposed for each. The proposals are examples. There is a need for product-specific adaptation and also for supplementation with regard to product properties.

Table 3: A proposal for product properties that contribute to the fulfilment of the essential characteristics of the sustainable use of natural resources according to Regulation (EU) 305/2011

Essential characteristics Annex I No. 7	Product property	Performance of a construction product by level or class Article 27
Reusability	Selective dismantlability	I. Dismantlability A. simple dismantling B. demanding dismantling of e.g. system components C. difficult dismantling of e.g. composite materials II. Recommended reusability check A. Visual check, B. partial repeat of checks according to standards, C. complete repeat of checks according to standards, or D. reuse excluded
Recyclability	Material → Designation Dependent on method → Standard recycling method → Manufacturer take-back → Thermal utilization or landfilling	I. Material designation (e.g. DIN EN ISO 1043 1 [191], DIN EN 10020 [274], wood type, concrete strength class as in Eurocode 2 [275] etc.) II. Recyclability A. Standard recycling method B. Manufacturer take-back C. Disposal or landfill
Recycled content	Mass balance in %	A. 80–100 % B. 30–80 % C. 0–30 %
Durability	Very durable Durable Not very durable	e.g., for components of the shell A. > 50 years B. 20–50 years C. < 20 years

A further obstacle would fall if recognized test criteria for the preference of reused building components or recycling building materials according to Section 45 of the KrWG (German recycling act) were available, and the criteria mentioned under Section 45 para. 2, sentences 1-4 can be evaluated comparatively. This requirement is also possible through the declaration of reusability, recyclability, use of recyclates and durability in levels and classes. Basically, the differentiated nature of the product requirements in Section 45 of the German recycling act still clearly exceeds the requirements of Regulation (EU) 305/2011, Annex 1, No. 7 [176], [272]. The need for standardization outlined in Table 3 is reinforced by the German recycling act.

Closing material loops requires, for example:

- → Product standards as a barrier to market entry, providing information on durability, reusability, recyclability, environmental compatibility and use of recyclates
- → Test standards that allow classification/qualification for the reuse of parts or components
- → Material-specific recyclate standards, with which the procedural processing process is specified and the processing success can be tested. Recyclate standards include test methods and quality criteria for materials that have undergone a recycling process. Regulation (EU) 305/2011 does not provide for this type of standard

Need 7.2: Extension of standards to include dismantling
In the interests of resource efficiency, the preservation of existing buildings is generally preferable to new construction.

Structures built in the future will be designed and constructed with flexible floor plans to ensure that they can accommodate a variety of uses over many decades. In terms of circularity, therefore, there is a need to move away from monofunctional floor plans and buildings. Demolition followed by new construction of structures should be avoided. Exceptions should only be made on the basis of load-bearing capacity and serviceability that cannot be verified (for example, fire protection, sound insulation, vibration). However, the requirement to provide verification implies an obligation to obtain a permit for demolition work, i.e., a departure from the notification requirement in German state building codes. An alternative dismantling must also be justified by a sustainability assessment in which the avoidance of CO_2 emissions, resource conservation, resource consumption by new construction/conversion/expansion, and economic efficiency are each included in the assessment in equal measure, e.g., 1/4 each. In addition, the qualification/training for architects and engineers must be expanded to include the preservation of existing buildings. There is a need for standardization in the expansion of existing standards to include the requirements described and, more specifically, in the standardization of verification and test methods.

Need 7.3: Requirements for building element catalogues according to a uniform classification system

The evaluation of structures can be standardized if uniform classification systems and component catalogues (lists) are made available. An example of a classification is given in Figure 34. The levels are described below.

There is a need for standardization in the definition and description of these five levels, which are described below.

→ The building level: The neutrality of use allows flexibility as well as adaptability and changeability; this means longevity of the floor plan structure. The potential for conversion and additions to existing buildings means conservation of resources and savings in grey emissions.

→ The building component level (e.g. external wall, floor, internal wall, etc.): This level consists of layered groups of building elements. The non-destructive dismantling of the entire (standardized) building component guarantees its reuse elsewhere, in other structures.

→ The building element level (e.g. load-bearing element/structural layer, window, door, sunshade element, etc.): Building elements are comprised of components. Standardized elementization systematically structures the building component and increases reusability. The dismantlability at the component level allows an adaptation to replacement cycles depending on the tectonically detachable element groups (e.g. exterior and interior cladding).

→ The component level (e.g. frame, sill, wood-based panel, fastener, electrical outlet, etc.): Standardization, grade purity, reversible compounds and freedom from pollutants guarantee dismantlability from the component level and subsequent reuse and recycling of the components. Non-destructive dismantling (reversibility) is achieved by means of positive-locking connections.

→ The material level (e.g. wood, clay, concrete, steel, fibres, etc.):

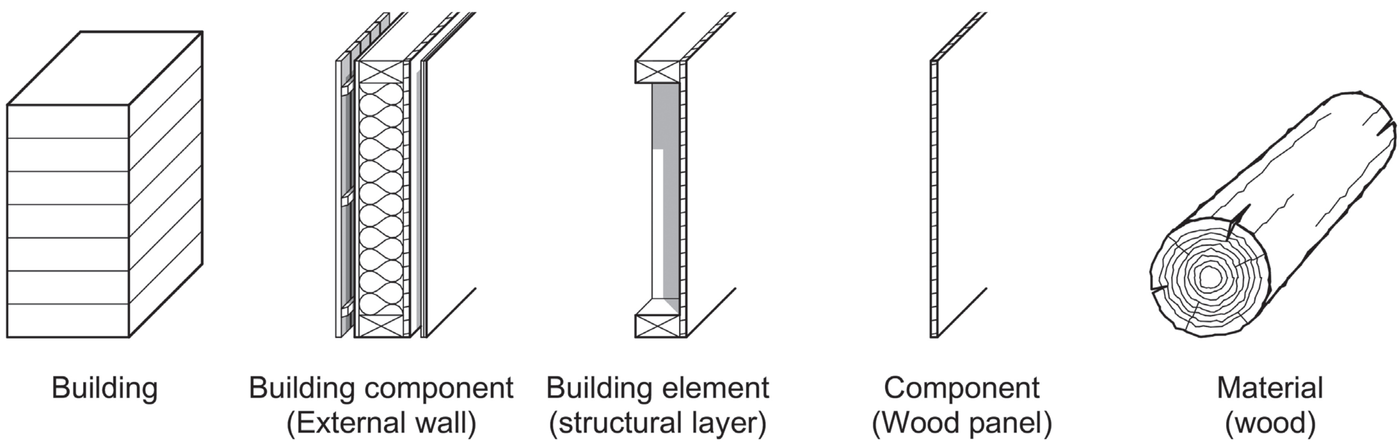


Figure 34: The different levels of recyclability of structures, here using timber construction as an example (Source: Graf, J., Birk, S., Poteschkin, V., & Braun, Y. (2022) [276])

This allows building-related, standardized and reliable assessments of durability, maintenance, serviceability, dismantability, recyclability, and resource and energy consumption (including grey energy).

Need 7.4: Adaptation of existing standards in the context of flexibility of use and longevity
Sustainable construction determines our future because it is climate-friendly, reduces resource consumption and avoids waste. Resources are to be integrated into biological and technical cycles. The linear economy must give way to the Circular Economy. The construction industry is obliged to ensure waste prevention, greenhouse gas emission reduction, and resource conservation. Structures must therefore be designed for flexibility of use and thus for a long service life (> 100 years or more, instead of 50 years as before) which is to be verified in the design and construction. New construction should only be approved if evidence of need is met.

The current life cycle assessment of buildings is based on linear economics (raw material extraction/product creation/construction/use/disposal/combustion (using wood as an example)). This should change based on VDI 2243 [277] taking into account the material cycle – reuse, further use, recycle, further recycle. DIN EN 15978:2012-10 [283] should be adapted to the Circular Economy. CO_2 emissions are to be coupled with resource consumption in a sustainability assessment, and limits are to be set for this in order to avoid CO_2-intensive recycling processes.

BUILDINGS

Need 7.5: Requirements for a building passport
Buildings are very complex and are assembled and operated as a whole from a variety of different products. In this process, the shell components usually remain for the entire life cycle and are at best partially supplemented or replaced. In contrast, the building components of the structural and technical equipment are replaced and exchanged several times, depending on their service life. Therefore, the creation of a building passport or a building certificate is associated with a large number of open questions, which are not covered by national and European standardization. At the current time, there is no uniform procedure for dealing with a building passport. The uncertainties regarding the building passport already start with the definition of the term and thus with the understanding of what the building passport is, what significance is to be attached to it within the building industry, what are the concrete objectives of the introduction of a (mandatory) building passport, and how a building passport is to be created as a result of the preceding, open questions. The content design, assessment methodology, and information gathering requirements are also largely undefined. Without a uniform regulation of the open questions concerning the building passport, a wide and efficient establishment of this auxiliary tool is hardly possible.

The requirements for the building passport correspond in essential points to the requirements for the digital product passport (DPP) The building passport is intended to provide the owners, users, planners and craftspersons in the construction phase, during the utilization phase and at the end of use with information about the type and quantity of products used, the type and extent of their use, the type and extent of resource and energy consumption during production and use, including information on the use and recycling of the respective products and materials (circularity, recyclability) at the end of their lives. A building passport contains the collection of all digital product passports of the building materials and system components used in the building, supplemented by the use-related changes made by the occupants, including possible contaminant inputs.

A particular focus of building passports should be to distinguish between the challenges of new construction and the existing building stock. While in new construction, complete documentation is possible with the delivery of the products to the construction site, in existing buildings, a building passport can only be created and supplemented with the newly added products as part of the stocktaking process during refurbishment and modernization.

Within the framework of standardization, a general definition of the term “building passport” and its contents should be provided in the first instance. For example, the building material passport, the building resource passport and others are integral parts of the product passports and thus of the building passport.

In the medium term, standardized methods and tools for a digital building resource passport assessment should be made available. In this context, the content of the building passport, the definition of parameters for the assessment of circularity, and the modular scope of the consideration both temporally and spatially (temporally, for example, in terms of the phases of the life cycle according to DIN EN 15804:2022, Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products [284], and spatially, in terms of the physical building model) must be defined in particular within the framework of standardization.

Need 7.6: Circular design (modularity, adaptivity and low-tech strategy)
In the course of digitalization and with technological progress, the possibilities for controlling and monitoring buildings and their conditions are constantly expanding. On the one hand, this holds a great deal of potential for reducing energy consumption during the building's utilization phase, but it often presupposes a certain understanding and willingness to adapt usage behaviour (for example, window ventilation) and, in the worst case, can lead to increased energy consumption in the event of incorrect behaviour. In addition, resources are also required for the installed technology, so a consideration must be made as to when this additional raw material use is justified by increased efficiency gains in the utilization phase. Moreover, with the increasing complexity of building technology, interactions are sometimes difficult to predict. In order to keep buildings usable for as long as possible, the occupants' comfort requirements must be taken into account without at the same time overburdening them with increased effort or confronting them with necessary usage behaviour that is difficult to implement individually. The use of actuators and sensors can lead to resource savings in adaptive buildings if this means that the supporting structure uses less material (for example, vibration dampers against wind/earthquakes). A trade-off must be made between the resources required for the actuator/sensor system versus the resource savings in the leaner design.

Modular construction has much potential for the effective Circular Economy through reuse or repurposing of individual modules in other buildings or the same building. However, there is still an enormous need for research in this area, from which a need for standardization may develop in the long term. Here, the following aspects in particular are suitable for standardization.

→ Guideline for comfort requirements as well as updating and anchoring of the criteria, e.g. in the information portal Sustainable Building of the Federal Ministry of Housing, Urban Development and Building (BMWSB) [278]
→ Guidelines for determining real construction needs (functional and utilization requirements), for documenting and making decisions transparent during the planning phase, and recommendations for dealing with conflicting goals (for example, in the form of a decision/evaluation matrix)
→ Evaluation of the complexity requirements of a building and a guide to which cases which technologies/complex construction methods can be applied
→ Guideline for the reasonableness of different technologies for different user groups, as well as definition of requirements for tolerant behaviour of the building as regards misuse and defects
→ Description of how to calculate and evaluate the occupancy costs of a building as part of the low-tech/high-tech trade-off to ensure functional and value preservation

Rethink

MUNICIPALITIES

Need 7.7: Standardized planning, calculation and evaluation tools for municipalities and regions in the transformation to a Circular Economy
The most significant challenge facing municipalities will be the transformation from municipal waste management to a product Circular Economy. Here, the EU Parliament aims for Europe to be waste-free by 2050 and for all products to be reusable, easy to repair, recyclable and free of harmful substances [2]. Since the Circular Economy relies on a circular infrastructure, this continues to be a matter of general interest for municipalities in many cases. So far, there is uncertainty in the municipalities as to what the transformation to circular value creation should look like and what tasks need to be performed. Orientation can be provided here by municipal heat planning, which is currently to be enshrined in law by the federal legislature [286].

This process could be supported by a guide that contains standardized planning, calculation and evaluation tools. This guide should consider all aspects of the Circular Economy, including strategic land use planning and circular land use management, infrastructure measures for reuse and repairability, management of the most volume-significant energy, material and product flows, e.g. in the construction industry, and opportunities for municipal Circular Economy. This guide would show how Circular Economy potentials are to be identified in the municipalities, how networks are to be established or expanded and how the municipal/regional participants in the administration, politics, economy and civil society are to be integrated, which goals can be set and measures derived, as well as how the relevant employees can be qualified. The municipalities and regions should independently determine their raw material potentials, but also their secondary raw material requirements, anchor the Circular Economy in existing concepts and plans and build up the necessary infrastructure and networks for this purpose.

BUILDINGS

Need 7.8: Design and construction principles for adaptive building structures
Since many resources are required for the construction of buildings, it is all the more important to keep the buildings in the utilization phase for as long as possible. In addition to ageing caused by the utilization itself and by environmental influences, changing needs of the users, e.g. due to the availability of new technologies or new legal requirements, are also reasons that make a building unattractive. Currently, conversion and refurbishment measures are often very expensive, so that on the one hand they are delayed for a long time and thus further exacerbate the problem, and on the other hand they are realized by investors who convert the building fabric in a way that generates as much income as possible with as little cost input as possible.

Standardization activities should differentiate requirements for new buildings so that they can be used longer in the future and more easily converted and reused before core renovation or even dismantling is necessary. In addition, guidelines are needed for the conversion and renovation of existing buildings. Since an upward trend in land use per person has been observed for years, further increasing resource consumption, recommendations for land-efficient construction for various uses are also needed.

In this context, it makes sense to draw up guidelines for the development of floor plan and building structures that can also meet changing functional requirements. For this purpose, different utilization classes should be defined (see e.g., the BNB criteria [279]), which provide the framework for general functional requirements and their flexibility. Based on this classification, it would also be conceivable to recommend or even prescribe priority use scenarios of the same class for subsequent use. For example, the addition of loads according to DIN EN 1991-1-1 [280] would be useful, with which the structure is designed for the corresponding use. In this context, criteria for the building's surroundings would also have to be defined for the individual classes so that the location and infrastructure (accessibility of facilities relevant to use) are still appropriate for the same use class decades later.

Criteria for the flexibility of building structures and the separability of interior spaces for subsequent use should also be defined. Recommendations should also be formulated on floor plan structures that also allow for conversion to other use classes with the recommendation that these requirements be considered primarily for these specific buildings. It is also necessary to specify requirements for the building envelope in order to be able to carry out a future building extension easily and, for example, by reusing the exterior walls, as well as to define a flexibility level that should be maintained depending on the building class.

METHODS AND TOOLS

Need 7.9: Define overarching terms, supplement missing terms and harmonize terms already used in standardization
In standardization, many terms already exist on the subject of circularity, which are often used synonymously, sometimes misleadingly, and are blurred. As an example, consider the terms reuse, recycle, and recycled content. The goal of the definition of terms must be that a uniform use of language leads to the establishment of a Circular Economy in which materials circulate in closed cycles in a high-quality manner This also requires the redefinition of terms and a delineation of concepts such as recycling and downcycling. With regard to the definition of material groups, the description and illustration of the materials should allow for the broadest possible application and processing and not be designed for individual areas. For this purpose, it makes sense to have as neutral and clear a structure as possible for the material groups and types in a designation system.

Need 7.10: Harmonization of existing methods and tools
There is currently no standard for the evaluation of circularity. Various methods exist that assess circularity at different levels (building, component, building product, and material levels) and with different indicators. A uniform/standardized assessment of circularity on building, component, building product and material level, as well as building services is urgently needed – also with regard to the presentation of circularity assessments in digital building resource passports.

There are various methods for assessing the aspects in order to be able to assess circularity at the building, component, building product and material levels. Here, too, there are not any standards yet, and thus there is a great need for standardization in order to create an agreed assessment for circularity in construction General requirements to be formulated for methods and tools for assessing the circularity of buildings are, in particular, the input/output option for Building Information Modelling (BIM)-less projects and interfaces to BIM (IFC standard according to ISO 16739-1:2018 [281]), the standardized description of components and materials (e.g. using BIM standards buildingSMART [282]), and an assessment method for the quality of input data.

Need 7.11: Clarification of the interfaces to the building life cycle assessment (LCA) as well as modifications to DIN EN 15804
Since LCA is only suitable to a limited extent for assessing aspects of circularity as well, further assessment methods are required For example, installation, assembly or composite situations are not covered or taken into account by the LCA. However, these are crucial for dismantlability and the assignment of correct possible end-of-life (EoL) scenarios within the building life cycle assessment according to DIN EN 15978 [283] and DIN EN 15804 [284]. That is, a parallel circularity assessment can help to refine an LCA for buildings at the end-of-life (modules C and D [284]). However, DIN EN 15804 [284] must also provide corresponding scenarios for this purpose. For example, there is no scenario for Module D that depicts the reuse of a building product or material. Up to now, there are generally only scenarios for material or thermal recycling. Reuse is not covered. Thus, the benefits of a building product that could be reused could not be correctly represented in a product-specific life cycle assessment (LCA) dataset (EPD) [284] or generic LCA dataset according to EN 15804 [284] and also consequently in a building LCA.

Reuse

BUILDINGS

Need 7.12: Review of normative framework/regulations
In planning, it is legally and financially more advantageous to use new, well-defined materials with a manufacturer's warranty. Reuse is hindered by technical specifications and directives. Components with special requirements are regulated on the basis of standards and specifications via liability law. The Construction Products Regulation is authoritative for regulated construction products. Construction products already in use are non-regulated construction products [272]. They must regain the status of a regulated component through certification or testing in order to be installed. Bricks, for example, must undergo approval on a case-by-case basis in the process of reintroduction, while luminaires must undergo renewed CE or VDE testing to meet safety requirements, protection classes and standards. Thus, second use requires re-testing according to current regulations. Secondary raw materials are only recycled if someone takes responsibility for the required properties and qualities. The implementation of e.g., an approval in individual cases to guarantee properties and qualities exceeds time and financial framework conditions.

It must be clarified whether, which and under which conditions regulated construction products may be newly installed as regulated construction products without renewed testing. Clear catalogues of criteria must be used to create an evaluation basis that favours efficient and economical reuse. Legal, structural and normative framework conditions must be created that reduce the costs of determining and guaranteeing properties and qualities to an acceptable level. Existing standards are to be reviewed and adapted with regard to possible exclusions for the reuse of used products.

Refurbish

BUILDINGS

Need 7.13: Data acquisition on site
The basis for assessing the recyclability of building materials in existing buildings is a comprehensive acquisition of data on site. All materials should be precisely measured, counted, described according to all apparent properties, photographed and supplemented with product and manufacturer information, which is then stored in the building resource passport. The assessment of the existing fabric with regard to structural preservation (e.g. concrete supporting structure) and material preservation/reuse are to be considered in particular. Standards can define criteria for an event-related data collection and the person responsible for it, and a guideline for the collection and evaluation of the inventory (scope, level of detail, content, procedure) can be developed.

Need 7.14: Selective dismantling
Selective, value-preserving dismantling means that previously described building components and materials are removed in a non-destructive manner. They must be packaged and stored in such a way that they are not damaged, their quality is not degraded, and their properties are not altered. A distinction must be made between structurally relevant building components and finishing elements.

Standards can define criteria for the preparation of a dismantling concept for structurally relevant building components and finishing elements, as well as criteria for the further training of dismantling companies on selective, resource-conserving dismantling, and concepts for the collection of usable secondary materials prior to dismantling. In relation to decommissioning and dismantling of renewable energy generation facilities, Need 2.10 in Chapter 2.2 can also be considered.

3 Cross-cutting topics

Work on the Standardization Roadmap has shown that there are the following five essential cross-cutting topics that cannot be assigned to any key topic alone, but must be discussed in a broader context: sustainability assessment, life extension, digital product passport (DPP), end-of-waste (EoW) and recyclability.

It is worth noting here that the cross-cutting topics identified are not predetermined topics, but rather have emerged from the work and discussions in the individual key topics. Thus, a cross-cutting topic can be understood as a focused view on the respective key topics. However, the goal is not to identify fundamental needs related to the cross-cutting topics, but merely to provide an integrated discussion of the needs identified in each of the key topics. At the end of each of the five individual cross-cutting topics is an overview with references to the relevant standardization needs from the point of view of the key topics.

3.1 Sustainability assessment

Basic structure of sustainability assessment systems
Just as the transformation process towards a Circular Economy within industrial production is progressing, new or updated sustainability assessment systems are continuously emerging, as well as the standards and specifications that govern them. In parallel and often with a time lag to the primary scientific (further) development of the methods and tools, extensive data and information are generated through practical application, which are then further used and communicated internally or externally.

Sustainability assessment systems form an important basic structure of information management in a Circular Economy. These systems generally consist of three generic elements:
→ Information gathering – data basis;
→ Evaluation and impact assessment – decision support;
→ Preparation – control/planning, monitoring, external reporting (indicators).

A comprehensive sustainability assessment system is usually supported and operationalized by appropriate standards and specifications. The basic structure of a sustainability assessment system is shown in Figure 35.

In general, the accumulation of data, the development and adaptation of methods, and the standardization of purpose-specific processing occur in an iterative process. The establishment of standards and specifications, as well as guidelines for the application of certain methods or systems, is an indispensable and empowering process of this development.

There is a wide variety of approaches to sustainability assessment, many of which have emerged independently and in different fields. At the same time, however, there are numerous efforts (especially in standardization) to harmonize this heterogeneous landscape of sustainability assessment systems, as well as the underlying methods, data and reporting formats (e.g., new EU standards for sustainability reporting).

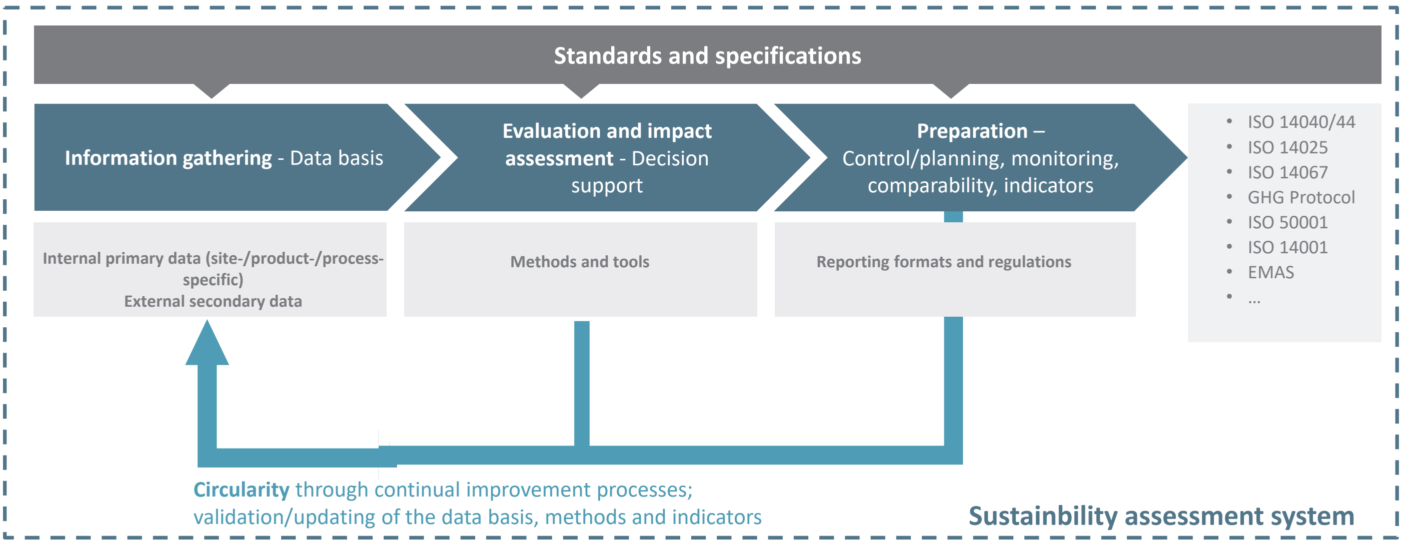


Figure 35: Structure of a sustainability assessment system (Source: DIN)

This makes collected data and information more comparable and reliable, which is an indispensable prerequisite for a Circular Economy.

For the sake of simplicity, it can be assumed that specific or clearly definable sustainability assessment systems follow the logic presented in Figure 35, regardless of whether they assess ecological, social or economic sustainability.

Therefore, the needs identified in the context of the key topics will be discussed accordingly. Particularly in the context of the Circular Economy, it still seems important to distinguish sustainability assessment approaches not only on the basis of the three dimensions of sustainability, but also to consider their respective boundaries of consideration (levels) (see Figure 36).

Assessment of ecological sustainability
Life cycle assessment (LCA) is considered the most important method of product-related environmental assessment and can be seen as the conceptual core of various other sustainability assessment methods. LCA has an inherent life cycle perspective, which in turn is indispensable for a comprehensive assessment of (circular) economic activities.

Depending on the characteristics and application of the methodological principles, LCA can also assess ecological implications at the meso or macro level that are related to product and service systems. The methodological principles and framework conditions for this are already being discussed and applied in the scientific community in the context of the “Consequential LCA”[5] [287]. Overall, however, it can be said that the quantification and interpretation of potential environmental impacts associated with the implementation of Circular Economy strategies cannot be described, or can only be described inadequately, using the common approach to LCA (i.e., “attributional LCA”)[5] [287]. This is due to the fact that there is little methodological guidance available for the life cycle assessment of large-scale changes affecting the market at the meso and macro levels. Appropriately adapted standards could thus help in the development and safeguarding of policy targets and measures that lead to the desired macroeconomic effects. Although the boundaries between the individual levels can sometimes become blurred in the context of LCA, LCA and the tools derived from it mostly target the product level. However, the product-related tools of the Circular Economy should not be understood as an end in themselves. The goal of all measures is to achieve greater sustainability in line with the 17 United Nations Sustainable Development Goals (UN SDGs) [203]. LCA makes the contribution to sustainability visible and comparable. If sustainability potential is lost in the transition to the product level of the Circular Economy, or if the transition to the product generates

5 Life cycle assessment (LCA) can be divided into two generic modelling approaches:
→ Attributional LCA: Description of the state of the environmental impacts attributed to an average product
→ Consequential LCA: Consequence of actions affecting a product system (e.g., changes in product design or production volume)

	Ecological	Economic	Social
Macro level (macroeconomic level)	…	e.g., national accounts, criticality of supply	…
Meso level (sectors, technologies, product groups)	e.g., ecological input-output analysis	e.g., input-output analysis	e.g., social input-output analysis
Micro level (product level)	e.g., life cycle assessment (LCA)	e.g., material flow cost accounting (MFCA), life cycle costing (LCC)	Social LCA

Figure 36: Differentiation of assessment approaches based on the three dimensions of sustainability and respective levels (Source: DIN)

the need for new Circular Economy measures, such as the service idea, (global) assessment systems, e.g., at the material, energy, substance, financial, or business model level of the Circular Economy, are to be preferred. Standardization in the context of LCA ensures maximization of sustainability potential, incorporating all contributions including Circular Economy measures.

Standards and specifications should fulfil the following key tasks and functions in the context of environmental sustainability assessment in a Circular Economy:

1. Creation of a common understanding and orientation for application

The broad application of LCA in science and industry can be seen as a success of standardization. This evolution has simultaneously led to a variety of novel expressions of the method and accompanying standards or consortial frameworks. There are numerous efforts to harmonize LCA practices not least because of these developments. The European Commission's initiatives in the development of the product environmental footprint (PEF) [166] are particularly noteworthy in this regard. Due to the partial inconsistencies between the PEF and the relevant standards (DIN EN ISO 14040 [80] and DIN EN ISO 14044 [81]), it is recommended that European and international activities be coordinated and the methodological differences classified or resolved. Ultimately, standardization could provide suitable guidance and reduce the existing uncertainty or lack of knowledge about the targeted application of LCA methods and tools. Such guidance is also desirable for the ultimate systematization and selection of appropriate LCA approaches. Concrete examples are the orienting and prospective (ex-ante) life cycle assessment, in order to enable suitable decision-making support in the early phases of the product development process.

2. Ensuring comparable information

The resilience as well as comparability of LCA results are being increasingly critically viewed. Compliance with the international standards DIN EN ISO 14040 [80] and DIN EN ISO 14044 [81] alone is not sufficient for this purpose, as these generally applicable (horizontal) standards still offer too much leeway and are thus susceptible to "standard-compliant" manipulation. Accordingly, it is recommended to define further rules for the individual elements (see Figure 35):

→ With regard to data acquisition, increased transparency and standardized disclosure of underlying assumptions and data quality appear essential (e.g., through aggregatable data quality indices).

→ Uniform circularity indicators should be defined as part of the assessment and impact assessment. Furthermore, clear rules are needed on when and under which circumstances weighting and/or prioritization of individual environmental impact categories is allowed.

→ There is also a need for further standardization in the processing of results and their communication. For stand-alone LCAs, this is already regulated in many cases by the corresponding formats of environmental product declarations. However, such a regulation does not yet exist for comparative LCAs, which will become increasingly important especially in the context of the Circular Economy.

Summary:

Although the Circular Economy is a macroeconomic model, the focus of the assessment of corresponding goals and measures (cf. 1.6.3 R-strategies) is often on the industrial product. This is also reflected in the context of materials and chemicals policy, resource conservation strategies and the Ecodesign Directive as part of the European Union's integrated product policy. This product-centric view is further manifested by the digital product passport (see Chapter 3.3). Although the overarching goal of the Circular Economy is overall societal resource reduction and stewardship, current sustainability assessment often requires product-level assessment. This also highlights a dilemma of sustainability assessment. On the one hand, very specific assessment approaches are required and needed, which inevitably leads to increased complexity in LCA practice. On the other hand, there is a need for assessment approaches that are less specific, simpler, and thus accessible to a wider group of stakeholders.

Assessment of economic sustainability

For the assessment of economic sustainability, there are comparable methods to LCA with LCC (life cycle costing) [290] and MFCA (material flow cost analysis) [291], which follow the logic of sustainability assessment systems described above. However, data acquisition is even more complex here, as material and energy flows have to be converted into monetary values and other costs (such as investment, wage and waste management costs) have to be determined and included. In addition, indirect environmental costs arising from in-house environmental protection can also be taken into account. The above-mentioned costs can be summarized as system costs and allocated to products, by-products and wastes, as well as to the individual process steps by means of allocation procedures. It would also make sense to include all resource consumption costs over the entire life cycle (e.g., costs due to environmental destruction during the mining and processing of primary materials). It is through the latter that the gains from the Circular Economy could be monetized.

The introduction of the R-strategies is also expected to reduce the demand for primary materials and thus the economic dependence of resource-poor countries on resource-rich countries. This can be achieved by incorporating supply criticality into economic sustainability assessment systems (e.g., via a bonus system).

Research is still needed to establish a uniform and comprehensive economic sustainability assessment (see also Need 5.4: Methods for the assessment of the conformity of economic sustainability).

Assessment of social sustainability

The assessment of social sustainability has recently become increasingly important in various contexts. These include corporate sustainability reporting (CSR) [292], which is mandatory for ever more companies, and the German Supply Chain Due Diligence Act (LkSG) [256]. For both, topics such as occupational safety, working conditions, and human and children's rights must be evaluated. In addition, assessments of social aspects (such as the "gender dimension", among others) are also required in the sustainability assessment of technological processes (for example, in the EU Horizon 2020 framework program [294]). There are still few methods for this (e.g., social LCA) and no comprehensive methods, so inter- and transdisciplinary research is needed, which should result in the development of a standard.

Holistic assessment of sustainability

When it comes to "sustainability", a distinction is usually made between the three dimensions – "ecological", "economic" and "social". In the context of standardization, ecological assessment has so far been best represented, although there is also a need for further standardization in this area. A new approach would be to develop a method in which the three dimensions mentioned above are assessed together. Corresponding needs were formulated in the key topics:

→ Packaging: Creation of a "Basic standard for sustainability assessment based on the three-pillar model"
→ Textiles: Combination with other sustainability aspects (economic, social) as well as with other products
→ Electrotechnology & ICT: Orientation for dealing with conflicting goals between individual parameters
→ Plastics: Criteria for uniform labelling of products

In addition, a fourth sustainability dimension is taken into account in further approaches. This dimension can be "culture", "health," "organization," or "leadership," depending on the perspective. In addition, the 17 UN SDGs [203] with their sub-goals and indicators can be used for a sustainability assessment. This last approach is probably the most comprehensive, inter- and transdisciplinary.

Overview of standardization needs for "sustainability assessment"

Key topics	Digitalization/ Business models Management/	Electrotech-nology & ICT	Batteries	Packaging	Plastics	Textiles	Construction & municipal-ities
Standard-ization needs	1.1	2.1	3.1	4.12	5.1	6.1	7.2
	1.4	2.4	3.3	4.14	5.2	6.11	7.4
	1.6	2.12	3.6	4.15	5.3	6.12	7.8
	1.21	2.21	3.7	4.16	5.4	6.13	
	1.22	2.34	3.8	4.17	5.5	6.33	
	1.24		3.9	4.18	5.8	6.34	
	1.36		3.12	4.19	5.9	6.35	
			3.13	4.20	5.17		
			3.16	4.29			

3.2 Life extension

Various R-strategies can be considered for product life extension. In addition to the R-strategies “reuse” and “repair”, which are relevant for all products in the various key topics, “refurbish”, “remanufacture” or “repurpose” have a different priority depending on the product, or in some cases play no role at all.

In addition to the professional reprocessing of a product for one’s own use, the extension of the utilization phase also brings into play the aspect that a change of owner can take place. In Germany today, the consumption of second-hand goods only plays a role in certain segments, such as mobility. In the meantime, however, a second-hand market has also emerged for various electronic devices (smartphones, tablets, etc.). The decisive factor for choosing a used product is the (high) price of the new product. For products that are available on the market both as low-cost, low-quality products and as high-priced, high-quality products, consumers often opt for the lower-cost virgin product. One reason is the desire to afford “something new”. This behaviour is particularly evident in the area of fashion. The fast fashion business model is designed to make and sell clothes cheaply so that people can buy new clothes often. Shopping behaviour is also strongly influenced by the social environment and social media.

Price sensitivity is also noticeable in the case of plastic recyclates. In principle, high-quality recyclates are good to sell because they are also versatile for different applications, e.g., recyclates from PET bottles or other recyclates from selective collection. Since such materials are sometimes more expensive than virgin materials, some industrial customers are also more inclined to reach for virgin materials of at least the same quality and at lower cost.

In order to strengthen the R-strategies “repair”, “reuse” and, if necessary, “repurpose”, it is necessary to change the behaviour of consumers to buy more used goods in the future. In this context, (new) business models may emerge that focus on maintaining the functionality of the product, as well as leasing and rental models (pay-per-use, product-as-a-service). In these models, ownership remains with the lender or lessor, who ensures the functionality and quality of the product for the agreed period.

Common needs

In all key topics that identified product life extension as an important contribution to the Circular Economy, the following needs were developed, although some of these differ in terms of specifications or requirements depending on the product. These differences are shown in the individual Needs.

Design standards for longevity and repairability

In general, good initial quality determines the service life of a product. Particularly with regard to the key topic of “textiles”, it was pointed out that a change in thinking from fast fashion to high-quality clothing is a prerequisite for reuse and the development and establishment of new business models to succeed. In the case of electrical and ICT products as well as batteries, the need lies in the ability to install or remove spare parts non-destructively for components that are susceptible to wear. In any case, in all key topics it is agreed that the design phase is of great importance for the longest possible product use. In general, there is also a need for a basic determination of what the expected service life of a product should be; this can be quite different depending on the product and its function. In addition, it was found that in terms of longevity, the repairability and recyclability of the product should also be considered.

The need for recyclable or reusable products was seen for packaging and textiles. In the textile sector, single-use products are often used for hand drying or in the medical sector. In the packaging sector, sales packaging in the B2C sector is designed as single-use products. Product standards and specifications can help to promote textile multiple use products or reusable packaging. In addition to material selection, hygiene and quality aspects, take-back systems or leasing or rental models should also be supported in this context.

Product information

All key topics of this Roadmap have in common that, in addition to comprehensive and consistent product information, usage history is particularly relevant for secondary users. This creates transparency and trust in the purchase of a used product. For the replacement and installation of components, it was mentioned in this context that an update of the usage history is considered useful, as the warranty conditions for these components may change. The use of a digital product passport (See Chapter 3.3) can facilitate the update of the usage history.

Repair index/quality index

To make purchasing decisions easier for both consumers and leasing or rental companies, standards are needed that evaluate a product’s quality, expected life, and repairability. These requirements must be developed on a product-specific basis in each case. Uniform standards for definitions, parameters and test methods create transparency and comparability of products and their components. An additional need was developed for electrical products, batteries and plastics, in particular, that the safety of consumers and repairers (product safety and occupational health and safety) must also be taken into account for the repairability of products. Without standardized information on disassembly instructions and requirements for the safety of the repairer, the repair would be hindered from the outset. The evaluation result, summarized in a repair index, would help to easily identify the repairability of a product. This could also include information on whether the product may only be repaired by authorized workshops for warranty claims.

In the case of used products, the previous utilization phase is of particular importance for potential secondary users. Even if the original product was of high quality, improper use or improper care may result in a defective condition that a layperson does not recognize when buying, or they do not know how long the expected service life for the used product still is. In order to increase trust in quality and transparency, a system of independent quality assurance should be developed, which can be applied by distributors of second-hand products. This information can be aggregated in a simplified form as a quality index for potential purchasing end users.

Availability of spare parts
Repair services cannot be performed without spare parts. The variety of products is huge, so standardized information for spare parts is necessary to facilitate procurement. Furthermore, the question must be answered as to how long spare parts are to be kept in stock by the manufacturing company if the goal is to extend the useful life of products compared to today. Publicly available information can also help to know the ageing and wear of components in order to intervene before a product fails (“maintenance routine” [101]). Overall, it is noted that cooperation in the area of spare parts, maintenance and repair, as well as the provision of information via the digital product passport (see Chapter 3.3), can significantly increase the extension of service life.

Manufacturer responsibility/warranty obligations
Repairs or the installation of new components may result in functional or safety-relevant changes. For various products, such as batteries, there is no technical framework for repair or reprocessing, so this may lead to a loss of type approval. In order to increase the confidence of consumers, but also to further guarantee product safety, uniform criteria are needed that determine at which change the original manufacturing company of the product is still responsible or from which point on the repairer or also the seller of a second-hand product is liable for the product as the new person placing it on the market. In this context, there is a need for a normative basis on which tests are to be carried out during repair, reprocessing or remanufacturing in order to restore the type approval or certification of a product. The experts agree that functional and safety-relevant changes should only be undertaken by professional service providers who also take responsibility for them. These criteria can form the basis for the establishment of a legal framework for markets in the field of reprocessing of products and used goods.

Looking ahead
Extending the useful life of as many products as possible plays an essential role in the Circular Economy. Business models in the “sharing economy” are only established in a few individual segments in Germany, such as professional workwear, reusable packaging systems and mobility. New products are often too cheap or spare parts too costly to use repair services; there is also little incentive for consumers to buy second-hand products.

Standards and standardized information help to increase transparency and trust in the quality of reprocessing and remanufacturing of products and of used goods, and thus form the basis for successfully establishing these business models. In addition, the development or expansion of communication technologies (such as apps, internet platforms, etc.) will make it easier for consumers to take advantage of second-hand, rental or leasing offers. However, it also requires a change in attitude toward consumption and possessions. In this respect, these sociopolitical measures should be accompanied by standardization.

Overview standardization needs for “life extension”

Key topics	Digitalization/ Business models Management/	Electrotechnology & ICT	Batteries	Packaging	Plastics	Textiles	Construction & municipalities
Standardization needs	1.2 1.33 1.35	2.1 2.3 2.4 2.16 2.20 2.21 2.24 2.25 2.26 2.27 2.28 2.30	3.5 3.6 3.7 3.11 3.12 3.14 3.16	4.9 4.10 4.11 4.12 4.13	5.7 5.8 5.9 5.10 5.36	6.1 6.6, 6.8 6.9 6.13 6.14 6.15 6.16 6.17 6.18 6.19 6.20 6.21 6.39	–

3.3 Digital Product Passport (DPP)

The DPP was addressed across topics as a central instrument for building a Circular Economy. It is intended to provide information that facilitates the implementation of various R-strategies or even makes them possible in the first place. The requirement for a DPP before sustainability and circularity aspects was formulated concretely for the first time by the European Commission in the context of the European Green Deal [2] in December 2019. What information it should contain and for which products it should become mandatory was initially left open. In the legislative proposal of the European Parliament and the Council for the Ecodesign for Sustainable Products Regulation (ESPR) [294] published on March 30, 2022, more specific targets and expected steps were then stated. According to this proposal, digital product passports would be the norm for all products covered by the Ecodesign Regulation for sustainable products. However, it has not yet been conclusively clarified what the product passport – or more precisely, the product passports – for different product groups will look like and when they will be introduced on a mandatory basis.

Already on 10 December 2020, the European Commission presented a draft for a new regulation on batteries and spent batteries [141]. In the future, this is to replace the previously applicable Directive 2006/66/EC [144] and provides for an amendment to Regulation (EU) No. 2019/1020 [148]. One of the initiative’s key objectives is to promote the Circular Economy by taking a holistic view of the battery life cycle. To this end Article 65 prescribes: “By 1 January 2026, each industrial battery and electric vehicle battery placed on the market or put into service and whose capacity is higher than 2 kWh shall have an electronic record (‘battery passport’). The battery passport shall be unique for each individual battery ...”.

Batteries will thus be the first product group for which a DPP will be mandatory. For this reason, numerous stakeholders are currently already looking at solutions for implementing the battery passport. But not only the battery passport is the subject of research: Other industries also already offer promising implementation concepts for digital product passports (e.g. the Building Resource Passport [296] or approaches from the packaging and food industries [297]). Legislators associate more than sustainability and circularity with the DPP. There is discussion regarding the need for a DPP for all mandatory product information under the New Legislative Framework (CE Marking) [298], for related proofs of conformity, access to market surveillance, etc.

The DPP will be able to realize its potential when interoperability is achieved across requirements, sectors and systems. The EU Commission already refers to the role of standardization for the DPP at several points in the ESPR. To implement a DPP and the related data and digitalization-related aspects, DG Connect structures the necessary elements along the following seven points:

1. Data carriers and unique identifiers
2. Access rights management
3. Interoperability (technical, semantic, organization), including data exchange protocols and formats
4. Data storage
5. Data processing (introduction, modification, update)
6. Data authentication, reliability, and integrity
7. Data security and privacy

The framework for how the DPP could be defined is listed in the draft ESPR [294]. For example, this already refers to ISO/IEC 15459:2015 [299]. This ESPR proposal is to be specified by "delegated acts" for each product group. With regard to the implementation of the battery passport, the "battery pass" project [300] funded by the Federal Ministry of Economic Affairs and Climate Action (BMWK) should be mentioned as a central activity. With regard to the definition of standardization needs on the DPP to the ESPR, the EU Commission has awarded, among others, a Coordination and Support Action Project, called CIRPASS [301], which will start in October 2022.

Information needs of different stakeholder groups

Many contributors along the value chain lack information (for example, about material composition) in order to keep products or parts of products, and thus valuable resources, in the system. At the same time, information sources (e.g., manufacturing companies) do not know what information they need to provide so that other stakeholders along the value chain can implement R-strategies. Here, standards would be useful to define which information is needed by which stakeholder group (e.g., recyclers, sorters, repairers, resellers, etc.) to implement the R-strategies. The "need to know" principle (no more data is requested than is really needed for the use case) is to be discussed and could provide an initial basis in the approach.

Interoperability of product and event data, and metadata through a unified ontology/taxonomy

In order for product (e.g., material composition, colours, etc.), event (e.g., repairs carried out) and metadata (e.g., sustainability assessment) to be exchanged efficiently via interfaces along the value chain, interoperability of the sector- and system-specific design of product passports and the respective IT systems is required. Among other things, this serves to avoid time-consuming manual data assignments. To achieve syntactic and semantic interoperability between different systems and organizations, standardized data structures, ontologies and taxonomies are needed to describe the products. These should build on the two aforementioned information needs and be based on existing standards and de facto standards. Data exchange formats need standards as a basis, such as EDI standards [302]. For event data, for example, the EPCIS Vocabulary of GS1 [303] is worth mentioning. Accordingly, this would need to be specifically extended to include events for carrying out the R-strategies. As an alternative, the "adminstration shell" from the field of Industrie 4.0 (DIN EN IEC 63278-1 [66]) could be applied in conjunction with the IEC Common Data Dictionary of IEC 61360 [304].

Data authentication, reliability and integrity

A central objective of the DPP is to enable well-founded and validated comparisons between products in order to incentivize sustainable purchasing decisions, among other things. Comparability is achieved on the one hand by a common structure and congruence of the information to be provided (see, for example, Needs 1.8 and 1.9). However, it is at least as important to define comparable or uniform methods for data collection and aggregation. For example, the underlying measurement and collection methods and datasets could be defined. If consistent data collection is not possible, the relevant stakeholders should at least be enabled to identify the differences between two data points. Here, for example, clearly defined data quality indicators could provide support. In principle, therefore, data collection methods and the assessment of data quality should be specified in appropriate standards (see also Need 1.16).

Identification numbers (identifiers)

For the unique identification numbers, the level at which they are used for products must be defined. Here there are three possible levels: product level (model), batch level or item level. Participants in a DPP system also need identifiers for their organization to identify where the data came from. Furthermore, it must be defined which requirements the identification numbers must fulfil, governance and allocation, so that an open system for different providers can be created.

A wide range of standardization needs for the DPP were identified for the seven key topics and described in detail for the sectors.

Overview standardization needs for the "digital product passport"

Key topics	Digitalization/ Business models Management/	Electrotech-nology & ICT	Batteries	Packaging	Plastics	Textiles	Construction & municipal-ities
Standardiza-tion needs	1.5	2.6	3.1	4.3	5.12	6.3	7.5
	1.7–1.17	2.13	3.2	4.4	5.13	6.19	7.13
		2.15	3.3	4.5	5.14	6.32	
		2.28	3.4	4.19	5.18	6.34	
		2.29	3.5	4.20		6.35	
		2.36	3.6	4.21		6.36	
		2.40	3.8	4.22		6.37	
		2.43	3.9	4.29		6.38	
			3.14			6.39	
			3.17			6.40	
			3.19				

3.4 End-of-Waste (EoW)

One of the key strategies of the Circular Economy is to recycle waste to the highest possible quality in order to return it to production processes. This is done with the aim of turning waste back into secondary raw materials, the production of which is then generally associated with significantly lower resource consumption and CO_2 emissions. Such secondary raw materials are freely tradable goods that are subject to the same legal requirements as primary raw materials. To achieve such status, recycled waste must leave the waste regime – and thus, the multitude of legal regulations attached to the handling, transport or use of waste. The fundamental objective of these waste regulations is, at their core, the avoidance of risks that waste could pose to humans or the environment – they are therefore often very restrictive, and for good reason: The aim is, for example, to prevent waste that should actually be disposed of from simply being mixed with other materials instead.

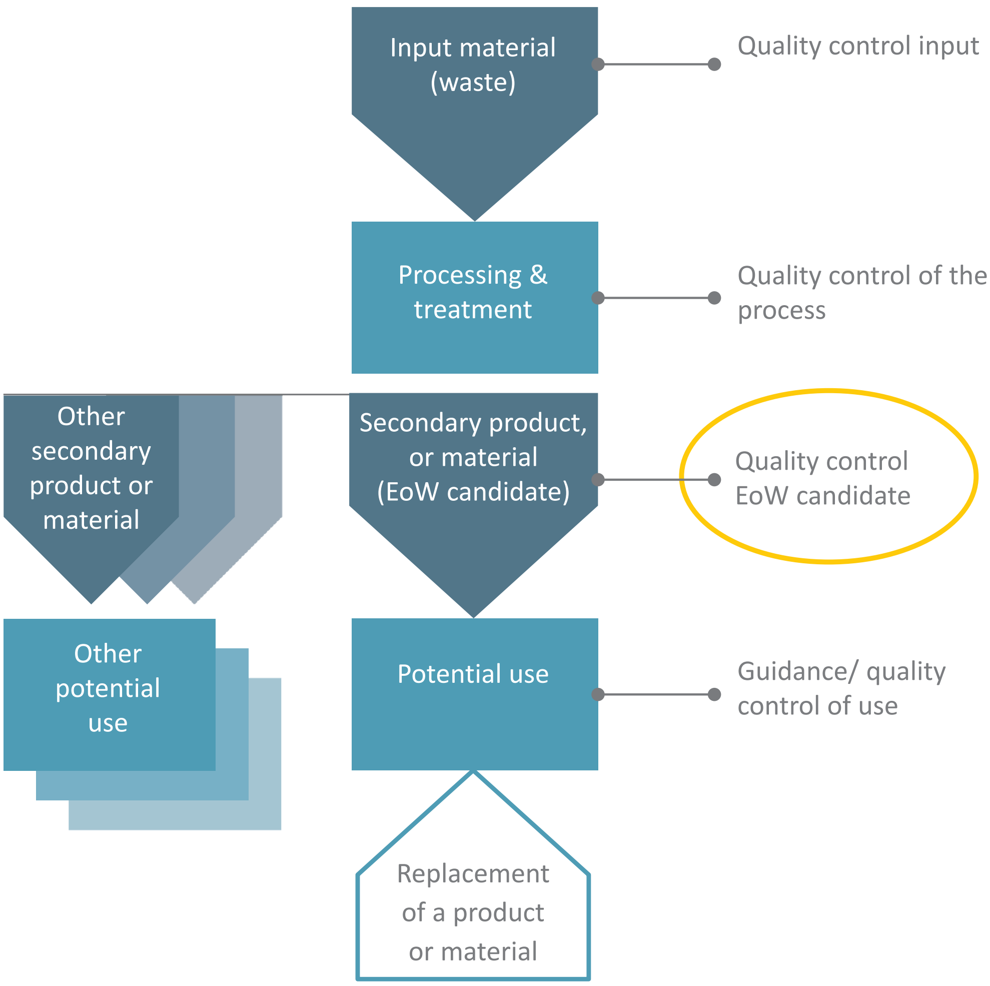
The topic of end-of-waste is currently being discussed at various political levels (for example, adaptations to the Basel Convention, Annex IV [305]). The technical implementation varies greatly due to the lack of standards (national) and depending on the industry.

Clear criteria are therefore needed as to when treated waste is no longer considered waste but can, for example, be freely exported and imported within the European Economic Area – for which it would have to fulfil a large number of notification and documentation requirements as waste. It is precisely for this purpose that the European Waste Framework Directive [174] defines requirements for EoW criteria: Requirements for recyclates and their treatment processes, the fulfilment of which should no longer be subject to waste law but to product law, see Figure 37.

Article 6 of the Waste Directive defines the following four general requirements for the development of such criteria:
1. The substance or object is to be used for specific purposes,
2. there is a market for or demand for that substance or object,
3. the substance or object meets the technical requirements for the intended purposes and complies with existing legislation and standards for products, and
4. the use of the substance or object does not lead overall to harmful environmental or health effects.

The European Commission can develop EoW criteria for individual wastes or leave this to the member states. The latter can become a challenge for the development of the Circular Economy, as a material may already be considered a product again in one country but be deemed waste again once it crosses the country's border.

Figure 37:
Requirements for recyclates in product legislation (Source: JRC 2009 [43])



The development of standards and specifications can help overcome the hurdles created for market participants through heterogeneous national regulations. Guides with a targeted description of the legal landscape and the associated processes for exporting and importing waste/products would increase the willingness of market participants to trade or acquire secondary raw materials outside their own member state as well. Standards that enable monitoring of material flows across national borders would lead to greater transparency in the market for secondary raw materials and enable new business models in both trade and raw material purchasing by manufacturers. Larger quantities of material would be visible, could be offered cumulatively and correspondingly larger raw material requirements could be met. Market demand could be mapped in a standardized way and, if necessary, considered in the context of the respective national and/or European legislation. Standardized reference methods and materials would help ensure that no health or environmental hazards are posed by secondary raw materials.

In addition, they would simplify quality assurance and also help lower the barriers to trade and the use of secondary raw materials.

Standards and specifications that, for example, (i) reduce administrative and bureaucratic efforts to comply with legal regulations on health and environmental protection, (ii) help to increase quality assurance, and/or increase confidence in the safe use of secondary raw materials, would contribute to the sustainable establishment of a Circular Economy.

Standards and specifications support the German government in implementing the socio-economic transformation of the economy described in the coalition agreement through the safe, sustainable and competitive use of secondary raw materials [1].

On the end-of-waste in the construction industry

Construction occupies a special place in waste management. Structures are generally very long-lived anthropogenic material stores with enormous resource consumption in their construction. The focus is on the mineral content, especially for the building materials concrete and brick. In Germany alone, the amount of building materials used is estimated at around 15 billion tonnes, which is almost 40 times the amount of raw materials used for other capital and consumer goods. These figures are also reflected in the waste statistics. More than half of the national waste generated in Germany each year is construction and demolition waste. However, the potential offered by high-quality use of these resources is not being fully exploited. One example is the extraction and further processing of concrete and reinforced concrete.

Direct reuse of entire components is often not possible for design reasons. In the case of the unavoidable crushing, at least for the structures built in the past, of the concrete and reinforced concrete supporting structures and their separation, the reinforcements are almost completely returned to the raw material cycle, but the mineral portion is preferably only used for backfilling in road construction and civil engineering. In addition, a significant portion is sent untreated to landfill due to inert or non-inert pollutants. This downcycling leads to the removal of waste from the raw material cycle. The reasons for this are, in particular, the lack of standards for handling these resources, which on the one hand clearly describe the procedures and on the other hand ensure their implementation by observing and following them up in the approval procedures.

With the guidelines for demolition and conversion of buildings upstream waste audits as one of the three measures in the Circular Economy Action Plan [306], the EU offers an assessment system for the methodical evaluation of all waste quantities and flows during demolition. This does not ensure that the materials remain in the raw material cycles. However, these guidelines do not regulate which of the identified and assessed building materials lose their waste properties immediately after they are generated at the construction site and are to be returned to the cycle as secondary raw materials. They also do not refer to the fact that, through technical processes, a production of secondary raw materials from the waste is possible and must be considered.

The recyclate resulting from the crushing of concrete structures should be compulsorily used as a raw material in the production of concrete and only in individual cases should be allowed for other uses or for landfilling. However, this cannot be achieved with the few national standards, some of which are outdated. Standards are needed that ensure the use of the recyclate as a raw material substitute, for example through specifications for admixture when using natural raw materials, or technical standards for waste pretreatment for inert and non-inert pollutants. It is precisely the secure binding by the cement that is a method of immobilization at contaminated sites. Equalization of the anthropogenic pollutant loads in the recyclate with the geogenic loads in the raw material makes technical sense and is to be demanded. The aim of these rules and procedures is to ensure that the materials remain in the raw material cycle, and to define the point at which a demolition material loses its waste properties.

Overview standardization needs for “end-of-waste”

Key topics	Digitalization/ Business models Management/	Electrotechnology & ICT	Batteries	Packaging	Plastics	Textiles	Construction & municipalities
Standardization needs	1.3 1.7	–	3.18	4.1 4.6 4.7 4.8 4.12 4.21 4.22 4.29	5.1 5.7	–	7.1

3.5 Recyclability

The work of the seven key topics has resulted in five focal themes for the aspect of “recyclability”, which are named here and substantiated on the basis of the needs:

1. Definitions in the field of “recyclability”
2. Design 4 recycling/circularity and recyclability
3. Collection, sorting and recyclability
4. Information and communication and recyclability
5. Collecting and assessing substances and recyclability

These subject areas also overlap, but they can still be presented well on their own. However, the overlappings play a role in the implementation of the Standardization Roadmap, as freedom from contradictions must be ensured.

Definitions in the field of “recyclability”

The emerging Circular Economy needs clear definitions of its conceptual world in order to survive in practice. This has also been demonstrated in the topic discussed here. Without uniform, standardized definitions, confusion, misunderstandings and, ultimately, a loss of trust arise. The standardization tasks are intended to do the exact opposite. Therefore, the topics for definition are also deliberately at the beginning of this list. Clear definitions are also essential for the topics discussed later, especially information standards.

The standardization of the term “recyclability” is of course of elementary importance for the topic. There is no uniform definition in the literature. This leads to different interpretations of the term depending on which stakeholders are involved, which can be problematic due to different interests. Here, “recyclability” is understood to be the ability of a material or product to be recovered from an existing use, fed into a recycling process and reprocessed in such a way that any new product can be made from it in a technically, economically, ecologically and socially sensible way.

In general, “recyclability” could be defined as the ability of a product to be processed at the end of its service life in such a way that new products can be economically manufactured from it. The recyclability of a product depends on the technological maturity of the recycling methods as well as the efficiency in terms of yield and selectivity of process control. These conceptual approaches may not cover all aspects; further elaboration and generalization of this should be left to the appropriate body.

Recyclates here should include both post-industrial (pre-consumer) and post-consumer materials. To set up a Circular Economy, it is of great importance to become aware of its recyclability. When it comes to reuse and recycling, both industry and legislation face the challenge that theoretical (th), technical (te) and real (r) recyclability can differ greatly (see Figure 38). These differences are often shaped by the industry, the application of the material and its availability, making standardization on use and recycling very difficult so far. As a rule, the theoretical recyclability is much higher than the technical recyclability and this in turn is higher than the real recyclability [179].

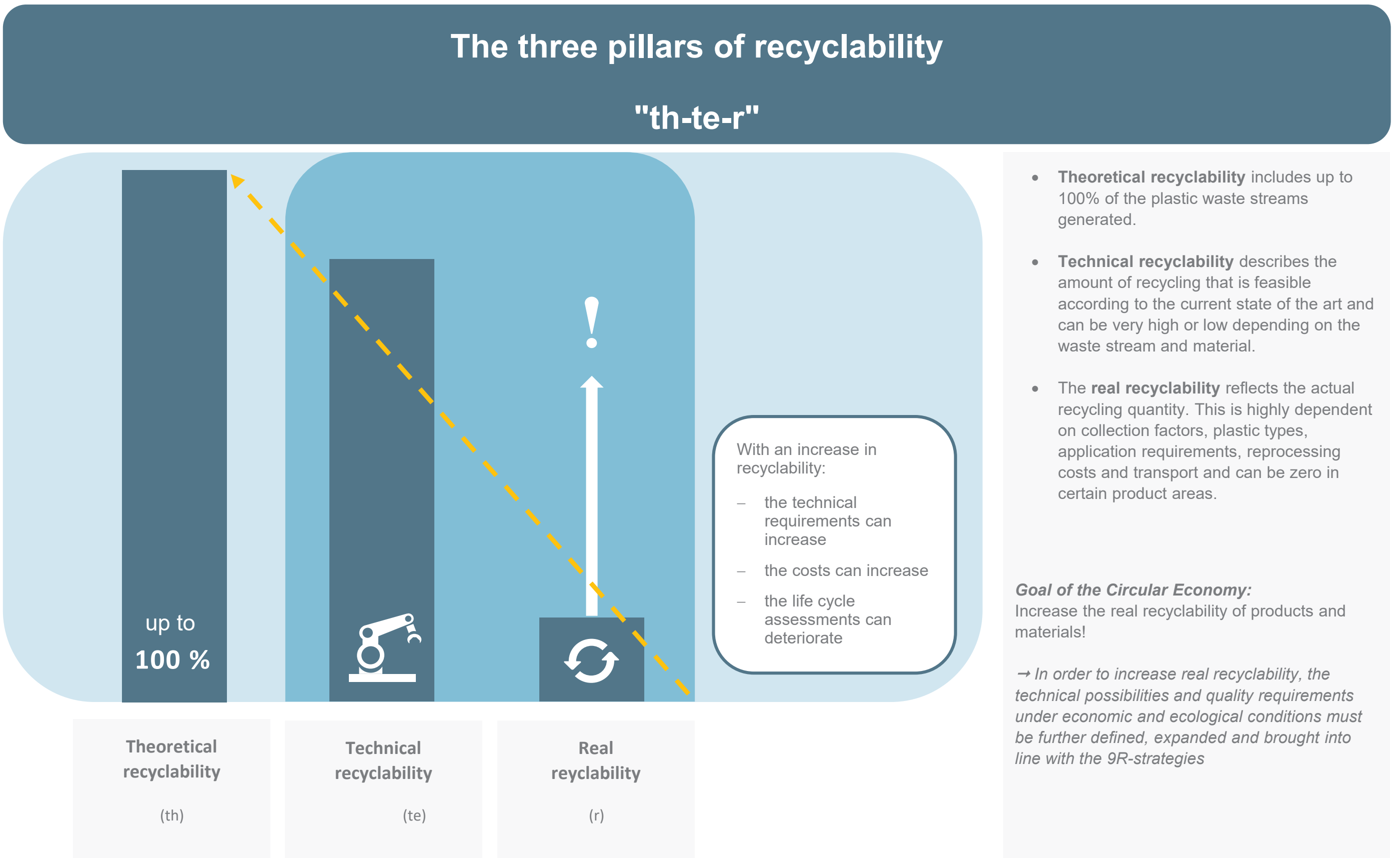


Figure 38: The three pillars of recyclability (Source: DIN, along the lines of (Pomberger 2021) [179])

Design 4 recycling/circularity and recyclability
Design 4 recycling (D4R) or design 4 circularity (D4C) starts at the beginning of the product life cycle and is an important aspect in ensuring recyclability. Very extensive needs have been identified for this purpose. There are many different "design 4 recycling" guidelines from different contributors [307], which are constantly being updated or are just being developed. In some cases, brand manufacturers and retailers create their own guidelines, which have a considerable influence on the entire market. These guidelines sometimes set different priorities, depending on the focus. In addition, other design 4 recycling guidelines are in development (e.g., ReWaste F, PTS-RH 025/2022, 4evergreen Guideline [308], [309], [310], [311]).

The design and construction of the products and the components and materials are crucial to increasing recyclability. The goal should be to
→ design products, components and materials in such a way that they can be used to produce high-quality recyclates at the end of their life cycle,
→ design products, components and materials to support collection and sorting and recovery technologies, and
→ develop a uniform recyclability assessment metric that takes into account the different recycling options.

In many product areas and application sectors, there is a lack of standards and specifications that describe "design 4 recycling" principles (to be defined uniformly) for increasing the mechanical recyclability of products, components and materials, and that can be given to the product developer at the beginning of a product life cycle in order to achieve the above-mentioned goals. Standards for the design of recyclable products should be written in such a way that they become binding in requests for proposals or invitations to tender. Even in the classification of recyclability itself and the coupling with specific recycling processes, there is a lack of technical rules and standards today that increase the recyclability of products and the recyclability of components and materials via a standardized selection of recyclable materials.

Initial guides have been developed by recycling associations [193], research bodies [194], foundations with statutory tasks [195], consultancies and consumer goods manufacturers mainly in the packaging sector and with a focus on mechanical recycling. There is a lack of generally accepted rules and standards developed by all stakeholders for all areas of application with reference to all recycling methods in order to ensure a standardization landscape that is open to all technologies.

A further need for research and standardization lies in the development of a guideline or recommended action for design, construction and processing of products in all sectors that are to be manufactured from recyclates or with the highest possible recyclate content from the outset. The guideline should serve as a recommendation as to how possible material variations can already be compensated for by a suitable design or process parameters. This need is distinguished from the widespread design 4 recycling or circularity in that it is not a matter of designing a product to be recyclable, but of designing a product so that it can be manufactured from recyclates in a simple, process- and application-stable manner, as well as economically.

Collection, sorting and recyclability

In order to be able to recycle products, you first have to get hold of them. Although this is actually self-evident and logical, it is not trivial in practice due to a number of difficulties.

The processes of collection and sorting, as decisive steps for good recyclate qualities, have not yet been standardized or have been standardized only inadequately. There is a need here for suitable standards that define characteristic values for composition and impurities for product or material groups, for example, and enable meaningful classification. In addition, the goal of these standards should be to increase the number of fractions sorted within the bounds of economic efficiency.

The objective here is a systematization via resulting waste/intermediate products; this increases the possibilities of material pooling, reuse and economic and ecological opportunities for recycling. A systematization of the resulting waste and intermediate/by-products can generate economically and ecologically sensible material streams both within an industry and across industries.

Information and communication and recyclability

There is an enormous need for information in the Circular Economy. To be efficient and develop high level solutions requires a significant amount of data, information and effective communication. This urgently requires clear, unambiguous boundary conditions and definitions. The increased need for information will have to be met by completely different approaches to information acquisition, provision, processing and backup than we know today if recycling is to be taken to the next level of development. This includes, above all, consistent digitalization. It is predicted at this point that not only sorting technology will change fundamentally in the next 10 to 15 years.

Should increased interoperability lead to technical solutions that use the same materials, standards aimed at making this information available would be beneficial. The information generated using these standards would have added value for recyclability. Reference to the materials should be emphasized. To ensure fair competition, these standards must not restrict the design freedom of manufacturing companies and thus slow down innovation processes.

Depending on the quality of the recyclable material processed and the process structure selected, a specific output is expected for each recycling infrastructure for its target product. However, side streams can in turn end up in recycling plants specialized for this purpose and complement the overall recycling from the point of view of the recyclable material. For example, in a recycling plant for beverage bottles, the focus is on PET, while the sleeves and caps go to specialized plants for each. It is therefore necessary to take into account the cascade of the various processes and their specific yields in the calculation when determining an overall recovery rate. Discharged contaminants, if they are not further recycled, and portions used for energy purposes should not be added to a recovery quota. In addition, the removal or remaining of contaminants from the respective recycling processes must also be considered in the life cycle assessment methods.

If methods are used in which the material is mixed with other material flows and it is not recognizable on the product from which source the material originates, the calculation method for the output rate must be specified. If the dilution of the recycled raw material, e.g., with virgin material, has an influence on the processability of the material and on the output rate of the process, this must be taken into account in the calculation method. If intermediate products are produced, the yield should be determined on the basis of the resulting quantity from the subsequent process steps. If the substances are not used for the production of the original application, they should be excluded from the calculation in the sense of the Circular economy.

Collecting and assessing substances and recyclability
Materials are usually equipped with aggregates to meet specific requirements. These can include flame retardants, UV stabilizers, antioxidants, but also colourants or surface modifiers and much more [312]. These are added to the virgin material to meet product-specific requirements. In the case of recycling, undefinable soiling, e.g., due to organic build-up or incompletely emptied containers, is an additional complicating factor. There is also a need for information on this, which has an impact on recyclability.

In the field of recyclates, there is currently a lack of standards governing the testing of non-intentionally added substances (NIAS) as interfering materials. Therefore, the analysis methods and results of different testing laboratories sometimes differ greatly. At this point, both the analysis methods (sample preparation and processing and instrumental requirements for the equipment) and the substances to be analysed and their identification, including limit values, must be regulated via contaminant lists, which can be material-specific and/or application-specific. The need for standardization is preceded here by a need for research. Due to the number of possible substances, a clever, scientifically validated substance list in the sense of surrogates would be useful here in order to keep the effort economically viable.

The same applies to REACH [73]: Companies must identify and manage the risks of the substances and products they place on the market. At the same time, it is important not to impede the targeted use of recyclates for the creation of a circular cycle, which comply with these values, by imposing excessively high testing and verification hurdles. Increased contaminant input due to the use of recycled materials should continue to be ruled out. A solution must be found that takes these two objectives into account.

Since, due to the end-of-waste problem, disposers are taking the step from being disposers to being producers of raw materials, this topic takes on significant relevance. The handling of substances from long-life products that were permitted during manufacture but are now banned, but are nevertheless contained in the substance stream, should also be regulated, e.g., by a harmonized standard.

Looking ahead
Recyclability, by its very name, is one of the critical issues in creating a Circular Economy. Like the other four cross-cutting topics mentioned above, addressing the five key issues mentioned above has a significant influence on raising the quality of recycled materials and thus on market confidence in these recycled materials. This is accompanied by a need for data and information that can hardly be overestimated, ranging from consumers in front of the waste bin who need the right information for collection/sorting at the right time, to dismantling and/or repair companies, to the recycler of a 20-year-old component who needs information on the substances added at that time. The vast majority of this information can no longer be provided by traditional means alone, let alone in the required time. Here, a DPP with the – massive – IT infrastructure behind it is likely to be the critical part of the solution. This solution can only be achieved with appropriate standards and specifications.

Overview standardization needs for “recyclability”

Key topics	Digitalization/ Business models Management/	Electrotechnology & ICT	Batteries	Packaging	Plastics	Textiles	Construction & municipalities
Standardization needs	1.3	2.3	3.15	4.1	5.6	6.3	7.1
		2.4	3.16	4.2	5.10	6.4	7.6
		2.11	3.17	4.3	5.15	6.7	7.14
		2.12		4.4	5.20	6.10	
		2.15		4.5	5.22	6.13	
		2.17		4.6	5.23	6.26	
		2.21		4.7	5.24	6.27	
		2.34		4.8	5.25	6.28	
		2.36		4.12	5.26	6.29	
		2.37		4.17	5.28	6.30	
		2.28		4.18	5.35	6.31	
		2.40		4.20	5.37	6.32	
		2.41		4.21	5.38		
		2.42		4.22			
				4.23			
				4.24			
				4.25			
				4.26			
				4.27			
				4.28			

4
Looking ahead

4.1 Implementation of current standardization needs and consideration of further industries and industrial sectors

The Circular Economy is of particular importance in achieving the targets of the Green Deal and the Climate Change Act of 2021. To achieve the ambitious climate protection targets, new and revised technical rules for the Circular Economy are needed. The Standardization Roadmap Circular Economy sets the path for this, thus driving forward the green transformation of Germany and Europe. The coalition agreement between the SPD, Bündnis 90/Die Grünen and FDP also states “Dare to make more progress” [1]: “We are bundling existing raw materials policy strategies in a ‘National Circular Economy Strategy’. On this basis, we are advocating uniform standards in the EU.”

With the development of this Standardization Roadmap, a diverse German body of opinion was created for future standardization activities in the context of the Circular Economy. The stakeholder challenges discussed led to standardization needs with varying degrees of detail and links to existing standardization activities. These various outcomes of the Standardization Roadmap require different approaches/measures for implementation. In some cases, a clear assignment to existing standardization bodies is possible, and needs can be evaluated there at short notice with the relevant participants and translated into concrete standardization activities at national, European or international level. For other needs, further measures such as workshops are necessary to flesh out the needs and involve other key stakeholders.

An important aspect of this is bringing together stakeholders from the standardization bodies and those who were previously outside standardization and who have contributed to the development of the Roadmap. This is where a great deal of leverage is available to disseminate the national interests that have been developed at European and international level and to create standards that offer German industry, science and society a competitive advantage. This is crucial because standards and specifications are developed by those who later apply them.

The Standardization Roadmap Circular Economy focused on seven key topics, which were aligned with the focus topics of the European Commission’s Circular Economy Action Plan [4]: Digitalization, business models & management, electrotechnology & ICT, batteries, packaging, plastics, textiles and construction and municipalities. The topic of the Circular Economy is, of course, essential in numerous other industries and industrial sectors such as mobility, energy, and financial services, and is an integral part of strategies for the future. For this reason, not only will the identified standardization needs be implemented in 2023, but other key topics and their stakeholders will also be identified, and various measures will be used to jointly move from challenges to concrete standardization activities.

4.2 From the industrial policy to the overall social agenda of the circular society

Critical discussions of Circular Economy approaches emphasize that they are often conceived as ecological modernization based on an interpretation of progress oriented toward quantitative economic growth. By contrast, issues of social and cultural sustainability, social participation, global justice, or an expanded understanding of prosperity and quality of life remain largely unconsidered [313]. The term Circular Society is used by various stakeholders in research and practice to refer to discourses and approaches that go beyond a mainly technologically and economically oriented perspective of progress and understand the transition to circularity in a broader sense as a profound socio-ecological transformation.

In line with the United Nations’ Agenda 2030 and the 17 Sustainable Development Goals, standardization plays a key role in the transformation to a Circular Society: They support the achievement of economic, social and environmental goals that, based on principles of circularity and sustainability, help to fundamentally transform the sphere of production and consumption. The following socio-political question arises in relation to standardization: Is an industrial policy agenda that is primarily geared to economic growth still the guiding principle, or should standardization – as has already been called for in innovation policy from various quarters recently – be geared to a mission-oriented or socio-ecological transformation agenda? [314]

Standardization projects in the context of circularity must develop standards and specifications that provide methods, technologies and tools that achieve significant reductions (refuse, sufficiency) in the use of resources, oriented to a resource-conserving culture of economic activity. Appropriate standards and specifications should also lay the foundations for making product development processes more transparent and inclusive. In this way, future users of the products can be enabled to contribute themselves to extending the service life of products wherever possible (repair, do-it-yourself, upcycling). Standards can also open up new ways and forms of public participation in production processes and contribute to the formation of production and use communities (e.g., standards for the design of open source firmware). For example, user surveys, focus groups, or living labs could be integrated into the process to increase the needs orientation of products and services and to strengthen the competencies of users.

It becomes clear that the standardization needs of a circular society go far beyond R-strategies and also represent a challenge for the standardization process as such. Non-governmental rule-setters such as DIN, DKE and VDI, with their structure and working methods, offer great potential for consensus-based adaptation of technical and process systems based on broad participation and support. Thus, it will be crucial for the development of a circular society that stakeholders from all stages of the value chain are represented in standardization, that regenerative and reproductive concerns are strengthened vis-à-vis productive ones, and that the participation of concerned experts from non-industrial sectors is supported.

Annex and references

Index of abbreviations

Abbreviation	Meaning
B2B	Business 2 Business
B2C	Business 2 Customer
BattG	German Battery Act
BattVO	EU Battery Regulation
BESS	Battery energy storage system
BMS	Battery management system
BNB	Assessment system for sustainable construction
CDD	Common Data Dictionary
CED	Circular Economy Design
CPD	Circular Product Design
CSRD	Corporate Sustainability Reporting Directive
D4C	Design 4 Circularity
D4R	Design 4 Recycling
DPP	Digital Product Passport
DT	Digital twin
EFRAG	European Financial Reporting Advisory Group
ElektroG	German Electrical and Electronic Equipment Act
EoL-Phase	End-of-Life-Phase
EPD	Environmental Product Declaration
EPR	Extended Producer Responsibility
EPREL	European Product Registry for Energy Labelling
ESRS	European Sustainability Reporting Standards
EV	Electric vehicle
EVOH	Ethylene vinyl alcohol
GRP	Building resources passport
GWP 100	Global Warming Potential, time horizon of 100 years
IDIS	International Dismantling Information System

Abbreviation	Meaning
ICT	Information and communications technology
IMDS	International Material Data System
IR/NIR	Infrared/near infrared
IR/NIR-Sortierung	Infrared/near infrared sorting
SME	Small- and medium-sized enterprises
KRA, VDI	Resource efficiency-Cumulative raw material input
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCT	Life Cycle Thinking
LkSG	German Supply Chain Due Diligence Act
LLDPE	Linear low-density polyethylene
LMT	Light Means of Transport
MCI	Material Circularity Indicator
MFA	Material flow analysis
MFCA	Material Flow Cost Analysis
NIAS	Non-intentionally added Substances
PA	Polyamide
PBT	Polybutylene terephthalate
PC	Polycarbonate
PCR	Product Category Rules
PE	Polyethylene
PEF	Product Environmental Footprint
PET	Polypropylene
PP	Polyethylene terephthalate
PPE	Personal protective equipment
PTFE	Polytetrafluoroethylene
PVC	Polyvinyl chloride
RAMI 4.0	Reference Architecture Model Industrie 4.0

Abbreviation	Meaning
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RoHS	Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment
SCIP	Substances of Concern In articles as such or in complex objects (Products)
SDGs	Sustainable Development Goals
sLCA	Social Life Cycle Assessment
SoH	State of health
SPI	Sustainable Product Initiative
VOC	Volatile Organic Compounds
WBCSD	World Business Council for Sustainable Development
WEEE	Waste electrical and electronic equipment
XaaS	Everything-as-a-Service

Glossary

Where no source is given, the definition comes from the authoring team of this Standardization Roadmap.

Key topic	Term	Definition
Textiles	(Continuous) man-made fibre	A fibre of very great length, which is considered endless [331]
Batteries	Reuse	Additionally addresses ageing/degradation of batteries that must be considered This applies particularly to safety aspects [50]
Electrotechnology & ICT Digitalization/Business Models/Management Textiles	Waste	Any substance or object which the holder discards or intends or is required to discard [47]
Electrotechnology & ICT	Waste recovery (Recovery)	Any process the principal result of which is waste within the plant or in the wider economy that is put to a useful purpose by replacing other materials that would otherwise have been used to perform a specific function, or the waste that is prepared so as to fulfil that function [320]
Batteries	Battery management system BMS	Electronic system connected to a battery, with the functions of regulating the current in case of overcharge, overcurrent, deep discharge, and overheating, and which monitors and/or manages the state of the battery, calculates secondary data, reports this data, and/or controls its environment to affect the safety, performance, and/or life of the battery [321]
Batteries	Battery pack	An energy storage device consisting of one or more electrically connected cells or modules and having monitoring circuitry that provides information (e.g., cell voltage) to a battery system to influence the safety, performance, and/or life of the battery [321]
Batteries	Battery system	System which comprises one or more cells, modules or battery packs and has a battery management system capable of controlling current in case of overcharge, overcurrent, overdischarge and overheating [321]
Textiles	Biodegradability (Biodegradable material)	Material capable of undergoing biological aerobic or anaerobic degradation during a certain period of time, resulting in the release of carbon dioxide and/or biogas and biomass, depending on the environmental conditions of the process [226]
Textiles	Regenerated cellulosic fibre	Fibres produced from naturally occurring polymers of cellulose, where processing by dissolution is needed to convert them into fibre form [226]
	Circular Economy	Economy that is restorative and regenerative by design, and which aims to keep products, components and materials at their highest utility and value at all times, distinguishing between technical and biological cycles [8]
Textiles Plastics Packaging	Closed loop	System by which products, components and materials are used and then recovered and turned into new products indefinitely, without losing their inherent properties [Source [226] modified – “Textile products” replaced by “products, components and materials”]
Plastics Packaging	Design from recycling	Design, construction and processing for products in all industries that are to be made from recyclates or with the highest possible recyclate content from the outset
Digitalization/Business Models/Management Electrotechnology & ICT Packaging	Digital twin	A concept for modelling products as well as machines and their components using digital tools, including all geometry, kinematics and logic data. Replica of the physical “asset” in the real factory and allows its simulation, control and improvement [340]

Key topic	Term	Definition
Plastics Packaging Construction and municipalities	Downcycling	Production of recycled material that is of lower economic value or quality than the original product [226]
Textiles	Fibre Textile fibre	A unit of matter characterised by its flexibility, fineness and high ratio of length to maximum transverse dimension, which render it suitable for textile applications [238]
Textiles	Fast Fashion	Business model of the textile industry in which many collections are produced and marketed at short intervals at low prices
Electrotechnology & ICT Digitalization/Business Models/Management Textiles	Durability Longevity	Ability to function as needed under specified conditions of use, maintenance, and repair until a limited condition is reached [318]
Textiles	Yarn	Linear structure made of textile fibres (staple fibres, filaments or tapes, see DIN 60001 Part 2) [327]
Textiles	Yarn finishing Fabric finishing Clothing finishing (Textile finishing)	Chemical or mechanical action on a textile such as dyeing, bleaching, scouring, printing as well as an application to achieve a specified appearance (e.g., brushed), handle (softness and drape), quality (e.g., fabric stability) or functional finish (e.g., durable water repellency, antifelt treatment, easy care) on the textile [226]
Textiles	Geotextiles	Woven, nonwoven, or knitted permeable textiles used in civil engineering and related activities, usually made from synthetic materials (such as polypropylene) but can also be made from natural materials [334]
Textiles	Woven fabric	A textile fabric produced (by weaving on a hand loom or a weaving machine) by interlacing warp threads with weft threads normally at right angles to each other [329]
Textiles	Knit (Crocheted or knitted fabric)	Fabric made of one or more threads or of one or more thread systems by mesh formation [328]
Textiles Plastics	Greenwashing	Unsubstantiated or misleading claim about the positive or negative environmental aspects of a product, service, technology or business practice [337]
Electrotechnology & ICT	Harmonized standard	A standard developed by one of the European standardization bodies listed in Annex I to Directive 98/34/EC of the European Parliament and of the Council of 22 June 1998 laying down a procedure for the provision of information in the field of technical standards and regulations and of rules on information society services, on the basis of a request from the Commission pursuant to Article 6 of Directive 98/34/EC [109]
Electrotechnology & ICT Digitalization/Business Models/Management	Component	Hardware component of a product that cannot be removed without destroying or impairing its intended use [319]
Electrotechnology & ICT	Critical raw material CRM	Material that is economically important according to a defined classification procedure and whose provision is associated with a high level of risk [317]
Textiles	Synthetic fibre	Fibre produced by conversion of natural polymers (macromolecular material occurring in nature) [332]

Key topic	Term	Definition
Textiles Plastics Cross-cutting topic Construction and municipalities Electrotechnology & ICT Digitalization/Business Models/Management	End of life EoL	Life cycle phase of a product, if proper waste management is applied to disposed end-use products [336] Also: Phase in the life cycle of a product that begins at the time the product is removed from its intended use phase [320]
Plastics Cross-cutting topics	Life Cycle Costing (LCC)	Method of calculating the cost of goods or services throughout their life cycle [8]
Electrotechnology & ICT	Material	Substance or mixture of substances in a product or component [317]
Batteries	Module	Group of cells connected to each other in either a series and/or a parallel circuit, with or without protective devices (e.g. fuse or PTC) and monitoring circuit [323]
Textiles	Natural fibres	Natural fibres are the fibres found in nature; these can be classified according to their origin as animal fibres, vegetable fibres and mineral fibres [330]
Textiles	Virgin raw material	Material that has not been subjected to use or processing other than that required for its initial manufacture [226]
Plastics Textiles Packaging	Life cycle assessment (LCA)	Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle [80]
Textiles Plastics Packaging	Open loop	System of products, components and materials transferred into another material category or application with a minimal loss of purity or quality [Source [226] modified – first half of sentence replaced with "System of products, components and materials"]
Textiles Plastics	Post-industrial waste	Materials that come from unavoidable waste from textile production [226]
Textiles Plastics Packaging	Post-consumer waste	Descriptive term covering material, generated by the end-users of products, that has fulfilled its intended purpose or can no longer be used (including material returned from within the distribution chain) [335]
Textiles	Pre-Consumer Waste	Descriptive term covering the product before it reaches the customer, such as off-class products, damaged or obsolete products; is often used interchangeably with post-industrial textile [226]
Batteries	Primary cell battery Non-rechargeable general purpose portable batteries	Cell or battery that is not designed to be electrically recharged after discharging [324]
Digitalization/Business Models/Management	Product	Result of labour or of a natural or industrial process [339]
Textiles Construction and municipalities	Recycled content	Proportion, by mass, of recycled material in products. Only pre-consumer and post-consumer materials shall be considered as recycled content [226]

Key topic	Term	Definition
Digitalization/Business Models/Management	Reference Architecture Model Industrie 4.0 (RAMI 4.0)	The reference architecture model Industrie 4.0, or RAMI 4.0 for short, represents a basic architecture for Industrie 4.0 as a three-dimensional layer model using a sophisticated coordinate system [74]
Textiles Electrotechnology	Repairability	Characteristic of a textile product that allows all or some of its parts to be separately repaired or replaced without having to replace the entire product [226]
Textiles Plastics	Pollutant, impurity, harmful substance, interfering substance (Contaminant)	Unwanted substance or material [335]
Batteries	Secondary battery Rechargeable battery	Cell intended for an electrical recharge [325]
Electrotechnology & ICT	Substance	Chemical elements and their compounds in the natural state or obtained by a manufacturing process, including additives necessary to maintain the stability of the product and impurities resulting from the process used, but excluding solvents which can be separated from the substance without affecting its stability and without altering its composition [317]
Textiles	Man-made fibre (Artificial fibre)	Fibre obtained by a manufacturing process [333]
Textiles	Textile product Textile	A product containing exclusively textile fibres in the raw, semi-processed, processed, semi-manufactured or made-up state, regardless of the process used to blend or combine them [238]
Digitalization/Business Models/Management Plastics	Upcycling	Process to convert waste products to new materials that are of higher economic value or quality than in the original product [226]
Electrotechnology & ICT	Upgrade Upgradeablility	Process of increasing the functionality, performance, capacity, or aesthetics of a product [338]
Electrotechnology & ICT	Wear (Wear out failure)	Failure due to cumulative deterioration caused by the stresses imposed in normal use [318]
Textiles	Nonwoven fabric	Engineered fibrous assembly primarily planar, which has been given a designed level of structural integrity by physical and/or chemical means, excluding weaving, knitting or papermaking [326]
Batteries	Cell	Basic functional unit, consisting of an assembly of electrodes, electrolyte, container, terminals and, usually, separators that is a source of electric energy obtained by direct conversion of chemical energy [322]
Textiles	Textile process waste (Waste from textile processing)	Substances or objects from textile processes which the holder intends to or is required to dispose of [226]
Electrotechnology & ICT	Reliability	Probability that a product will function under the given conditions, including maintenance, for functions as required for a given period of time without a limiting event [318]

Index of authors

Heads of working groups

Joachim Felix Aigner, W. L. Gore & Associates GmbH

Peter Bartel, Circular Economy Solutions GmbH

Prof. Dr. Andrea Büttner, Fraunhofer-Institut für Verfahrenstechnik und Verpackung IVV

Dr. Edith Claßen, Hohenstein Institut für Textilinnovation gGmbH

Prof. Dr. Hans-Josef Endres, Institut für Kunststoff- und Kreislauftechnik, Leibniz Universität Hannover (LUH)

Dr. Jens Giegerich, Vorwerk & Co. KG

Prof. Dr. Peter Jehle, Technische Universität Dresden

Prof. Andrea Klinge, Fachhochschule Nordwestschweiz FHNW, ZRS Architekten Ingenieure

Nicole Kösegi, solutions for business

Prof. Dr. Horst-Christian Langowski, Fraunhofer-Institut für Verfahrenstechnik und Verpackung IVV

Dr. Harald Lehmann, REMONDIS Recycling GmbH & Co. KG

Mario Malzacher, circular.fashion UG

Dr. Christian Rosenkranz, Clarios Germany GmbH & Co. KG

Prof. Eike Roswag-Klinge, Technische Universität Berlin, ZRS Architekten Ingenieure

Dr. Moritz-Caspar Schlegel, Bundesanstalt für Materialforschung und -prüfung (BAM)

Dr. Henning Wilts, Wuppertal Institut für Klima, Umwelt, Energie gGmbH

Heads of sub-working groups

Holger Alwast, Alwast Consulting

Prof. Dr. Gesa Beck, Institut für Angewandte Ressourcenstrategien, SRH Berlin University of Applied Science

Karlheinz Blay, SGS Institut Fresenius

Agnes Bünemann, cyclos GmbH

Martin Doedt, Kunststoff-Institut Lüdenscheid

Charlotte Dorn, Technische Universität Dresden

Prof. Dr. Jürgen Graf, Technische Universität Kaiserslautern

Christiane Grünewald, TÜV SÜD Product Service GmbH

Monica Harting Pfeifer, REMONDIS Recycling GmbH & Co. KG

Ansgar Hoffmann, HOFFMANN + VOSS GmbH

Karsten Hunger, Industrieverband Papier- und Folienverpackung e. V. (IPV)

Dr. Achim Ilzhöfer, Covestro AG

Dr.-Ing. Stephan Kabasci, Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik UMSICHT

Prof. Maren Kohaus, Bayerische Architektenkammer, Technische Hochschule Rosenheim, sustainable architecture GmbH

Monika Korbmann, Duale Hochschule Baden-Württemberg Karlsruhe

Dr. Jan Kortmann, Technische Universität Dresden

Johannes Leis, Sächsisches Textilforschungsinstitut e. V.

Kathrin Lenz, SEA ME GmbH

Holger Lühn, Kautex Textron GmbH & Co. KG

Klaus Meyer, Energie Impuls OWL e. V.

Dr. Julia Migenda, BASF SE

Tom Ohlendorf, WWF Deutschland

Dr. Anika Oppermann, Mehrwegverband Deutschland e. V., shafuto

Dr. Susanne Pankov, DFGE Institute for Energy, Ecology and Economy

Jörg Rodehutskors, Innovation Campus Lemgo e. V.

Klemens Sattlegger, XIPHOO GmbH

Gabi Schock, Umweltberatung Gabi Schock

Carolin Senkel, Technische Universität Dresden

Nicole Seyring, circulatemore

Dr. Madina Shamsuyeva, Institut für Kunststoff- und Kreislauftechnik, Leibniz Universität Hannover (LUH)

Henning H. Sittel, Effizienz-Agentur NRW

Dieter Stellmach, Deutsche Institute für Textil- und Faserforschung Denkendorf (DITF)

Sebastian von Oppen, Bundesarchitektenkammer e. V.

Jenny Walther-Thoß, Berndt+Partner Consultants GmbH

Dr. Karl-Anders Weiß, Fraunhofer-Institut für Solare Energiesysteme ISE

Reinhard Weissinger, Universität Genf

Ingomar Welke, Greenance

Rainer Zies, MKV GmbH Kunststoffgranulate

Iris Zwickel-Bakker, CPV Circular Performance & Verification

Further authors

Thomas Ahlmann, Dachverband FairWertung e. V.

Levke Albertsen, Stiftung KlimaWirtschaft

Lore Ameel, Concular GmbH

Florian Andrews, Grüner Hering – Agentur für Circular Economy

Thomas Anton, Hochschule Trier – Umwelt Campus Birkenfeld

Fabian Anzmann, HKI – Industrieverband Haus-, Heiz- und Küchentechnik e. V.

Alexander Appel, MHP Management und IT-Beratung GmbH

Prof. Dr. Vasiliki-Maria Archodoulaki, Technische Universität Wien

Dr. Bastian Bach, Siemens AG

Daniel Bahro, EnBW Energie Baden-Württemberg AG

Dr. Sandra Balzereit, ALBIS Distribution GmbH & Co. KG

Maximilian Bannasch, circolution GmbH

Andreas Bastian, plastship GmbM

Ralf Benecke, sonnen GmbH

Alexandra Berendes, reCup GmbH

Anna Bergmann, reCup GmbH

Iris Berneder, TÜV SÜD AG

Jürgen Bertling, Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik

Anton Berwald, Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration IZM

Tobias Bielenstein, Arbeitskreis Mehrweg GbR

Stefanie Bierwirth, DIN Deutsches Institut für Normung e. V.

Prof. Stephan Birk, Technische Universität München

Dr. Petra Blumenroth, Bayern Innovativ GmbH

Anna Blunck, Avocado Store GmbH

Dr. Ralph Boch, Hans Sauer Stiftung & Circular Society Roadmap Team

Michel Böhm, GdW Bundesverband deutscher Wohnungs- und Immobilienunternehmen e. V.

Tillmann Böhme, HolyPoly GmbH

Boris Böhme, Bundesministerium für Wirtschaft und Klimaschutz

Pamela Böhmke, PerZero Stiftung & Co. KG

Janik Bollé, IVK-Industrieverband Klebstoffe e. V.

Evelin Bong, FALKE KGaA

Dr. Anne Bonhoff, UL GmbH (UL Solutions)

Simone Boyles, Duni Group

Stefanie Brauer, Forum MedTech Pharma e. V.

Manfred Braun, Schneider Electric GmbH

Michael Braun, Medienhaus Waltrop

Julia Breidenstein, HUMANA Kleidersammlung GmbH

Dr. Frank Brozowski, Umweltbundesamt

Dr. Tim Brückmann, DKE Deutsche Kommission Elektrotechnik Elektronik und Informationstechnik

Dr. Andreas Bruckschen, BDE Bundesverband der Deutschen Entsorgungs-, Wasser- und Kreislaufwirtschaft e. V.

Prof. Dr. Lennart Brumby, DHBW Duale Hochschule Baden-Württemberg

Bianca Brunke, DMK Deutsches Milchkontor GmbH

Robert D. Brunner, B´IMPRESS

Prof. Dr. Roman Brylka, THE GREEN BRIDGE Ingenieurgesellschaft mbH

Rainer Buchholz, WirtschaftsVereinigung Metalle e. V.

Ina Budde, circular.fashion UG

Dr. Frauke Bunzel, Fraunhofer-Institut für Holzforschung, Wilhelm-Klauditz-Institut WKI

Erik Bunzel, GOLDBECK GmbH

Katrin Büscher, ASA e. V. Arebitsgemeinschaft Stoffspezifische Abfallbehandlung

Dr. Rolf Buschmann, International Association for Sustainable Building an Living – natureplus e. V.

Dominik Campanella, Concular GmbH

Arne Campen, Apple GmbH

Dr. Alessio Campitelli, Technische Universität Darmstadt

Prof. Evelyn Canelas-Santiesteban, Universidad Privada Boliviana

Dr. Caroline Cassignol, Siemens AG

Dr. Bahar Cat-Krause, bck2planet

Dr. Mohammad Chehadé, Rheinisch-Westfälische Technische Hochschule (RWTH) Aachen

Sylvi Claußnitzer, Zentralverband des Deutschen Baugewerbes e. V.

Tim Cramm, Flughafen Berlin Brandenburg GmbH

Prof. Dr. Rainer Dahlmann, Rheinisch-Westfälische Technische Hochschule (RWTH) Aachen

Sebastian Daus, FixFirst – Prodisfy UG

Jan de Meer, Hochschule für Technik und Wirtschaft Berlin, smartspacelab.eu GmbH

Ute Dechantsreiter, Dipl.-Ing. Architektin Ute Dechantsreiter Architekturbüro für nachhaltiges Bauen

Sascha Dechow, Talado Recycling GmbH

Gustav Dengel, Jokey SE

Prof. Dr. Michael Denzer, Hochschule Biberach

Kamelia Detig-Karlou, BMW AG

Marc Diefenbach, rhinopaq

Dr. Stefan Dirlich, Helmholz-Zentrum Dresden-Rossendorf e. V.

Thomas Dittrich, Beratung Normung und Gefahrgut

Dr. Alice do Carmo Precci Lopes, Technische Universität Darmstadt

Merle Doliwa, Implement Consultin Group

Michael Dörnert, Hera GmbH & Co. KG

Bernd Dörre, European Pallet Association e. V. (EPAL)

Georg Dost, Polysecure GmbH

Hagen Droste, droste consult

Chris Droste, Pöppelmann GmbH & Co. KG

Patrick Düren-Rost, Institut Feuerverzinken GmbH

Danuta Dworaczek, Industrieverband Klebstoffe e. V.

Christian Dworak, BSH Hausgeräte GmbH

Laura Echternacht, GS1 Germany GmbH

Prof. Dr. Silke Eckardt, Hochschule Bremen

Robert Eckert, FRIATEC Aktiengesellschaft

Julia Eckert, Gesamtverband textil+mode

Andreas Ellenberger, QBE-ProSense GmbH

Dietmar Endres, TÜV SÜD Product Service GmbH

Alexandra Engelt, DIN Deutsches Institut für Normung e. V.

Heiner Englisch, Röchling SE & Co. KG

Ludolf C. Ernst, ERNST | RECHT Anwaltskanzlei

Niklas Ernst, RecycleMe GmbH (Deutschland)

Dr. Sonja Eser, Sinnenwandel

Dominique Essigkrug, DIN Deutsches Institut für Normung e. V.

Birgit Essling, Lippe zirkulär, Kreis Lippe

Helen Yi Fabian, Panasonic R&D Center Germany GmbH

Alexandra Fabricius, DKE Deutsche Kommission Elektrotechnik Elektronik und Informationstechnik

Leonie Feist, Phoenix Contact Gruppe

Prof. Dr. Sabine Flamme, Fachhochschule Münster

Hermann Fraidling, HANS KOLB Wellpappe GmbH & Co. KG

Dr. Christian Frank, SIKORA AG

Gregor Franßen, Franßen & Nusser Rechtsanwälte PartGmbB

Lorena Franz, GOLDBECK GmbH

Prof. Dr. Henning Friege, N³ Nachhaltigkeitsberatung Dr. Friege & Partner

Melanie Lisa Fürch, TEXAID Textilverwertungs-AG

Susanne Gaksch, Siemens AG

Creta Gambillara, Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH

Kai Garrels, ABB Asea Brown Boveri Ltd

Dr. Jens Gayko, DKE Deutsche Kommission Elektrotechnik Elektronik und Informationstechnik

Dr. Anja Geburtig, Bundesanstalt für Materialforschung und -prüfung (BAM)

Dr. Frauke Germer, Hochschule Bremen

Tanguy Gernigon, Deutscher Textilreinigungs Verband -DTV- e. V.

Andreas Gessner, Siemens Mobility

Jan-Hinrich, Gieschen, VDI/VDE Innovation + Technik GmbH

Dr. Ludwig Glatzner, Dr. Ludwig Glatzner Münstersches Büro für Umwelt, Qualität und Sicherheit

Torsten Göth, Weberei Pahl GmbH

Kai-Uwe Götz, Gesamtmasche e. V.

Andrea Gräfe, bardusch GmbH & Co. KG

Manfred Graudejus, SEW-EURODRIVE GmbH & Co KG

Dr. Kathrin Greiff, Rheinisch-Westfälische Technische Hochschule (RWTH) Aachen

Jakob Grelck, Concular GmbH

Laura Griestop, WWF Deutschland

Dr. Daniel Gruber, BellandVision GmbH

Sören Grumptmann, VDMA e. V.

Arne Grünewald, VDE Renewables GmbH

Elisa Guimaraens, Polysecure GmbH

Dr. Susanne Guth-Orlowski, Spherity GmbH

Andreas Habel, bvse-Bundesverband Sekundärrohstoffe und Entsorgung e. V.

Herbert Haberl, Fachgemeinschaft für Lebensdienlichkeit und Wohlergehen

Jens Hack, Umicore

Prof. Dr. Annette Hafner, Ruhr-Universität Bochum

Tabea Hagedorn, Technische Universität Darmstadt

Dr. Tim Hahn, Oexle Kopp-Assenmacher Lück Partnerschaft von Rechtsanwälten mbB

Carolin Hamm, Fraunhofer-Institut für Produktionstechnologie IPT

Sigrid Hams, Fachhochschule Münster

Dr. Ronny Hanich-Spahn, Fraunhofer-Institut für Chemische Technologie

Andreas Hänsch, Trans-Textil GmbH

Melanie Hanstedt, Handwerkskammer Braunschweig-Lüneburg-Stade Körperschaft des öffentlichen Rechts

Martin Hartmann, Verband der Keramischen Industrie e. V.

Marion Hasper, Bund für Umwelt und Naturschutz Deutschland e. V. (BUND) – Friends of the Earth Germany

Fynn Hauschke, Ökopol Institut für Ökologie und Politik GmbH

Christian Hauspurg, Thüringisches Institut für Textil- und Kunststoff-Forschung Rudolstadt e. V. (TITK)

Dr. Vera Haye, Industrieverband Klebstoffe e. V.

Franziska Heckel, Hochschule Pforzheim – Gestaltung, Technik, Wirtschaft und Recht

Andrea Heil, EPEA GmbH – Part of Drees & Sommer

Benjamin Hein, DIN Deutsches Institut für Normung e. V.

Patrick Heininger, VDE Renewables GmbH

Beate Heisterkamp, BP Europa SE

Christoph Heller, Zentek GmbH & Co. KG

Andre Hempel, lab of rent e.K.

Nadja Hempel, Hans Sauer Stiftung

Nadja Hempel, Hans Sauer Stiftung & Circular Society Roadmap Team

Dr. Benedikt Hendan, TÜV SÜD Product Service GmbH

Isabelle Henkel, Deutsche Gesellschaft für Abfallwirtschaft e. V. (DGAW)

Dirk Hensch, Braskem, Open Innovation

Prof. Dr. Anja Hentschel, Hochschule Darmstadt

Dr. Robert Hermann, TÜV SÜD Landesgesellschaft Österreich GmbH

Sanya Hermes, LANXESS Deutschland GmbH

Barbara Hettche, Charta der Vielfalt e. V.

Dr. Marta Heuser, APK AG

Sandra Heydel, Verband der Chemischen Industrie e. V. Landesverband Nordrhein-Westfalen

Thomas Hilche, Genossenschaft Deutscher Brunnen eG

Esther Hild, ZVEI e. V.

Uwe Hilmer, Detlef Hegemann Umwelttechnik GmbH

Christian Hinz-Morgenstern, DS Smith Plc

Dr. Thomas Hipke, Fraunhofer-Institut für Werkzeugmaschinen und Umformtechnik IWU

Gudrun Höck, BTE Bundesverband des Deutschen Textil-, Schuh- und Lederwareneinzelhandels e. V.

Daniel Hoffmann, Verband Deutscher Metallhändler und Recycler e. V.

Detlef Hoffmann, Webasto SE

Dr. Florian Hofmann, BTU Cottbus-Senftenberg & Circular Society Roadmap Team

Timm Hollstein, Umweltbundesamt

Stephanie Hölzen, CRRC New Material Technologies GmbH

Prof. Dr. Helmut Horn, Hochschule für Angewandte Wissenschaften Hamburg (HAW Hamburg)

Bernd Horrmeyer, PHOENIX CONTACT Deutschland GmbH

Sabine Huck, Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz (BMUV)

Roland Huempfner

Mona Huschyar, Verband der Nordwestdeutschen Textil- und Bekleidungsindustrie e. V.

Merle Hüsgen, Rheinisch-Westfälischen Technischen Hochschule (RWTH) Aachen

Prof. Dr. Wolfgang Irrek, Hochschule Ruhr West

Constance Ißbrücker, European Bioplastics e. V. (EUBP)

Dr. Anne Ixmeier, Ludwig-Maximilians-Universität München

Prof. Dr. Melanie Jaeger-Erben, BTU Cottbus-Senftenberg & Circular Society Roadmap Team

Prof. Dr. Melanie Jäger-Erben, BTU Cottbus-Senftenberg, Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration IZM

Dr. Michael Jahr, APK AG

Pauline Jegen, INZIN e. V.

Robert Jöst, Bundesgemeinschaft der Architektenkammern, Körperschaften des Öffentlichen Rechts e. V.

Uwe Junglas, DKE Deutsche Kommission Elektrotechnik Elektronik und Informationstechnik

Christian Kalytta, CEMEX Deutschland AG

Tina Kammer, InteriorPark

Prof. Dr. Anette Kämpf-Dern, Frankfurt University of Applied Sciences

Benjamin Kampmann, Pöppelmann GmbH & Co

Patric Kannberg, OBJECT CARPET GmbH

Robert Kapferer, Circularity Germany GmbH i.G.

Michael Kappler, rethink now GmbH

Marcus Keppelen-Frech, SEW-EURODRIVE GmbH & Co. KG

Marcel J.Q. Keuenhof, Netherlands Institute for Sustainable Packaging (KIDV)

Nicole Kiefer, MEWA Textil-Service AG & Co. Management OHG

Prof. Matthias Kimmerle, Hochschule Albstadt- Sigmaringen

Rainer Kimmich, SEW-EURODRIVE GmbH & Co KG

Dr. Manfred Kircher, KADIB-Kircher Advice in Bioeconomy

Karina Klaes, Phoenix Contact GmbH & Co. KG

Prof. Dr. Wolfgang Klett, Oexle Kopp-Assenmacher Lück Partnerschaft

Dr. Mathias Kliem, Kunststoff-Zentrum in Leipzig gemeinnützige Gesellschaft mit beschränkter Haftung

Dr. Christian Klünder, Philips Semiconductors GmbH

Gerald Knauf, Wissenschaftsladen Bonn e. V.

Dörthe Knefelkamp, Fachhochschule Bielefeld

Roland Knobloch, Saft Groupe SAS

Torben Knöß, IK Industrievereinigung Kunststoffverpackungen e. V.

Beate Kolkmann, Food-Processing Initiative e. V.

Ludwig Kopp, De'Longhi Group

Lea Körber, BellandVision GmbH

Lena Kramer, iPoint-systems gmbh

Dipl.-Ing. Martin Krausewitz, HDB Recycling GmbH

Dr. Eike Kretzschmar, IVKP Vertreterin

Sven Kristen, Siemens AG

Petra Krücken, Trevira GmbH

Dirk Krüger, The Dow Chemical Company

Diana Krüger, Bayerischer Industrieverband Baustoffe, Steine und Erden e. V.

Jacques Kruse Brandao, SGS Société Générale de Surveillance SA

Dr. Wilhelmine Kudernatsch, VDI/VDE Innovation + Technik GmbH

Marlene Kühn, Bündnis Textil der Cradle to Cradle NGO

Luise Henriette Kuhr, Hessischer Industrie- und Handelskammertag (HIHK) e. V.

Dr. Beate Kummer, Polysecure GmbH

Ulrike Künnemann, InnoZent OWL e. V.

Dr. Robert Kupfer, Technische Universität Dresden

Morris Kurz, hey circle GmbH

Tina Kussin, WWF Deutschland

Christoph Küsters, 3M Deutschland GmbH

Silke Küstner, WWF Deutschland

Tobias Lachnit, Technische Universität Berlin

André Lang-Herfurth, SEA ME GmbH

Isabella Leber, Hochschule RheinMain

Susanne Lehmann-Brauns, Fraunhofer-Institut für Bauphysik IBP

Sebastian Lemp, ALPLA Werke Alwin Lehner GmbH & Co KG

Nicola Leopold Ackermann, SGS Holding Deutschland B.V. & Co. KG

Barbara Lersch, Hans Sauer Stiftung & Circular Society Roadmap Team

Bernd Lesker, MAPEI GmbH (DE)

Thomas Leucht, Weber & Leucht GmbH Application Lab

Selina Leusch, LANXESS Deutschland GmbH

Greta Leutzbach, Avocado Store GmbH

Frank Liesner, Knauf Gips KG

Thorsten Lindner, Bundesministerium für Wirtschaft und Technologie BMWi

Dr. Elske Linß, Materialforschungs- und -prüfanstalt an der Bauhaus-Universität Weimar

Michael Lipka, Huawei Technologies Co., Ltd.

Michael Löscher, Schwarz Unternehmenskommunikation GmbH & Co. KG

Henning Ludwig, PrimePort GmbH

Ilona Maennchen, Art und Scenography-Design

Stefan Maier, Forschungszentrum Jülich GmbH

Ines Mansfeld, NEVARIS Bausoftware GmbH

Marvin Marek, bauforumstahl e. V.

Dr. Max Marwede, Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration IZM

Nina Masson, Cyclic Design UG (haftungsbeschränkt)

Dr. Stefan Mathis, ebm-papst Mulfingen GmbH & Co. KG

Lisa Matthies, Brands Fashion GmbH

Ralph Matthis, Bundesinnungsverband des Glaserhandwerks

Prof. Dr. Johanna May, Technische Hochschule Köln

Annekatrin Mayer, DIN Deutsches Institut für Normung e. V.

Dr. Martin Mayershofer, Sympatex Technologies GmbH

Julian Meier, MOCOM Compounds GmbH & Co. KG

Prof. Dr. Gavin Melles, Technische Universität Dresden

Aslihan Memisoglu, Hochschule Niederrhein

Kilian Menzel, Hochschule für Technik, Wirtschaft und Kultur Leipzig

Dr. Thomas Merkel, FEhS – Institut für Baustoff-Forschung e. V.

Dr. Renate Messing, UL LLC

Hannah Metzger, Horn & Co. Group

Dr. Rüdiger Meyer, Phoenix Contact GmbH & Co. KG

Steffen Meyer, Pöppelmann GmbH & Co. KG

Maximilian Meyer, Meyer Recycling und Bauschutt-deponie GmbH

Gunter Miegel, HolyPoly GmbH

Dr. Jürgen Miller, SEW-EURODRIVE GmbH & Co KG

Jochen Moesslein, Polysecure GmbH

Wolfgang Möller, Schneider Electric GmbH

Volker Molthan, BUND e. V.

Claudia Mommer, Lenzing AG

Marina Mönikes, Phoenix Contact GmbH & Co. KG

Christoph Mönnigmann, Bundesministerium für Wirtschaft und Klimaschutz (BMWK)

Yannick Motcheu, ElringKlinger AG

Janine Mügge, Fraunhofer-Institut für Produktionsanlagen und Konstruktionstechnik IPK

Dr. Michael Müller, Rosenberger Hochfrequenztechnik GmbH & Co. KG

Franziska Müller, Senatsverwaltung für Umwelt, Mobilität, Verbraucher- und Klimaschutz Berlin

Peter Müller, logsolut AG

Torsten Müller, Fraunhofer-Institut für Chemische Technologie ICT

Frank Müller, VG-ORTH GmbH & Co.KG

Markus Müller-Drexel, Interseroh+ GmbH

Brendan Muscutt, Umicore NV/SA

Dr. Marcel Neitsch, Bundesanstalt für Materialforschung und -prüfung (BAM)

Johanna Nesselhauf, PreZero Stiftung & Co. KG

Arianna Nicoletti, Circular City – Zirkuläre Stadt e. V.

Martin Nieberl, Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik UMSICHT

Jens Nießmann, Reclay Holding GmbH

Dieter Niggemeier, Duttenhöfer T+L GmbH & CO. KG

Heinz Noe, Schneider Electric GmbH

Harald Notz-Lajtkep, Hohenstein Laboratories GmbH & Co. KG

Dr. Ines Oehme, Umweltbundesamt

Dr. Ronald Orth, Fraunhofer-Institut für Produktionsanlagen und Konstruktionstechnik IPK

Mario Ortmann, Rittal GmbH & Co. KG

Daniel Pacner, Verband der Automobilindustrie e. V. (VDA)

Dina Padalkina, Circular City – Zirkuläre Stadt e. V.

Susanne Pass, Dialog Textil-Bekleidung e. V.

Jan Patzer, Crafting Future GmbH

Anna Pehrsson, TEXAID Beteiligungsverwaltung Deutschland GmbH

Falk Petrikowski, Umweltbundesamt

Jan Philipp Borrmann, Denso Corporation

Franziska Pichlmeier, Hochschule München

Dr. Christiane Plociennik, Deutsches Forschungszentrum für Künstliche Intelligenz GmbH (DFKI)

Martin Pohner, SEW-EURODRIVE GmbH & Co KG

Martin Pool, POOL LEBER ARCH. Architekten Stadtplaner BDA

Michael Poschmann, WKW Aktiengesellschaft

Katja Prasol, Biophysical Tools GmbH

Lisa Pusch, Kreis Lippe

Bardo Quint, Mercedes-Benz Group AG

Julia Rätzer, Metecno Bausysteme GmbH

Andrea Rechtsteiner, RECHTSTEINER – Andrea Rechtsteiner CONSULTING Beratungs- und Dienstleistungsunternehmen

Dr. Max Rehberger, TÜV SÜD AG

Gregor Reischle, AM Entrepreneur

Dr. Jean-Francois Renault, Forschungszentrum Jülich GmbH

Matthias Reuter, Verband der Deutschen Heimtextilien-Industrie e. V.

Anja Reveriego Wind, Interseroh+ GmbH

Albrecht Richter, InformationsZentrum Beton GmbH

Jörn Richter, Heidemann Recycling GmbH

Jakob Ries-Kalteich, Avocado Store GmbH

Dr. Lisa Risch, acatech – Deutsche Akademie der Technikwissenschaften e. V.

Tim Risthaus, ElringKlinger AG

Lisa Rödig, Ökopol Institut für Ökologie und Politik GmbH

Lukas Romanowski, GOLDBECK GmbH

Prof. Dr. Anja Rosen, Bergische Universität Wuppertal

Thiemo Rößle, SICK AG

Sascha Roth, BDE Bundesverband der Deutschen Entsorgungs-, Wasser- und Kreislaufwirtschaft e. V.

Karl Rottnick, Verband Deutscher Maschinen- und Anlagenbau e. V. (VDMA)

Christian Rudolf, MHP Management- und IT-Beratung GmbH

Christine Ruiz Duran, Deutsche Gesellschaft für Nachhaltiges Bauen – DGNB e. V.

Tilman Rüsch, Back Market Germany GmbH

Dr. Regina Sachse, TÜV SÜD Energietechnik GmbH

Cathrine Sachweh, LIST AG

Dr. Kerstin Sann-Ferro, DKE Deutsche Kommission Elektrotechnik Elektronik und Informationstechnik

Elke Schäfer, Henkel AG & Co. KGaA

Nora Schäfer, Ministerium für Umwelt, Landwirtschaft, Natur- und Verbraucherschutz des Landes Nordrhein-Westfalen

Michael Scharpf, Holcim Deutschland GmbH

Manuel Schaubt, Institut für angewandtes Stoffstrommanagement (IfaS)

Dr. Robert Scherf, Fraunhofer-Institut für Grenzflächen- und Bioverfahrenstechnik IGB

Dr. Celine Schielke, DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e. V.

Achim Schier, HARTING Deutschland GmbH & Co. KG

Michaela Schierholz, DIN Deutsches Institut für Normung e. V.

Maximilian Schildt, Lehrtstuhl für Energieeffizientes Bauen (E3D), RWTH Aachen University

Levin Schilling, Technische Universität Dresden

Jennifer Schinkel, Wuppertal Institut für Klima, Umwelt, Energie gGmbH

Adrian Schlegel, Hans Sauer Stiftung & Circular Society Roadmap Team

Dr.-Ing. Miriam Schleipen, EKS InTec GmbH

Barbara Chr. Schlesinger

Simon W. Schmeisser

Jonas Schmidle, Bananeira GmbH & Co. KG

Stefan Schmidmeyer, bvse-Bundesverband Sekundärrohstoffe und Entsorgung e. V.

Dr. Christian Schmidt, Jowat SE

Stephan Schmidt, Miele & Cie. KG

Christine Karin Schmidt, VDMA e. V. Textilmaschinen

Sebastian Schmidt, Senatsverwaltung für Umwelt, Mobilität, Verbraucher- und Klimaschutz Berlin

Stefan Schmidt, Industrieverband Veredlung-Garne-Gewebe-Technische Textilien e. V.

Dr. Julia Schmitt, Johannes Kepler Universität Linz

Christian Schmitz, Honeywell GmbH

Michael Schmitz, Jokey SE

Thorsten Schmitz, EKS InTec GmbH

Dr. Guido Schmülling, Commeo GmbH

Heike Schneeweiß, Knauf Gips KG

Andreas Schneider, Sony Professional Solutions Europe

Dr. Tanja Schneider, ElringKlinger AG

Nico Schneider, Technische Hochschule Deggendorf

Andreas Schneider, Global Textile Scheme GmbH

Fabian Schoden, Fachhochschule Bielefeld

Joachim Schonowski, msg systems ag

Juana Schons, Thüringer Energie- und GreenTech-Agentur GmbH (ThEGA)

Sven Schöppe, LEO System GmbH

Theresa Schreiner, Kelheim Fibres GmbH

Karsten Schubert, CEMEX Deutschland AG

Anna Schulte, Fraunhofer-Institut für Umwelt-, Sicherheits- und Energietechnik UMSICHT

Felix Schulz, HolyPoly GmbH

Jürgen Schulz, Metecno Bausysteme GmbH

Andreas Schumacher, Deutscher Textilreinigungs-Verband e. V. (DTV)

Jörg Schumacher, Bundesarchitektenkammer e. V.

Marcel Schuricht, Hochschule für nachhaltige Entwicklung Eberswalde (HNEE)

Anne Schütte, Handwerkskammer Hildesheim-Südniedersachsen

Antonia Schüttler, Interzero GmbH & Co. KG

Rainer Schweda, Braskem Europe GmbH

7In memoriam Thomas Schwilling, Senatsverwaltung für Umwelt, Verkehr und Klimaschutz Berlin

Hanna Seefeldt, VDI Verein Deutscher Ingenieure e. V.

Uwe Seidel, VDI/VDE Innovation + Technik GmbH

Stephanie Seidel, Duni Group

Bianca Seidel, Bianca Seidel Unternehmensberatung

Aliaksandra Shuliakevich, Verband der Chemischen Industrie e. V.

Dr. Raban Siebers, bauforumstahl e. V.

Rudolf Siegle, wir.kiste.kreis. UG

Ramona G. Simon, DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e. V.

Angelika Smuda, Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz

Dr. Anna Sokol, FEhS – Institut für Baustoff-Forschung eingetragener Verein (e. V.)

Juliane Spieker, PFABO GmbH

Dirk Staasmeier, Röben Tonbaustoffe GmbH

Frank Stammer, TecPart Verband Technische Kunststoff-Produkte e. V.

Peter Starziczny, Allianz SE

Leo Stein, Siemens AG

Thomas Steinhauser, Bayern-Fass Rekonditionierungs GmbH

Jürgen Steinhäuser, ELESTA GmbH

Stephan Steinke, Schneider Electric GmbH

Dr. Anja Stenger, Bundesministerium für Wirtschaft und Klimaschutz

Andreas Stiedl, HUAWEI TECHNOLOGIES Deutschland GmbH

Wendy Stikvoort, UL International Netherlands BV

Celestin Julian Stretz, Fachhochschule Münster

Franziska Struck, Fachhochschule Münster

Oliver Stübs, Infosim GmbH & Co. KG

Axel Subklew, Gemeinsame Stelle dualer Systeme Deutschlands GmbH

Rebecca Tauer, WWF Deutschland

Prof. Dr. Angèle Tersluisen, ee concept GmbH

Christoph Teusch, AfB gemeinnützige GmbH

Sebastian Theißen, LIST AG

Matthias Thesing, rhinopaq

Philipp tho Pesch, Henkel AG & Co. KGaA

Bastian Tielmann, Bundesverband der Deutschen Sportartikel-Industrie e. V. (BSI)

Thomas Timke, SOLARWATT GmbH

Anna Trawnitschek, DIN Deutsches Institut für Normung e. V.

Amy Treick, Polysecure GmbH

Christiane Trumpp, Verband der Wellpappen-Industrie e. V.

Birte Turk, Deutsche Gesellschaft für Abfallwirtschaft e. V. (DGAW)

Michael Urs Hemm, Hemm Architekt

Dr. Anke Valentin, Wissenschaftsladen Bonn e. V.

Venkateshwaran Venkatachalam, Institut für Kunststoff- und Kreislauftechnik, Leibniz Universität Hannover (LUH)

Christina Vogel, Institut für ökologische Wirtschaftsforschung GmbH

Kai Vogt, VAUDE Sport GmbH & Co. KG

Jennifer von der Heydt, ProjectTogether gGmbH

Detlev von See, VELUX Deutschland GmbH

Rudolf von Stokar, Reco-Ventures AG

Dr. Reinhard von Wittken, acatech – Deutsche Akademie der Technikwissenschaften e. V.

Andreas Wade, Viessmann Climate Solutions SE

Lena Wagner, Unverpackt-Verband e. V.

Florian Wagner, RecycleMe GmbH

Dr. Eduard Wagner, Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration IZM

Dr. Reiner Wahl, SEW-EURODRIVE GmbH & Co KG

Dr. Daniel Waldmann, BASF SE

Dr. Christof Walter, Verband der Chemischen Industrie e. V.

Daniel Weber, Rieber GmbH & Co. KG

Michael Weinert, Crafting Future GmbH

Dr. Petra Weißhaupt, Umweltbundesamt

Katja Wendler, DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e. V.

Johanna Weppel, Arbeitsgemeinschaft Stoffspezifische Abfallbehandlung (ASA) e. V.

Daniela Werlich, CELLFORCE GROUP GMBH

Karl Wessel, Stadt Lemgo

Dr. Gottfried Weyhe, POLIFILM EXTRUSION GmbH

Michael Wieland, Kautex Textron GmbH & Co. KG

Dr. Mateusz Wielopolski, Circulix GmbH

Tim Winkler, dotch GmbH

Dirk Wissmann, AMETEK GmbH

Sven Witthöft, VYTAL Global GmbH

Matthias Wobbe, Mawos-Oeko-Modefabrik

Dr. Nina Woicke, Freiberufliche Ingenieurin

Dr. Diana Wolf, MEWA Textil-Management

Johannes Wöllhaf, Alfred Kärcher Vertriebs-GmbH

Daja Wolter, Der Grüne Punkt – Duales System Deutschland GmbH

Dr. Simone Wurster, Technische Universität Berlin

Dr. Antje Zehm, VDI/VDE Innovation + Technik GmbH

Eva Zeitz, DIN Deutsches Institut für Normung e. V.

Petrumila Zhendova, TEXAID Beteiligungsverwaltung Deutschland GmbH

Brigitte Zietlow, Umweltbundesamt

Standardization bodies in the context of the Circular Economy

National standardization bodies in the context of the Circular Economy

Digitalization/Business Models/Management	
DIN	
NA 147	DIN Standards Committee Quality Management, Statistics and Certification
NA 159	DIN Standards Committee Services
NA 159-01-15 AA	Asset Management Systems
NA 159-04-01 AA	Maintenance
NA 159-04-01-01 AK	Lifecycle record of technical objects
NA 172	DIN Standards Committee Principles of Environmental Protection
NA 172-00-02 AA	Environmental management/Environmental audit
NA 172-00-14-01 AK	Circular Economy

DKE	
DKE/K 113	Information structures and information elements, principles of identification and marking, documentation and graphic symbols.
DKE/AK STD_1941.0.2	Digital Product Passport (DPP)
DKE/GAK 431.0.11	Product data and tools
DKE/K 931	System aspects of automation
DKE/AK 931.0.12	Life Cycle Management
DKE/GK 914	Functional safety of electrical, electronic and programmable electronic systems (E, E, PES) for the protection of persons and the environment

VDI	
VDI 2882	Obsolescence management from the perspective of users and operators
VDI 2885	Uniform data for maintenance planning and determination of maintenance costs – Data and data determination
VDI 4800	Resource efficiency
VDI 4803	Methods for the efficient use of resources in companies
FA Production-integrated environmental protection	
FA Resource efficiency	
Interdisciplinary Group Digital Transformation (IGDT)	

Electrotechnology & ICT	
DKE	
DKE/K 191	Environmental protection and sustainability for products in electrical engineering, electronics, information technology
DKE/K 135	Detection of substances in electrical engineering products
DKE/K 513	Household appliances, usage properties
DKE/AK 742.0.12	Environment in K 742 (audio, video, and multimedia systems, devices, and components)
DKE/AK 931.0.10	Energy efficiency in industrial automation
DKE/AK 931.0.15	Resource efficiency in the process industry

Batteries	
DKE	
DKE/K 371	Batteries
DKE/AK 371.0.14	Stationary use of lithium-ion batteries from the automotive sector, including second life applications

VDI	
Technical Committee Energy Storage	

Packaging	
DIN	
NA 115	DIN Standards Committee Packaging
NA 115-04-10 AA	Packaging and the Environment

VDI	
VDI 3617	Single-use / reusable packaging – Requirements and decision-making aids for cost comparison

Plastics	
DIN	
NA 054	DIN Standards Committee Plastics
NA 054-03-01 AA	Plastics and environmental aspects
NA 054-03-02 AA	Biodegradable plastics
NA 054-03-03 AA	Recycling of plastics in the circular economy
NA 054-03-04 AA	Circularity and recyclability of fishing gear and aquaculture equipment

VDI	
Advisory Board Plastics Technology	
VDI 4095	Assessment of plastics in the circular economy

Textiles	
DIN	
NA 106	DIN Standards Committee Textiles and Textile Machinery
NA 106-01-22 GA	Joint working committee Textilnorm/NAW: Textiles – Environmental aspects , national mirror committee for ISO/TC 38/WG 35
NA 106-01-23 AA	Circular Economy for textile products and the textile chain

VDI	
VDI 3469 Blatt 3	Emission control – Production and processing of fibrous materials – Textiles made of organic and inorganic fibres

Construction & municipalities	
DIN	
NA 005	DIN Standards Committee Building and Civil Engineering
NA 005-01-31 AA	Sustainability in building construction (national mirror committee for ISO/TC 59/SC 17 and CEN/TC 350)

VDI	
VDI 2074	Recycling in the building services
VDI/WTA 3817 Blatt 1	Monuments and listed buildings – General requirements and planning principles
VDI-EE 4802 Blatt 1	Resource efficiency in building – Buildings

European and international standardization bodies in the context of the Circular Economy

Schwerpunktthema Digitalisierung, Geschäftsmodelle & Management	
ISO	
ISO/TC 176	Quality management and quality assurance
ISO/TC 207	Environmental management
ISO/TC 251	Asset management
ISO/TC 323	Circular Economy
ISO/TC 324	Sharing Economy
ISO/IEC JTC 1/SC 27/WG 5	Identity management and privacy technologies
ISO/IEC JTC 1/SC 31	Automatic identification and data capture techniques
ISO/IEC JTC 1/SC 32	Data management and interchange

CEN	
CEN/TC 319	Maintenance
CEN/CLC/JTC 13	Cybersecurity and Data Protection

IEC	
IEC/TC 3	Information structures, documentation and graphical symbols
IEC/SyC SM	Smart Manufacturing
IEC/SC 65A	System aspects
IEC/TC 65/WG 19	Life-cycle management for systems and products used in industrial-process measurement, control and automation

CLC	
CLC/SR 3	Information structures, documentation and graphical symbols
CLC/TC 65X	Fieldbus

Electrotechnology & ICT	
IEC	
IEC/TC 59	Performance of household electrical appliances
IEC/TC 65/JWG 14	Energy Efficiency in Industrial Automation (EEIA)
IEC/TC 100	Audio, video and multimedia systems and equipment
IEC/TC 111	Environmental standardization for electrical and electronic products and systems

CLC	
CLC/TC 59X	Performance of household and similar electrical appliances
CLC/TC 100X	Audio, video and multimedia systems and equipment
CLC/TC 111X	Environment

Batteries	
IEC	
IEC/TC 21	Secondary cells and batteries
IEC/SC 21A	Secondary cells and batteries containing alkaline or other non-acid electrolytes

CLC	
CLC/TC 21X	Secondary cells and batteries

Packaging	
ISO	
ISO/TC 122/SC 4	Packaging and the environment

CEN	
CEN/TC 261/SC 4	Packaging and the Environment

Plastics	
ISO	
ISO/TC 61/SC 14	Environmental aspects

CEN	
CEN/TC 249/WG 9	Bio-based and biodegradable plastics
CEN/TC 249/WG 11	Plastics recycling
CEN/TC 249/WG 24	Environmental aspects

Textiles	
ISO	
ISO/TC 38/WG 35	Environmental aspects

CEN	
CEN/TC 248/WG 39	Circular Economy for textile products and the textile chain

Construction & municipalities	
ISO	
ISO/TC 59/SC 17	Sustainability in buildings and civil engineering works

CEN	
CEN/TC 350	Sustainability of construction works

Annex: Overview of standardization needs

	Title
	Digitalization/Business Models/Management
1.1	Development of circularity criteria for specific product categories
1.2	Quality assurance, conformity assessment and declaration of reused products and products with extended service life (“product life extension”)
1.3	Definition and valuation/measurement method for determining the financial value of raw materials (originally waste)
1.4	Circular Economy and sustainability reporting
1.5	Definition and delimitation of the different concepts for making product-related data available on the basis of a suitable framework concept
1.6	Development of a taxonomy of abstracted product groups in the context of the Circular Economy
1.7	Use of semantic technologies for data exchange in the context of the Circular Economy
1.8	Normative principles for the structure of defined cross-sector content and its presentation in the digital product passport (basic structure for the presentation of information that can be displayed equally for all products)
1.9	Normative principles for the structure and grouping of product-specific content and its presentation in the digital product passport
1.10	Definition of standardized data structures of life cycle-relevant data in the digital product passport or in the form of one or more submodels for the Industrie 4.0 administration shell on the topic of Circular Economy/life cycle assessment
1.11	Standardized and exchangeable simulation models for dynamic information as a function of time or various other parameters, as well as versioning of data/information over the life cycle or various combined life cycles
1.12	Normative basis for the presentation and linking of data that is already publicly available in databases and linking with the new requirements for the digital product passport (information requirements for various product groups)
1.13	Development of a user-centred, digital solution through standardized methods and tools, as well as guidance on the use of the DPP for the various stakeholder groups
1.14	Standardization should support legislators in defining and implementing the individual access rights of various stakeholders along the value chain
1.15	Existing standards and specifications that define the technical features for different identifiers should be examined for their applicability to the DPP
1.16	Establishment or adaptation of standardized mechanisms to ensure data quality and trustworthy information in the digital product passport
1.17	Standards and specifications should provide a framework for the depth of data required

	Title
1.18	Integration of the Circular Economy into strategies, business models and management systems of companies
1.19	Systematic approach to Circular Economy potential development
1.20	Maturity level of the overall business concept
1.21	Circularity assessment of services
1.22	Key figure for use of recyclates
1.23	Exploiting the Circular Economy potential for business model innovation and re-design
1.24	Creation of measurement bases to determine “circularity success factors” and to allow comparisons to be made
1.25	Definition of terms for the Circular Economy
1.26	Definition of units and variables for the Circular Economy
1.27	Management of technical and legal interfaces
1.28	Communication between participants in the value loops
1.29	Classification of business models
1.30	Establishment of an infrastructure to support reverse logistics
1.31	Design and depth of service degree/level (service depth and breadth).
1.32	Definition of circular business management processes
1.33	Include the Circular Economy in the design phase
1.34	Uniform description of roles and responsibilities for an effective opportunity management process
1.35	Right to maintenance (maintenance/repairability)
1.36	Social standards for circular jobs
1.37	Training/qualification for the Circular Economy
1.38	Definition of features for the identification of services for the Circular Economy

	Title
	Electrotechnology & ICT
2.1	Normative foundations for indicators for the comparison of individual R-strategies, combinatorial approaches and for the measurement of overall circularity
2.2	Guides for filling and checking the SCIP, EPREL and other databases
2.3	Product group-specific standards for functional durability, repairability, reusability, remanufacturability and recyclability based on the DIN EN 4555x series
2.4	Guidelines on “design 4 recycling” and “design 4 circularity” and an approach to evaluate the optimal R-strategy for a specific product
2.5	Coordination of standardization activities on the Circular Economy
2.6	Establishment of standardized information transfer based on international standards and development of cost-effective and simple analytics for quality assurance of secondary raw materials
2.7	Necessity of European/International Standards
2.8	Assessment of the usefulness of the digitalization rate of products and services
2.9	Inclusion of circular-oriented funding criteria to promote innovation and research in addition to the energy efficiency of products
2.10	Standards for the decommissioning and dismantling of renewable energy generation plants
2.11	Revision of the normative basis for the use of flame retardants, taking into account recyclates and integrated measuring systems
2.12	Holistic product evaluation based on environmental and material efficiency parameters
2.13	Consideration of standards on data interfaces in the digital product passport
2.14	Standards for the measurement of product change during the uploading and installation of updates
2.15	Guide to circularity-oriented information on substances
2.16	Standard for changing product performance through software updates
2.17	Standard for application-related differentiation of joining and fastening techniques
2.18	Quality standards and reference materials for recyclates
2.19	Standard for determining the consumption of (industrial) systems
2.20	Standard for functionally stable operation
2.21	Standardized assessment criteria for energy and material efficiency of building services and installations
2.22	Standards for determining the durability of products
2.23	Normative basis for the definition of circularity-oriented warranty claims of consumer products

	Title
2.24	Criteria for classification of repaired, refurbished and remanufactured products
2.25	Design standards for defect-free disassembly/removal and secondary installation
2.26	Revision of the standard on data destruction DIN 66399 with regard to the reuse, refurbishment and remanufacturing of electrotechnology and ICT products
2.27	Standards for assessing repairability at the product level
2.28	Standards on product information (see product passport) and interoperability of components and wear parts
2.29	Standardized criteria for the provision of product or system information on composition, structure and usage history
2.30	Standard for onboard diagnostics of products
2.31	Extension of DIN EN 45554 to include metrics for refurbishing
2.32	Standards for implementing upgradeability-by-design
2.33	Standardized catalogue of criteria for evaluating the change in product purpose
2.34	Standard for calculating the environmental impact of materials (conversion factors)
2.35	Standard for the description of reference materials for secondary raw materials
2.36	Information standard for the provision of information relevant to recycling
2.37	Standards on design 4 recycling
2.38	Standards for calculating the recycling rate of electrotechnical and ICT products based on the products actually disposed of
2.39	Extension of the DIN EN 50625 series of standards to include consideration of the current state of the art as well as quality requirements
2.40	Recommendations for standardized information transfer and extension of the DIN EN 62321 series of analytical standards to include recycling-relevant substances
2.41	Revision of the DIN 66399 series to enable the recovery of critical raw materials, such as neodymium from hard drives
2.42	Standards to provide common material compositions in the case of established technical solutions
2.43	Standards for the traceability of materials for secondary raw materials

	Title
	Batteries
3.1	Standards for the interchangeability of batteries
3.2	Carbon footprint of lead-acid batteries
3.3	Standards on the digital battery passport
3.4	Standards on data about condition
3.5	Definition of safety limits for reuse
3.6	Safety standards for the replacement of battery modules and cells
3.7	Standards for the mechanical and electrical design of energy storage systems
3.8	Standards on data about condition
3.9	Standards on the digital battery passport
3.10	Standards on mechanical and electrical tests
3.11	Safety standard with non-destructive test methods
3.12	Standards for the modular design of batteries
3.13	Standard for the suitability testing of used components
3.14	Standards on 2nd life
3.15	Labelling
3.16	Decomposability
3.17	Standards on the digital battery passport
3.18	Availability of recyclates
3.19	Standards on the digital battery passport
	Packaging
4.1	Uniform definition framework based on the German minimum standard ZSVR
4.2	Uniform methodologies, metrics, and limit values for assessing recyclability
4.3	Catalogue/database for standardized packaging
4.4	Catalogue for total and combination packaging
4.5	Uniform recyclability label/digital product passport for packaging
4.6	Uniform guidelines for design 4 recycling for packaging

	Title
4.7	Guidelines valid throughout Europe for the country-specific assessment of the recyclability of packaging
4.8	Linking guideline with separation instructions/product labelling
4.9	Definition of sustainability
4.10	Establishment of principles for the uniform assessment of the sustainability of packaging
4.11	Representation and naming of industry references and differences
4.12	Clear definition of the term life phase including all raw material sources, production steps as well as components of the considered packaging system and possible differences in product life/product losses
4.13	Definition of communication rules
4.14	Hygiene and quality standards for unpackaged and reusable solutions
4.15	Definition of terminology relating to systems for reuse
4.16	Standardized requirements for properties for the compatibility of reusable packaging during take-back in systems for reuse
4.17	Standardization for secondary and transport packaging in the reusable and unpackaged sector
4.18	Standardization for the use of labels, tapes, adhesive tape and closures
4.19	Standardization of automated take-back for reusable packaging
4.20	Interoperability between package marking, capture, sorting and databases
4.21	Readability of the digital product passport in the automated sorting of recyclables
4.22	Marking of packaging materials and packaging applications
4.23	Uniform design of specifications for the description of sorted recyclables
4.24	Guide for SMEs regarding compliance work
4.25	Labelling of material from or with recyclates
4.26	Extension of DIN SPEC 91446 to include data relevant to conformity
4.27	Functional barriers
4.28	Compatibility assessment of dangerous goods and packaging (recycle)
4.29	Labelling and identification, digital interfaces

	Title
	Plastics
5.1	Allocation of the end-of-life of plastics
5.2	Delineation of an LCA and PCF and PEF by impact categories and scope as well as communication type
5.3	Standardized definitions of terms, methods/selection of overarching criteria, and methods for review
5.4	Methods for the assessment of the conformity of economic sustainability
5.5	Regulating occupational safety in chemical and mechanical recycling or in the processing of recycled material
5.6	Review and update of existing standards regarding realistic environmental conditions in the evaluation of the biodegradability of plastics
5.7	Qualification for reuse after present end-of-life
5.8	Assessment of the reusability of plastics
5.9	Standardized information on additives for the recycling of plastics
5.10	Uniform design of data sheets for the description of sorted materials
5.11	Harmonization of take-back and collection systems for commercial sectors and products
5.12	Technical guideline for the definition of open and closed loop systems
5.13	Addition of recycling-oriented information in the digital product passport for plastics
5.14	Uniform documentation requirement for the traceability of plastics
5.15	Uniform calculation rules for determining the output rate in recycling processes
5.16	Rules for the calculation of the recyclate content
5.17	Delimitation of recycling technologies/methods for plastics and uniform life cycle assessment
5.18	Systematization of markers and process requirements for destruction in the second recycling process and quantification of the environmental impacts
5.19	Requirements for a paint system in terms of design 4 recycling and sustainable paint stripping processes
5.20	Systematics of combinations of organic and inorganic pigments in plastics for optimal recycling
5.21	Determination of input streams with regard to foreign polymers and fillers and reinforcing materials
5.22	Mechanical recycling in preparation for further depolymerization or dissolution of the target fraction
5.23	Upstream processes – Quality-related standardization of input streams
5.24	Conversion and recycling processes – Description of chemical and physical conversion and recycling processes (Technical reports to illustrate the state of the art)

	Title
5.25	Downstream processes – Quality-related standardization of chemical products from physical and chemical recycling
5.26	Test standard for the determination of NIAS (non-intentionally added substances) in recyclates
5.27	Strategies for sampling, homogenization, and retained samples for all recycling methods and process steps, and for evaluating batch variations
5.28	Analysis of persistent contaminants and their accumulation in recycled materials
5.29	Standardization of the indication of quality specifications for recyclates (data sheets)
5.30	Standardization of testing standards for bulk density
5.31	Test standard for determining odour
5.32	Test standard for determining volatile organic compounds (VOC)
5.33	Promotion of research on the correlation of recyclate and product properties and screening methods
5.34	Promotion of research on the introduction of contaminants into recyclates
5.35	Design FROM recycling guideline
5.36	Technical guide to the classification of defect groups and types of product/processing defects specifically for recyclates
5.37	Occupational safety regulation for the processing of recyclates
5.38	Development of a test method for evaluating the degree of degradation and guideline for the addition of additives
	Textiles
6.1	Prioritization of reusable products in product standards over single-use products
6.2	"On demand" production
6.3	Data basis on maintainability, separability and recyclability for material selection/use – material index
6.4	Extension of chemical management to include closed-loop aspects – Chemical index
6.5	Clustering of product groups
6.6	Definition of longevity for product groups (longevity index)
6.7	Guidelines for design 4 recycling
6.8	Definition of quality requirements and standardized test procedures for a quality index
6.9	Evaluation criteria of longevity in relation to other sustainability criteria
6.10	Methods for determining and identifying recyclate content and sources in semi-finished products and products at batch level, etc.

	Title
6.11	Measurement or determination of consumption data and product components
6.12	Calculation methodology and data management
6.13	Development of an indicator methodology for products as well as for companies (keyword: traffic light system) with regard to the Circular Economy (closed loop indicators)
6.14	Extension of textile care labelling
6.15	Additional standards for various care and reprocessing procedures
6.16	Promotion of rental and leasing systems
6.17	Specifications for the description/labelling of textiles for the second-hand market
6.18	Non-destructive methods for condition assessment of used textiles
6.19	Define standardized product information about spare parts
6.20	Definition of repair or spare part requirements as well as standards that can be included in a repair index (repair index)
6.21	Identification of repairability
6.22	Requirements for the condition and environment (location) of depot containers
6.23	Uniform marking of collection containers
6.24	Requirements for the process of removal of the collected goods from the depot containers
6.25	Standardization/product specification according to sorted collection of textile waste from other sources
6.26	Establishment of regulations and criteria for used textile sorting plants
6.27	Product specification after sorting of mixed collected used textiles
6.28	Definition of permissible materials and verifiable information as “recycled content”
6.29	Establishment of criteria and definitions for the traceability of material streams
6.30	Determination of test criteria and the test time for the detection of the potential pollutant input
6.31	Standards and specifications for the evaluation of textile waste and its recyclates/recycled fibres
6.32	Tamper-proof material labelling and marking
6.33	Standardized definitions of terms related to environmental statements
6.34	Establishment of overarching criteria for product labelling that define the Circular Economy framework
6.35	Definition of an overall index (composite index) with variables for Circular Economy labelling
6.36	Information needs of different stakeholder groups

	Title
6.37	Information needs for different product groups
6.38	Interoperability of product and event data, and metadata through a unified ontology/taxonomy
6.39	Care instructions for washing machines
6.41	Identification numbers (identifiers) and data carriers
	Construction & municipalities
7.1	Formulation of standards and specifications that clearly describe the transition from waste to product (end-of-waste) and/or ensure minimum qualities with regard to suitability and warranty
7.2	Extension of standards to include dismantling
7.3	Requirements for building element catalogues according to a uniform classification system
7.4	Adaptation of existing standards in the context of flexibility of use and longevity
7.5	Requirements for a building passport
7.6	Circular design (modularity, adaptivity and low-tech strategy)
7.7	Standardized planning, calculation and evaluation tools for municipalities and regions in the transformation to a Circular Economy
7.8	Design and construction principles for adaptive building structures
7.9	Define overarching terms, supplement missing terms and harmonize terms already used in standardization
7.10	Harmonization of existing methods and tools
7.11	Clarification of the interfaces to the building life cycle assessment (LCA) as well as modifications to DIN EN 15804
7.12	Review of normative framework/regulations
7.13	Data acquisition on site
7.14	Selective dismantling

Bibliography

Since this is a translation of the German Standardization Roadmap, the following bibliography mostly refers to German sources.

[1] Mehr Fortschritt wagen, Bündnis für Freiheit, Gerechtigkeit und Nachhaltigkeit Koalitionsvertrag 2021–2025 zwischen Der Sozialdemokratischen Partei Deutschlands (SPD), Bündnis 90/Die Grünen und den Freien Demokraten (FDP), Berlin, den 7. Dezember 2021, https://www.bundesregierung.de/resource/blob/974430/1990812/04221173eef9a6720059cc353d759a2b/2021-12-10-koav2021-data.pdf?download=1

[2] European Commission (2019), Green Deal, Europäischer Grüner Deal | EU-Kommission (europa.eu)

[3] Bundes-Klimaschutzgesetz (Federal Climate Change Act) of 12 December 2019 (BGBl. I p. 2513), amended by Article 1 of the act of 18 August 2021 (BGBl. I p. 3905), KSG.pdf (gesetze-im-internet.de)

[4] European Commission (2020), A new Circular Economy Action Plan for a cleaner and more competitive Europe, https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0016.02/DOC_1&format=PDF

[5] United Nations (2015), 70th Session, Agenda Item Nos. 15 and 116, General Assembly of the United Nations, 18. September 2015, https://www.un.org/Depts/german/gv-70/band1/ar70001.pdf

[6] DIN EN 643:2014-11 Paper and board – European list of standard grades of paper and board for recycling, https://www.beuth.de/de/norm/din-en-643/223947791

[7] Kirchherr et al. (2017), Conceptualizing the circular economy: An analysis of 114 definitions, in Resources, Conservation & Recycling 127, 221–232, at: http://dx.doi.org/10.1016/j.resconrec.2017.09.005

[8] DIN ISO 20400:2021-02, Sustainable procurement – Guidance (ISO 20400:2017), https://www.beuth.de/de/norm/din-iso-20400/325002764

[9] Ellen MacArthur Foundation (2021), Circular economy glossary https://ellenmacarthurfoundation.org/topics/circular-economy-introduction/glossary

[10] ISO – ISO/CD 59004 – Circular Economy – Terminology, Principles and Guidance for Implementation, https://www.iso.org/standard/80648.html

[11] W. Steffen et al., Science 347, 1259855 (2015), Planetary boundaries: Guiding human development on a changing planet, https://www.science.org/doi/pdf/10.1126/science.1259855

[12] United Nations (1999), The World at Six Billion, https://search.archives.un.org/uploads/r/united-nations-archives/4/b/8/4b8e1e4538ee528ec43c72fcbdd3bddb9718410f3e414240617f97ac98d388e2/S-1092-0117-01-00002.pdf

[13] Sartor, O. et al. (2022), Mobilisierung der Kreislaufwirtschaft für energieintensive Materialien. Material Economics, Lund

[14] Acatech, Circular Economy Initiative Deutschland, SYSTEMIQ (2021), Circular Economy Roadmap for Germany, https://www.circular-economy-initiative.de/circular-economy-roadmap-fr-deutschland

[15] Eurostat (2021), Circular Material Use Rate, https://ec.europa.eu/eurostat/databrowser/view/cei_srm030/default/tau ble?lang=en

[16] German Advisory Council on the Environment (2020), Circular economy: Putting ideas into practice, https://www.umweltrat.de/SharedDocs/Downloads/DE/01_Umweltgutachten/2016_2020/2020_Umweltgutachten_Kap_03_Kreislaufwirtschaft.html;jsessionid=DB0166D519DC51C970022E4B7E09B76E.intranet211?nn=400294

[17] Federal Environment Agency (editor) (2020), Innovationen für die Circular Economy – Aktueller Stand und Perspektiven: Ein Beitrag zur Weiterentwicklung der deutschen Umweltinnovationspolitik, https://www.umweltbundesamt.de/sites/default/files/medien/5750/publikationen/2021_01_11_uib_01-2021_innovationen_circular_economy.pdf

[18] H. Wilts et al. (2022), Zirkuläre Wertschöpfung 2030. Studie im Auftrag des MWIDE NRW, Wuppertal.

[19] A. Tukker (2004), Eight Types of Product – Service System: Eight ways to sustainability, in: Business Strategy and the Environment Bus. Strat. Env. 13, 246–260 (2004), https://venturewell.org/wp-content/uploads/Tukker-2004-Business_Strategy_and_the_Environment.pdf

[20] H. Wilts, M. Fecke, C. Zeher (2021), Economics of Waste Prevention: Second-Hand Products in Germany, Economies 9, no. 2: 74, https://doi.org/10.3390/economies9020074

[21] Directive 2009/125/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for the setting of ecodesign requirements for energy-related products, https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:285:0010:0035:de:PDF

[22] Federal Environment Agency (editor) (2019), Evaluation des Deutschen Ressourceneffizienzprogramms ProgRess, https://epub.wupperinst.org/frontdoor/deliver/index/docId/7298/file/7298_ProgRess.pdf

[23] Endres, H.-J., Shamsuyeva, M. (2020), Kreislaufwirtschaft braucht bessere Standards, in: Plastverarbeiter, 06/20

[24] Government of the Netherlands (no year), Circular Dutch economy by 2050, https://www.government.nl/topics/circular-economy/circular-dutch-economy-by-2050

[25] Langsdorf, Susanne; Duin, Laurens (2021), Absolute Reduktion der Ressourcennutzung. Vorreiter Niederlande – Ein Vorbild für Deutschland? Ecologic Institut, Berlin, https://www.ecologic.eu/sites/default/files/publication/2021/Langsdorf_Duin_Reduktion-Ressourcennutzung-NL.pdf

[26] Green Deal (o.J.), Evaluation of Green Deals, https://www.greendeals.nl/sites/default/files/2022-02/Evaluation%20Green%20Deals%20KWINK%202016-%20summary-%20EN.pdf

[27] S.K. van Langen, R. Passaro (2021), The Dutch Green Deals Policy and Its Applicability to Circular Economy Policies. Sustainability 2021, 13, 11683. https://doi.org/10.3390/su132111683

[28] Ministère de la Transition écologique (2020), The anti waste law in the daily lives of the French people- what does it mean in practice? https://www.ecologie.gouv.fr/sites/default/files/en_DP%20PJL.pdf

[29] Ellen MacArthur Foundation (2021), France's Anti waste and Circular Economy Law: eliminating waste and promoting social inclusion, https://emf.thirdlight.com/link/e9kl4x8ts2er-2za9sx/@/#id=0

[30] ISO – Technical Committees. https://www.iso.org/technical-committees.html

[31] J. Zhu et al. (2018), Efforts for a circular economy in China. A comprehensive review of policies, in: Journal of Industrial Ecology, at: https://onlinelibrary.wiley.com/doi/abs/10.1111/jiec.12754

[32] R. Bleischwitz et al. (2022), The circular economy in China: Achievements, challenges and potential implications for decarbonization, in: Resources, Conservation & Recycling 183 (2022) 106350, at: https://doi.org/10.1016/j.resconrec.2022.106350

[33] N. Luhmann (2021), Die Grenzen der Verwaltung, Auflage 1, Suhrkamp Verlag

[34] International Organization for Standardization, www.iso.org

[35] International Electrotechnical Commission, www.iec.ch

[36] International Telecommunication Union, www.itu.int

[37] European Committee for Standardization www.cen.eu

[38] European Committee for Electrotechnical Standardization www.cenelec.eu

[39] European Telecommunications Standards Institute www.etsi.org

[40] K. Blind (2022), Standards and innovation. What does the research say? ISO R & I papers. Geneva, at: https://www.iso.org/files/live/sites/isoorg/files/store/en/PUB100466.pdf

[41] Basel Convention, Revised glossary of terms, document UNEP/CHW/OEWG.10/INF/10 (18 March 2016), at: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwjJ14usgP34AhXIn-P0HHfYGAj0QFnoECAgQAQ&url=https%3A%2F%2Fwww.basel.int%2FPortals%2F4%2Fdownload.aspx%3Fd%-3DUNEP-CHW-OEWG.10-INF-10.English.pdf&usg=AOvVaw3Fme5MrjoWtt8Qgg9vYbMe

[42] EUR 23990 EN – Joint Research Centre – Institute for Prospective Technological Studies

[43] L. Delgado et al (2009), End-of-Waste Criteria, https://publications.jrc.ec.europa.eu/repository/bitstream/JRC53238/jrc53238.pdf

[44] United Nations Environment Programme (2019), www.unenvironment.org/circularity abgerufen am 27.09.2022, basiere end auf Potting et al. (2017, p. 5)

[45] Denise Reike, Walter J.V. Vermeulen, Sjors Witjes (2017), The circular economy: New or Refurbished as CE 3.0? – Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options,Resources, Conservation and Recycling, Volume 135, 2018 https://www.sciencedirect.com/science/article/pii/S0921344917302756?via%3Dihub

[46] DIN EN 4555X Standards series on material efficiency https://www.din.de/de/din-und-seine-partner/presse/mitteilungen/auf-dem-weg-zur-circular-economy-790988
to DIN EN 45559:2019-10 Methods for providing information relating to material efficiency aspects of energy-related products https://www.beuth.de/de/norm/din-en-45559/309791451

[47] DIRECTIVE 2008/98/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCILof 19 November 2008 on waste and repealing certain Directives, https://eur-lex.europa.eu/legal-content/DE/TXT/?uri=celex%3A32008L0098

[48] DIN SPEC 5010:2018-05 Testing of paper and board – Determination of the transfer of mineral oil hydrocarbons from food contact materials manufactured with portions of recycled pulp; Text in German and English, https://doi.org/https://dx.doi.org/10.31030/2842535

[49] DIN SPEC 91446:2021-12 Classification of recycled plastics by Data Quality Levels for use and (digital) trading; Text in English, https://doi.org/https://dx.doi.org/10.31030/3304036

[50] DIN VDE V 0510-100:2021-11 Safety of lithium-ion batteries from electrically propelled road vehicles for use in stationary applications, https://www.vde-verlag.de/normen/1500229/e-din-vde-v-0510-100-vde-v-0510-100-2021-11.html

[51] VDI 2074 – Recycling in the building services | VDI. (n. d.), https://www.vdi.de/richtlinien/details/vdi-2074-recycling-in-der-technischen-gebaeudeausruestung

[52] VDI 2343 Blatt 1 – Recycling of electrical and electronic products – Principles and terminology | VDI. (n. d.), https://www.vdi.de/richtlinien/details/vdi-2343-blatt-1-recycling-elektrischer-und-elektronischer-geraete-grundlagen-und-begriffe

[53] R. Weissinger (2022), Circular Economy: Entwicklung einer Normen-Taxonomie, in: DIN-Mitteilungen, Dezember 2022, Seiten 19-25, https://www.din.de/resource/blob/900294/e003fa872649530f4ec31d8f4b321531/ce-taxonomie-weissinger-din-mitteilungen-2022-12-data.pdf

[54] Normenrecherche Version 1.7.1 (April 2022)

[55] Normenrecherche (August 2022), https://www.din.de/go/normenrecherche-circular-economy

[56] ISO 14009:2020-12 Environmental management systems – Guidelines for incorporating material circulation in design and development, https://www.beuth.de/de/norm/iso-14009/334145171

[57] Corvellec, H., Stowell, A. F., & Johansson, N. (2022), Critiques of the circular economy. Journal of Industrial Ecology, 26(2), 421–432, https://doi.org/10.1111/JIEC.13187

[58] Reike, D., Vermeulen, W. J. V., & Witjes, S. (2018). The circular economy: New or Refurbished as CE 3.0? – Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. Resources, Conservation and Recycling, 135, 246–264, https://doi.org/10.1016/J.RESCONREC.2017.08.027

[59] United Nations Environment Programme (2017), The Long View: Exploring Product Lifetime Extension, https://wedocs.unep.org/20.500.11822/22394

[60] Forti, V., Peter Baldé, C., Kuehr, R., & Bel, G. (2020), The Global E-waste Monitor 2020 -Quantities, flows, and the circular economy potential, https://ewastemonitor.info/wp-content/uploads/2020/11/GEM_2020_def_july1_low.pdf

[61] Ellen MacArthur Foundation (2017), A New Textiles Economy: Redesigning fashion's future. Summary of findings, at: A New Textiles Economy – Full Report | Shared by Fashion (thirdlight.com)

[62] Sustainability reporting standards roadmap – EFRAG. (n. d.), https://www.efrag.org/Activities/2010051123028442/Sustainability-reporting-standards-roadmap

[63] EFRAG PTF- ESRS. (2022), [Draft] ESRS E5 Resource use and circular economy, https://www.efrag.org/Assets/Download?assetUrl=%2Fsites%2Fwebpublishing%2FSiteAssets%2FED_ESRS_E5.pdf

[64] ISO 14025:2006-07 Environmental labels and declarations – Type III environmental declarations – Principles and procedures, https://www.beuth.de/de/norm/iso-14025/92334997

[65] ISO – ISO/WD 59040 – Circular Economy – Product Circularity Data Sheet, https://www.iso.org/standard/82339.html

[66] DIN EN IEC 63278-1:2022-07 – Draft VDE 0810-781:2022-07 Asset Administration Shell for industrial applications – Part 1: Asset Administration Shell structure (IEC 65/867/CD:2021) https://www.beuth.de/de/norm-entwurf/din-en-iec-63278-1/354882246

[67] DIN & DKE. (2020), DIN and DKE ROADMAP German Standardization Roadmap on Industrie 4.0, https://www.din.de/resource/blob/95954/fef3e0c46a3b5d042f25078c50547f0d/aktualisierte-roadmap-i40-data.pdf

[68] DIN EN IEC 62890:2021-06 VDE 0810-890:2021-06 Industrial-process measurement, control and automation – Life-cycle-management for systems and components (IEC 62890:2020, https://www.beuth.de/de/norm/din-en-iec-62890/338000188

[69] Blomsma, F. & Tennant, M. (2020), Circular economy: Preserving materials or products? Introducing the Resource States framework. Resources, Conservation and Recycling, 156, 104698, https://doi.org/10.1016/J.RESCONREC.2020.104698

[70] Semantische Technologien – International Center for Computational Logic. (o.J.), Retrieved July 22, 2022, from https://iccl.inf.tu-dresden.de/web/Semantische_Technologien

[71] DIN EN 61360 (all parts), Standard data element types with associated classification scheme

[72] ISO 13584-1:2001-04 Industrial automation systems and integration – Parts library – Part 1: Overview and fundamental principles, https://www.beuth.de/de/norm/iso-13584-1/43272129

[73] REGULATION (EC) No 1907/2006 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL | of 18 December 2006 | concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC, https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:02006R1907-20220501&from=DE

[74] DIN SPEC 91345, Reference Architecture Model Industrie 4.0 (RAMI4.0), https://www.beuth.de/de/technische-regel/din-spec-91345/250940128

[75] IMDS | International Material Data System. (no year), https://www.mdsystem.com/imdsnt/startpage/index.jsp

[76] IDiS – Initiative Digitale Standards. (no year), https://www.dke.de/de/normen-standards/normung-strategie/deutsche-normungsstrategie/idis

[77] About – I4R Platform. (o.J.), I4R, https://i4r-platform.eu/about/

[78] ISO/IEC TR 10032:2003, Information technology – Reference Model of Data Management, https://www.vde-verlag.de/iec-normen/215825/iso-iec-tr-10032-2003.html

[79] ISO – ISO/AWI 22373 – Security and resilience – Authenticity, integrity and trust for products and documents – Framework for establishing trustworthy supply chains, https://www.iso.org/cms/render/live/en/sites/isoorg/contents/data/standard/05/02/50276.html?browse=tc

[80] DIN EN ISO 14040:2021-02 Environmental management – Life cycle assessment – Principles and framework (ISO 14040:2006 + Amd 1:2020), https://doi.org/https://dx.doi.org/10.31030/3179655

[81] DIN EN ISO 14044:2021-02 Environmental management – Life cycle assessment – Requirements and guidelines (ISO 14044:2006 + Amd 1:2017 + Amd 2:2020), https://doi.org/https://dx.doi.org/10.31030/3179656

[82] Greenhouse Gas Protocol (n.d.), https://ghgprotocol.org/

[83] Single Market for Green Products – The Product Environmental Footprint Pilots – Environment – European Commission. (n. d.). Retrieved September 30, 2022, from https://ec.europa.eu/environment/eussd/smgp/ef_pilots.htm

[84] World Business Council For Sustainable Development (WBCSD). (o.J.), https://www.wbcsd.org/

[85] European Commission. (n.d.), Ecodesign for sustainable products, https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/sustainable-products/ecodesign-sustainable-products_en

[86] DIN EN ISO 9004:2018-08 Quality management – Quality of an organization – Guidance to achieve sustained success (ISO 9004:2018); German and English version, https://www.beuth.de/de/norm/din-en-iso-9004/283875061

[87] Stucki, T., & Wörter, M. (2021), Statusbericht der Schweizer Kreislaufwirtschaft Erste repräsentative Studie zur Umsetzung der Kreislaufwirtschaft auf Unternehmensebene, https://www.arv.ch/data/docs/de/5970/Kreislaufwirtschaft-2021-11-repräsentative-Studie-zur-Umsetzung-der-Kreislaufwirtschaft.pdf?v=1.0

[88] acatech, Circular Economy Initiative Deutschland, & SYSTEMIQ. (2021), Circular Business Models: Overcoming Barriers, Unleashing Potentials. at: https://en.acatech.de/publication/circular-business-models-overcoming-barriers-unleashing-potentials/

[89] The British Standards Institution (2017), BS 8001:2017 Framework for implementing the principles of the circular economy in organizations-Guide.

[90] ISO – ISO/CD TR 59032.2 – Circular economy – Review of business model implementation. Retrieved September 30, 2022, from https://www.iso.org/standard/83044.html

[91] ISO – ISO/CD 59010 – Circular Economy – Guidance on the transition of business models and value networks. abgerufen am 30. September 2022, https://www.iso.org/standard/80649.html

[92] Moraga, G., Huysveld, S., Mathieux, F., Blengini, G. A., Alaerts, L., Van Acker, K., de Meester, S., & Dewulf, J. (2019), Circular economy indicators: What do they measure? Resources, Conservation and Recycling, 146, 452–461, https://doi.org/10.1016/J.RESCONREC.2019.03.045

[93] Circulytics Resources. (n.d.), https://ellenmacarthurfoundation.org/resources/circulytics/resources

[94] ISO – ISO/CD 59004 – Circular Economy – Terminology, Principles and Guidance for Implementation, https://www.iso.org/standard/80648.html

[95] Apra (n.d.), APRAs Remanufacturing Translations – Terms and Definitions, https ://apraeurope.org/wp-content/uploads/2021/05/Remanufacturing_Translation_Matrix.pdf

[96] Apra (2012), Remanufacturing Terminology Remanufacturing Term Guideline, https://apraeurope.org/wp-content/uploads/2021/04/Remanufacturing_Terminology.pdf

[97] Ellen MacArthur Foundation (2013), TOWARDS THE CIRCULAR ECONOMY Economic and business rationale for an accelerated transition, https://ellenmacarthurfoundation.org/towards-the-circular-economy-vol-1-an-economic-and-business-rationale-for-an

[98] Hansen, Erik G.; Wiedemann, Patrick; Fichter, Klaus; Lüdeke-Freund, Florian; Jaeger-Erben, Melanie; Schomerus, Thomas et al. (2021), Circular Business Models: Overcoming Barriers, Unleashing Potentials (Full Report). Ed. V. ACATEC

[99] wbcsd (2022), CIRCULAR TRANSITION INDICATORS V3.0 Metrics for business, by business, https://www.wbcsd.org/Programs/Circular-Economy/Metrics-Measurement/Resources/Circular-Transition-Indicators-v3.0-Metrics-for-business-by-business

[100] KVD-Service-Studie 2021, www.kvd.de

[101] Prakash, S., Dehoust, G., Gsell, M., Schleicher, T., & Stamminger, R. (2016), Einfluss der Nutzungsdauer von Produkten auf ihre Umweltwirkung: Schaffung einer Informationsgrundlage und Entwicklung von Strategien gegen „Obsoleszenz.“ https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_11_2016_einfluss_der_nutzungsdauer_von_produkten_obsoleszenz.pdf

[102] Dr. I. Oehme (2015), Umweltbundesamt (Hrsg.), Wirksame Unterstützung von Reparaturnetzwerken- Reparierbarkeit und Reparaturinformationen als mögliche Elemente von verbindlichen Ökodesign-Anforderungen. https://www.umweltbundesamt.de/sites/default/files/medien/378/dokumente/avdialog_3-reparieren_oehme_reparierbarkeit_als_oekodesignanforderung.pdf

[103] Cradle to Cradle Certified 4.0 (n.d.), Vierte und weitreichendste Cradle to Cradle-Version angekündigt, https://www.baulinks.de/webplugin/2021/0727.php4

[104] Cradle to Cradle Products Innovation Institute (n.d.), Home, https://www.c2ccertified.org/

[105] International Electrotechnical Commission (n.d.), CDD, Common Data Dictionary, https://cdd.iec.ch/cdd/iec61360/iec61360.nsf

[106] ZVEI e. V. (2022), Die deutsche Elektro- und Digitalindustrie – Daten, Zahlen und Fakten, https://www.zvei.org/fileadmin/user_upload/Presse_und_Medien/Publikationen/Regelmaessige_Publikationen/Daten_Zahlen_und_Fakten/Die_deutsche_Elektroindustrie_Daten_Zahlen_Fakten/Faktenblatt-September-2022.pdf

[107] REGULATION (EU) 2019/881 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 April 2019 on ENISA (the European Union Agency for Cybersecurity) and on information and communications technology cybersecurity certification and repealing Regulation (EU) No 526/2013 (Cybersecurity Act), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2019:151:FULL&from=EN

[108] DIRECTIVE 2012/19/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 4 July 2012 on waste electrical and electronic equipment (WEEE), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2012:197:FULL&from=EN

[109] DIRECTIVE 2011/65/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment 88, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2011:174:FULL&from=EN

[110] COMMISSION IMPLEMENTING DECISION C (2015)9096 of 17.12.2015 on a standardisation request to the European standardisation organisations as regards ecodesign requirements on material efficiency aspects for energy-related products in support of the implementation of Directive 2009/125/EC of the European Parliament and of the Council, https://ec.europa.eu/growth/tools-databases/mandates/index.cfm?fuseaction=search.detail&id=564

[111] Directorate-General Environment (DG ENV), https://ec.europa.eu/info/departments/environment_de

[112] Committee on the Environment, Public Health and Food Safety, European Parliament, https://www.europarl.europa.eu/committees/de/envi/home/highlights

[113] Directorate-General Communications Networks, Content and Technology (DG CONNECT), https://ec.europa.eu/info/departments/communications-networks-content-and-technology_de

[114] General-Directorate Internal Market, Industry, Entrepreneurship and SMEs (DG GROW), https://ec.europa.eu/info/departments/internal-market-industry-entrepreneurship-and-smes_de

[115] IEC/TC 111 Environmental standardization for electrical and electronic products and systems, https://tc111.iec.ch/#about

[116] SMB ahG 94 "Product carbon footprint data for the electrotechnical sector", https://iectest.iec.ch/ords/f?p=103:85:700800350293008::::FSP_ORG_ID:28126

[117] CLC/TC 59X on the CENELEC-Website: https://standards.cencenelec.eu/dyn/www/f?p=305:7:0::::FSP_ORG_ID:2672477

[118] European Commission (n.d.), Commitments and deliverables of the Circular Plastics Alliance, https://single-market-economy.ec.europa.eu/industry/strategy/industrial-alliances/circular-plastics-alliance/commitments-and-deliverables-circular-plastics-alliance_en

[119] International Resource Panel of the UN Environment Programme (UNEP IRP), https://www.unep.org/explore-topics/resource-efficiency/what-we-do/international-resource-panel

[120] ISO/TC 262 "Risk management", https://www.iso.org/committee/629121.html

[121] ISO/TC 261 "Additive manufacturing", https://committee.iso.org/home/tc261

[122] E DIN EN IEC 1406, VDE 0810-406:2022-08 Identification link, https://www.vde-verlag.de/normen/1800736/e-din-en-iec-61406-vde-0810-406-2022-08.html

[123] DIN/TS 54405:2020-12 Construction adhesives – Guideline for separation and recycling of adhesives and substrates from bonded joints, https://www.beuth.de/de/vornorm/din-ts-54405/329917716

[124] DIN SPEC 15240:2019-03 Energy performance of buildings – Ventilation for buildings – Inspection of air-conditioning systems, https://www.beuth.de/de/technische-regel/din-spec-15240/300937690

[125] REGULATION (EU) 2017/1369 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R1369&from=EN

[126] SCIP – ECHA. (n.d.), Legislation, https://echa.europa.eu/de/scip

[127] European Commission (2022), EPREL – European Product Registry for Energy Labelling, https://eprel.ec.europa.eu/screen/home

[128] DIN EN 50678:2021-02, VDE 0701:2021-02 General procedure for verifying the effectiveness of the protective measures of electrical equipment after repair, https://www.beuth.de/de/norm/din-en-50678/331987182

[129] DIRECTIVE 2014/35/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 26 February 2014 on the harmonisation of the laws of the Member States relating to the making available on the market of electrical equipment designed for use within certain voltage limits, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014L0035&from=EN

[130] DIRECTIVE 2006/42/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 17 May 2006 on machinery, and amending Directive 95/16/EC (recast), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02006L0042-20190726&from=EN

[131] Directive 2000/53/EC of the European Parliament and of the Council of 18 September 2000 on end-of life vehicles, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:02000L0053-20200306&from=EN

[132] Business plan DIN SPEC 91472 Remanufacturing (Reman) – Quality classification for circular processes, https://www.din.de/de/forschung-und-innovation/din-spec/alle-geschaeftsplaene/wdc-beuth:din21:352617945

[133] Regulation (EU) 2019/1021 of the European Parliament and of the Council of 20 June 2019 on persistent organic pollutants (recast), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32019R1021&from=en

[134] Elektro- und Elektronikgerätegesetz (Electrical and Electronic Equipment Act) of 20 October 2015 (BGBl. I p. 1739), last amended through Article 23 of the Act of 10 August 2021 (BGBl. I p. 3436), https://www.gesetze-im-internet.de/elektrog_2015/ElektroG.pdf

[135] DIN EN 50625 (all parts), Collection, logistics & Treatment requirements for WEEE Available at www.beuth.de or www.vde-verlag.de

[136] DIN EN 62321-1:2014-02, VDE 0042-1-1:2014-02 Determination of certain substances in electrotechnical products – Part 1: Introduction and overview (IEC 62321-1:2013) https://www.beuth.de/de/norm/din-en-62321-1/195506088

[137] DIN EN IEC 63000:2019-05, VDE 0042-12:2019-05 Technical documentation for the assessment of electrical and electronic products with respect to the restriction of hazardous substances (IEC 63000:2016) https://www.beuth.de/de/norm/din-en-iec-63000/302205544

[138] DIN 66399 (all parts): Office machines – Destruction of data carriers Available at www.beuth.de

[139] Bitkom Bundesverband Informationswirtschaft, Telekommunikation und neue Medien e. V. (2008), Leitfaden zum Sicheren Datenlöschen, Version 2.0, p. 8, https://www.bitkom.org/sites/default/files/file/import/080602-Sicheres-Datenloeschen-Version-2-0-vom-300508.pdf

[140] European Commission (n.d.), Ecodesign for sustainable products, https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/sustainable-products/ecodesign-sustainable-products_en

[141] Proposal for a DIRECTIVE 2006/66/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2006:266:FULL&from=EN

[142] Official Journal of the European Union C347 – Amendments adopted by the European Parliament on 10 March 2022 on the proposal for a regulation of the European Parliament and of the Council concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) 2019/1020 (COM(2020)0798 – C9-0400/2020 – 2020/0353(COD)), https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:C:2022:347:FULL&from=EN

[143] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020, https://data.consilium.europa.eu/doc/document/ST-7103-2022-REV-1/EN/pdf

[144] European Commission, & Directorate-General for Environment (2020), Annex to the Communication on the new Circular Economy Action Plan For a cleaner and more competitive Europe, https://eur-lex.europa.eu/resource.html?uri=cellar:9903b325-6388-11ea-b735-01aa75ed71a1.0016.02/DOC_2&format=PDF

[145] European Commission. Mandate – M/579 COMMISSION IMPLEMENTING DECISION C (2021)8614 of 7.12.2021on a standardisation request to the European standardisation organisations as regards performance, safety and sustainability requirements for batteries, https://ec.europa.eu/growth/tools-databases/mandates/index.cfm?fuseaction=search.detail&id=603&lang=en

Note: It is possible that after the publication of the Battery Regulation the mandate will be renewed under another number, Mandate (europa.eu)

[146] Results of the research of Circular Economy standards (Excel list, as of April 2022), www.dke.de/normenrecherche-circular-economy

[147] Gesetz über das Inverkehrbringen, die Rücknahme und die umweltverträgliche Entsorgung von Batterien und Akkumulatoren (Batteriegesetz – BattG) (German Battery Act), https://www.gesetze-im-internet.de/battg/BJNR158210009.html

[148] Regulation (EU) 2019/1020 of the European Parliament and of the Council of 20 June 2019 on market surveillance and compliance of products and amending Directive 2004/42/EC and Regulations (EC) No 765/2008 and (EU) No 305/2011 (Text with EEA relevance.), https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32019R1020

[149] IEV Dictionary (in German) (n.d.), https://www2.dke.de/de/online-service/dke-iev/Seiten/IEV-Woerterbuch.aspx

[150] DIRECTIVE 2008/98/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 November 2008 on waste and repealing certain Directives, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2008:312:FULL&from=EN

[151] DIN EN 60335-1:2020-08, VDE 0700-1:2020-08 Household and similar electrical appliances – Safety – Part 1: General requirements (IEC 60335-1:2010, modified + COR1:2010 + COR2:2011 + A1:2013, modified + A1:2013/COR1:2014 + A2:2016 + A2:2016/COR1:2016); https://www.vde-verlag.de/normen/0701249/din-en-60335-1-vde-0700-1-2020-08.html

[152] DIN EN IEC 62115:2021-04 VDE 0700-210:2021-04 Electric toys – Safety (IEC 62115:2017 + COR1:2019), https://www.vde-verlag.de/normen/0701295/din-en-iec-62115-vde-0700-210-2021-04.html

[153] IEC – SC 21A Dashboard > Project IEC 63369-1 ED1 Methodology for the Carbon Footprint calculation applicable to Lithium-ion batteries. (access may be restricted), https://www.iec.ch/ords/f?p=103:38:613773854859277::::FSP_ORG_ID,FSP_APEX_PAGE,FSP_PROJECT_ID:1410,23,104590

[154] Projects: IEC 63372 ED1 Quantification and communication of Carbon FootPRINT and GHG emission reductions/avoided emissions from electric and electronic products and systems – Principles, methodologies, requirements and guidance. (Access may be restricted), https://www.iec.ch/ords/f?p=103:38:613773854859277::::FSP_ORG_ID,FSP_APEX_PAGE,FSP_PROJECT_ID:1314,23,104597#

[155] DIN VDE V 0510-100:2021-11 – Entwurf VDE V 0510-100:2021-11 Safety of lithium-ion batteries from electrically propelled road vehicles for use in stationary applications, https://www.vde-verlag.de/normen/1500229/e-din-vde-v-0510-100-vde-v-0510-100-2021-11.html

[156] Standardization body DKE/K 371 "Akkumulatoren" DKE/K 371 Akkumulatoren oder https://www.dke.de/de/ueber-uns/dke-organisation-auftrag/dke-fachbereiche/dke-gremium?id=2000115&type=dke%7Cgremium

[157] Federal Environment Agency (n.d.), Verpackungsabfälle, https://www.umweltbundesamt.de/daten/ressourcen-abfall/verwertung-entsorgung-ausgewaehlter-abfallarten/verpackungsabfaelle#verpackungen-uberall

[158] Bundesministerium der Justiz (2017), Gesetz über das Inverkehrbringen, die Rücknahme und die hochwertige Verwertung von Verpackungen (VerpackG) (German Packaging Act), https://www.gesetze-im-internet.de/verpackg/

[159] Stiftung Zentrale Stelle Verpackungsregister (2021), Mindeststandard für die Bemessung der Recyclingfähigkeit von systembeteiligungspflichtigen Verpackungen gemäß § 21 Abs. 3 VerpackG, https://www.verpackungsregister.org/fileadmin/files/Mindeststandard/Mindeststandard_VerpackG_2021.pdf

[160] Dänischer Abfallverband danskaffaldsforening (n.d.), https://danskaffaldsforening.dk/

[161] Arbeitskreis Mehrweg GbR (2020), Leitfaden zur Nutzung des MMP Pools, https://uploads.n-bnn.de/Leitfaden_zur_Nutzung_des_MMP-Pools_Nov.2020.pdf

[162] Kröger, Melanie; Pape, Jens; Wittwer, Alexandra (ed.) (2020), Einfach weglassen? München: Oekom Verlag.

[163] International Labour Organization (ILO), ILO Kernarbeitsnormen, https://www.ilo.org/berlin/arbeits-und-standards/kernarbeitsnormen/lang--de/index.htm

[164] VDI 4095 – Project: Assessment of Plastics in the Circular Economy, https://www.vdi.de/richtlinien/details/vdi-4095-bewertung-von-kunststoffen-in-der-kreislaufwirtschaft

[165] European Commission: Initiative on substantiating green claims der EU, https://ec.europa.eu/environment/eussd/smgp/initiative_on_green_claims.htm

[166] European Commission (2012), Product Environmental Footprint (PEF) Guide, https://ec.europa.eu/environment/eussd/pdf/footprint/PEF%20methodology%20final%20draft.pdf

[167] Federal Environment Agency (2019), Treibhauspotentiale (Global Warming Potential, GWP) ausgewählter Verbindungen und deren Gemische gemäß Viertem Sachstandsbericht des IPCC bezogen auf einen Zeitraum von 100 Jahren, https://www.umweltbundesamt.de/dokument/treibhauspotentiale-global-warming-potential-gwp

[168] Casson, Andrea, et al. Beyond the eco-design of case-ready beef packaging: The relationship between food waste and shelf-life as a key element in life cycle assessment. Food Packaging and Shelf Life, 2022, 34. Year, p. 100943.

[169] REGULATION (EC) No 1935/2004 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 October 2004 on materials and articles intended to come into contact with food and repealing Directives 80/590/EEC and 89/109/EEC, https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2004:338:FULL&from=EN https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:338:0004:0017:en:PDF

[170] Commission Regulation (EU) No 10/2011 of 14 January 2011 on plastic materials and articles intended to come into contact with food Avail. at https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2011:012:0001:0089:EN:PDF, last retrieved on 30.09.2022

[171] Lebensmittel- und Futtermittelgesetzbuch (German Food and Feed Code) in der Fassung der Bekanntmachung vom 15. September 2021 (BGBl. I S. 4253), das durch Artikel 7 des Gesetzes vom 27. September 2021 (BGBl. I S. 4530) geändert worden ist, https://www.gesetze-im-internet.de/lfgb/BJNR261810005.html

[172] Council of Europe Committee of ministers (partial agreement in the social and public health field), Resolution AP (89) 1 on the use of colourants in plastic materials coming in to contact with food, https://rm.coe.int/16804f8648

[173] Council of Europe Committee of ministers (partial agreement in the social and public health field), Resolution AP (92) 2 on control of aids to polymerization (technological coadjuvants) for plastics materials and articles intended to come into contact with foodstuffs, https://rm.coe.int/16804d0d41

[174] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives https://eur-lex.europa.eu/legal-content/de/TXT/PDF/?uri=CELEX:02008L0098-20180705&from=EN

[175] European Parliament and Council Directive 94/62/EC of 20 December 1994 on packaging and packaging waste, https://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A31994L0062

[176] Gesetz zur Förderung der Kreislaufwirtschaft und Sicherung der umweltverträglichen Bewirtschaftung von Abfällen (Kreislaufwirtschaftsgesetz – KrWG) (German Recycling Act), https://www.gesetze-im-internet.de/krwg/

[177] DIN EN ISO 14021:202110: Environmental labels and declarations – Self-declared environmental claims (Type II environmental labelling), https://www.beuth.de/de/norm/din-en-iso-14021/336875741

[178] Dehoust et. al. (2021), Ökologische Gestaltung der Beteiligungsentgelte gemäß § 21 VerpackG, insbesondere Entwicklung einer Methodik zur Erfassung der Praxis der Sortierung und Verwertung (ÖkoGeB), https://www.umweltbundesamt.de/sites/default/files/medien/5750/publikationen/2021-01-22_texte_11-2020_oekologische_beteiligungsentgelte.pdf, last retrieved on 30.09.2022

[179] R. Pomberger (2020), Über theoretische und reale Recyclingfähigkeit. Österreichische Wasser- und Abfallwirtschaft Volume 73, https://doi.org/10.1007/s00506-019-00648-6

[180] ISO 18603:2013-01 Packaging and the environment – Reuse, https://www.beuth.de/de/norm/iso-18603/171300811

[181] DIN EN 13698-1:2004-01: Pallet production specification – Part 1: Construction specification for 800 mm × 1200 mm flat wooden pallets, https://www.beuth.de/de/norm/din-en-13698-1/60040228

[182] European Food Safety Authority (n.d.), Plastics and plastic recycling, https://www.efsa.europa.eu/en/topics/topic/plastics-and-plastic-recycling

[183] DIN ISO 13065:2017-07, Sustainability criteria for bioenergy, https://www.beuth.de/de/norm/din-iso-13065/271386386

[184] EU Commission (2022) (DRAFT): COMMISSION IMPLEMENTING DECISION of XXX on a request for standardization to the European Committee for Standardization and the European Committee for Electrotechnical Standardization related to plastics recycling and recycled plastics in support of the European Strategy for Plastics in the Circular Economy

[185] DIN CEN/TS 16010:2021-04, Plastics – Recycled plastics – Sampling procedures for testing plastics waste and recyclates, https://www.beuth.de/de/vornorm/din-cen-ts-16010/324958916

[186] DIN CEN/TS 16011:2013-04 DIN SPEC 91011:2013-04, Plastics – Recycled plastics – Sample preparation, https://www.beuth.de/de/technische-regel/din-cen-ts-16011/152250361

[187] DIN EN 15343:2008-02 Plastics – Recycled Plastics – Plastics recycling traceability and assessment of conformity and recycled content, https://www.beuth.de/de/norm/din-en-15343/99632421

[188] DIN CEN/TS 17627:2021-07 Plastics – Recycled plastics – Determination of solid contaminants content, https://www.beuth.de/de/vornorm/din-cen-ts-17627/330285919

[189] DIN EN 15344:2021-07, Plastics – Recycled plastics – Characterization of Polyethylene (PE) recyclates, https://www.beuth.de/de/norm/din-en-15344/333190085

[190] E DIN EN 15347:2022-04, Plastics – Recycled plastics – Characterisation of sorted plastics wastes; https://www.beuth.de/de/norm-entwurf/din-en-15347/347420181

[191] DIN EN ISO 1043-1:2016-09, Plastics – Symbols and abbreviated terms – Part 1: Basic polymers and their special characteristics (ISO 1043-1:2011 + Amd.1:2016), https://www.beuth.de/de/norm/din-en-iso-1043-1/254567106

[192] DIN EN ISO 11357-3:2018-07, Plastics – Differential scanning calorimetry (DSC) – Part 3: Determination of temperature and enthalpy of melting and crystallization (ISO 11357-3:2018), https://www.beuth.de/de/norm/din-en-iso-11357-3/282639092

[193] RecyClass. (n.d.), Homepage, https://recyclass.eu/

[194] Gürlich, U., Kladnik, V., & Pavlovic, K. (2021), CIRCULAR PACKAGING DESIGN GUIDELINE – EMPFEHLUNGEN FÜR DIE GESTALTUNG RECYCLINGGERECHTER VERPACKUNGEN. https://www.fh-campuswien.ac.at/fileadmin/redakteure/Forschung/FH-Campus-Wien_Circular-Packaging-Design-Guideline_V04_DE.pdf

[195] Stiftung Zentrale Stelle Verpackungsregister (2021), Mindeststandard für die Bemessung der Recyclingfähigkeit von systembeteiligungspflichtigen Verpackungen gemäß § 21 Abs. 3 VerpackG, https://www.verpackungsregister.org/fileadmin/files/Mindeststandard/Mindeststandard_VerpackG_2021.pdf

[196] Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directives 2005/29/EC and 2011/83/EU as regards empowering consumers for the green transition through better protection against unfair practices and better information, https://op.europa.eu/en/publication-detail/-/publication/ccf4e0b8-b0cc-11ec-83e1-01aa75ed71a1/language-en/format-PDF

[197] COMMISSION REGULATION (EC) No 282/2008of 27 March 2008 on recycled plastic materials and articles intended to come into contact with foods and amending Regulation (EC) No 2023/2006 9–18, EUR-Lex – 32008R0282 – EN – EUR-Lex (europa.eu)

[198] Bundesregierung unterstützt Initiative der EU-Kommission für nachhaltige Produkte | Pressemitteilung | BMUV. (n. d.). retrieved on 26 July 2022, https://www.bmuv.de/pressemitteilung/bundesregierung-unterstuetzt-initiative-der-eu-kommission-fuer-nachhaltige-produkte

[199] ISO 12418-1:2012-09, Plastics – Post-consumer poly(ethylene terephthalate) (PET) bottle recyclates – Part 1: Designation system and basis for specifications, https://www.beuth.de/de/norm/iso-12418-1/165434703

[200] ISO 15270:2008-06, Plastics – Guidelines for the recovery and recycling of plastics waste, https://www.beuth.de/de/norm/iso-15270/110156950

[201] Prof. Dr. Hans-Josef Endres (2022): Hochwertigere Rezyklate und konstantere Inputströme, in: K-Zeitung vom 19.05.2022, https://www.k-zeitung.de/hochwertigere-rezyklate-und-konstantere-inputstroeme

[202] Orth, P., Bruder, J., & Rink, M. (2022). Normung und Standardisierung für Kunststoffe im Kreislauf. In Kunststoffe im Kreislauf (pp. 183–193). Springer Vieweg, Wiesbaden, https://doi.org/10.1007/978-3-658-37814-1_14

[203] United Nations, & UN Department of Economic and Social Affairs (2015), THE 17 GOALS | Sustainable Development, https://sdgs.un.org/goals

[204] DIN EN 17410:2021-11, Plastics – Controlled loop recycling of PVC-U profiles from windows and doors, https://www.beuth.de/de/norm/din-en-17410/339503681

[205] VDI 3822- Draft, Failure analysis – Fundamentals and performance of failure analysis, https://www.vdi.de/richtlinien/details/vdi-3822-schadensanalyse-grundlagen-und-durchfuehrung-einer-schadensanalyse

[206] DIN EN ISO 9001:2015-11, Quality management systems – Requirements, https://www.beuth.de/de/norm/din-en-iso-9001/235671251

[207] VDI 4800 Blatt 2, Resource efficiency – Evaluation of raw material demand, https://www.vdi.de/richtlinien/details/vdi-4800-blatt-2-ressourceneffizienz-bewertung-des-rohstoffaufwands

[208] VDI 3800, Determination of costs for industrial environmental protection measures, https://www.vdi.de/richtlinien/details/vdi-3800-ermittlung-der-aufwendungen-fuer-massnahmen-zum-betrieblichen-umweltschutz

[209] DIN SPEC 91466- Business plan, Packaging waste sorting plants – efficiency in resource recovering and other quality features – measurement procedures and documentation, https://www.din.de/de/forschung-und-innovation/din-spec/alle-geschaeftsplaene/wdc-beuth:din21:346868777

[210] DIN EN ISO 60:2000-01, Plastics – Determination of apparent density of material that can be poured from a specified funnel, https://www.beuth.de/de/norm/din-en-iso-60/24622445

[211] VDA 270 (05/2022), Determination of the odour behaviour of materials used in automotive interiors, https://webshop-dev.vda.de/VDA/en/vda-270-052022

[212] European Commission (2022), Sustainable and Circular Textiles by 2030 https://ec.europa.eu/commission/presscorner/detail/en/FS_22_2017

[213] Textil+Mode (2017), DIE ZUKUNFT IST TEXTIL Die deutsche Textil- und Modeindustrie stellt sich vor, https://textil-mode.de/de/documents/4/2017-03-13_Imagebroschüre_dt_web-2.pdf

[214] DIN CEN/TS 16822:2016-02, DIN SPEC 64677:2016-02 Textiles and textile products – Self-declared environmental claims – Use of the terms, https://www.beuth.de/de/technische-regel/din-cen-ts-16822/225404076

[215] European Commission (2022), EU strategy for sustainable and circular textiles, https://environment.ec.europa.eu/strategy/textiles-strategy_en

[216] Greenpeace e. V. (2017), After the Binge, the Hangover- International Fashion Consumption Survey Insights into the Minds of Clothing Consumers, https://www.greenpeace.de/publikationen/2017-05-08-greenpeace-konsum-umfrage-mode.pdf

[217] Köhler, A., Watson, D., Trzepacz, S., Löw, C., Liu, R., Danneck, J., Konstantas, A., Donatello, S., Faraca, G., & Europäische Kommission Gemeinsame Forschungsstelle. (2021), Circular Economy Perspectives in the EU Textile sector, EUR 30734 EN, https://doi.org/10.2760/858144

[218] Wagner, J., Steinmetzer, S., Theophil, L., Strues, A.-S., Kösegi, N., & Dr. Hoyer, S. (2022), UBA (Herausgeber), Evaluation der Erfassung und Verwertung ausgewählter Abfallströme zur Fortentwicklung der Kreislaufwirtschaft, Abschlussbericht, https://www.umweltbundesamt.de/publikationen/evaluation-der-erfassung-verwertung-ausgewaehlter

[219] Greenpeace e. V. (2015), Wegwerfware Kleidung, https://www.greenpeace.de/publikationen/20151123_greenpeace_modekonsum_flyer.pdf

[220] Produktsicherheitsgesetz (Product Safety Act) of 27 July 2021 (BGBl. I S. 3146, 3147), https://www.gesetze-im-internet.de/prodsg_2021/ProdSG.pdf

[221] Federal Environment Agency (2019), Die Textilindustrie in Deutschland, https://www.umweltbundesamt.de/themen/wirtschaft-konsum/industriebranchen/textilindustrie#die-textilindustrie-in-deutschland

[222] Nimkar, U. (2018), Sustainable chemistry: A solution to the textile industry in a developing world. Current Opinion in Green and Sustainable Chemistry, 9, 13–17, https://doi.org/10.1016/J.COGSC.2017.11.002

[223] BMUV (n.d.), Bundesregierung unterstützt Initiative der EU-Kommission für nachhaltige Produkte | Pressemitteilung, https://www.bmuv.de/pressemitteilung/bundesregierung-unterstuetzt-initiative-der-eu-kommission-fuer-nachhaltige-produkte

[224] BMUV (2022), Bundesregierung unterstützt Initiative der EU-Kommission für nachhaltige Produkte, https://www.bmuv.de/pressemitteilung/bundesregierung-unterstuetzt-initiative-der-eu-kommission-fuer-nachhaltige-produkte

[225] EU Commission (2022), Sustainable products initiative (SPI), https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12567-Initiative-fur-nachhaltige-Produkte_en

[226] E DIN EN ISO 5157, Textiles – Environmental aspects – Vocabulary, https://www.beuth.de/de/norm-entwurf/din-en-iso-5157/357661382

[227] Hessisches Ministerium für Wirtschaft, Energie, Verkehr und Wohnen (2021), Mit Ecodesign zu einer ressourcenschonenden Wirtschaft, https://redaktion.hessen-agentur.de/publication/2021/3319_ecodesign_2021_final_web.pdf

[228] COMMISSION REGULATION (EC) No 552/2009 of 22 June 2009 amending Regulation (EC) No 1907/2006 of the European Parliament and of the Council on the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) as regards Annex XVII, https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:164:0007:0031:EN:PDF

[229] DIN EN ISO 12947 (all parts), Textiles – Determination of the abrasion resistance of fabrics by the Martindale method, https://www.beuth.de/de/norm/din-en-iso-12947-1/97753105

[230] DIN EN ISO 9073-4, Nonwovens – Test methods – Part 4: Determination of tear resistance by the trapezoid procedure, https://www.beuth.de/de/norm/din-en-iso-9073-4/330766694

[231] DIN EN ISO 13937 (all parts), Textiles – Tear properties of fabrics – Part 1: https://www.beuth.de/de/norm/din-en-iso-13937-1/20269932

[232] REGULATION (EU) 2016/425 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 9 March 2016 on personal protective equipment and repealing Council Directive 89/686/EEC https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32016R0425

[233] Verordnung über die Bewirtschaftung von gewerblichen Siedlungsabfällen und von bestimmten Bau- und Abbruchabfällen (Ordinance on the Management of Commercial Municipal Waste and Certain Construction and Demolition Waste)1, https://www.gesetze-im-internet.de/gewabfv_2017/index.html

[234] DIN EN ISO 13934-1:2013-08 Textiles – Tensile properties of fabrics – Part 1: Determination of maximum force and elongation at maximum force using the strip method (ISO 13934-1:2013), https://www.beuth.de/de/norm/din-en-iso-13934-1/187071021

[235] European Environment Agency (2022), Eionet Report – ETC/CE 2022/2, Textiles and the Environment The role of design in Europe ‘s circular economy, ETC_Design-of-Textiles.pdf (cscp.org)

[236] Textilkennzeichnungsgesetz (Textile Labelling Act) of 15 February 2016 (BGBl. I p 198), https://www.gesetze-im-internet.de/textilkennzg_2016/TextilKennzG.pdf

[237] EURATEX (o.J.), A joint initiative for industrial upcycling of textile waste streams & circular materials, https://euratex.eu/rehubs/

[238] REGULATION (EU) No 1007/2011 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 September 2011 on textile fibre names and related labelling and marking of the fibre composition of textile products and repealing Council Directive 73/44/EEC and Directives 96/73/EC and 2008/121/EC of the European Parliament and of the Council, https://eur-lex.europa.eu/legal-content/ENLSU/?uri=CELEX:32011R1007

[239] Textilkennzeichnungsgesetz (Textile Labelling Act), https://www.gesetze-im-internet.de/textilkennzg_2016/

[240] DIN EN ISO 14001:2015-011 Environmental management systems – Requirements with guidance for use, https://www.beuth.de/de/norm/din-en-iso-14001/236721041

[241] Ellen MacArthur Foundation (n.d.) Material Circularity Indicator (MCI), https://ellenmacarthurfoundation.org/material-circularity-indicator

[242] Deutsche Institute für Textil + Faserforschung (DITF) (o.J.), Forschung, https://www.ditf.de/de/forschung/kompetenzzentren/textilchemie-umwelt-und-energie.html

[243] DIN EN ISO 3758, Textiles – Care labelling code using symbols https://www.beuth.de/de/norm-entwurf/din-en-iso-3758/349818212

[244] Clevercare.info (http://clevercare.info)

[245] DIN EN ISO 15797:2018-05 Textiles – Industrial washing and finishing procedures for testing of workwear (ISO 15797:2017), https://www.beuth.de/de/norm/din-en-iso-15797/279031118

[246] DIN EN ISO 30023, Textiles – Qualification symbols for labelling workwear to be industrially laundered, https://www.beuth.de/de/norm/din-en-iso-30023/345625575

[247] DIN EN ISO 3175 (all parts), Textiles – Professional care, drycleaning and wetcleaning of fabrics and garments, https://www.beuth.de/de/norm/din-en-iso-3175-1/279447041

[248] Gözet, Wilts (2022), Kreislaufwirtschaft als Baustein nachhaltiger Entwicklung, in: Christiane Meyer (Hg.), „Transforming our World“. Zukunftsdiskurse zur Umsetzung der UN-Agenda 2030. [transcript] Neue Ökologie, Seite 173-180

[249] MIT Technology Review, Heft 2 (2022), REDUCE, REUSE, Recycle, REPEAT. Kreislauf statt Einbahnstraße: Neue Strategien für die zirkuläre Wirtschaft, Seite 14-21

[250] H. Wilts, M. Fecke (2020), ReUse und Secondhand in Deutschland Einstellungen zum Thema Abfallvermeidung und Nachhaltigkeit, OPUS 4 | ReUse und Secondhand in Deutschland : Einstellungen zum Thema Abfallvermeidung und Nachhaltigkeit (wupperinst.org)

[251] European Parliament resolution of 7 April 2022 on the right to repair 2022/2515(RSP), https://www.europarl.europa.eu/doceo/document/TA-9-2022-0126_EN.html

[252] Gemeinschaft für textile Zukunft (2021), Textile Zukunft Informationen – Hintergründe – Strategien zum Umgang mit Alttextilien, https://textile-zukunft.de/wp-content/uploads/2014/10/Textile-Zukunft-Brosch%C3%BCre-der-Gemeinschaft-f%C3%BCr-Textille-Zukunft.pdf

[253] Fachverband Textilrecycling (Hrsg.) (o.J), Bedarf, Konsum und Wiedervendung von Bekleidung und Textilien in Deutschland, https://www.bvse.de/dateien2020/1-Bilder/03-Themen_Ereignisse/06-Textil/2020/studie2020/bvse%20Alttextilstudie%202020.pdf

[254] CEN/TC 183/WG 1 Waste containers, https://www.din.de/de/mitwirken/normenausschuesse/nkt/europaeische-gremien/wdc-grem:din21:54756197

[255] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on shipments of waste and amending Regulations (EU) No 1257/2013 and (EU) No 2020/1056, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52021PC0709

[256] Gesetz über die unternehmerischen Sorgfaltspflichten zur Vermeidung von Menschenrechtsverletzungen in Lieferketten (Lieferkettensorgfaltspflichtengesetz-LkSG) (Supply Chain Due Diligence Act) Section 1 (In force in the future), (2021), https://www.gesetze-im-internet.de/lksg/LkSG.pdf

[257] OEKO-TEX (2022), Startseite, https://www.oeko-tex.com/de/

[258] Grüner Knopf, https://www.gruener-knopf.de/?gclid=EAIaIQobChMI39jl2sq8-gIVYY9oCR3foQExEAAYASAAEgK8BfD_BwE

[259] Baratsas, S. G., Masoud, N., Pappa, V. A., Pistikopoulos, E. N., & Avraamidou, S. (2021), Towards a Circular Economy Calculator for Measuring the „Circularity“ of Companies. Computer Aided Chemical Engineering, 50, 1547–1552. https://doi.org/10.1016/B978-0-323-88506-5.50239-4

[260] DIN EN ISO 14024:2018-06, Environmental labels and declarations – Type I environmental labelling – Principles and procedures (ISO 14024:2018), https://www.beuth.de/de/norm/din-en-iso-14024/288864675

[261] European Commission. Joint Research Centre. & Organisation for Economic Co-operation and Development. (2008), Handbook on constructing composite indicators: methodology and user guide. OECD, https://www.oecd.org/els/soc/handbookonconstructingcompositeindicatorsmethodologyanduserguide.htm

[262] Circular Fashion (2020), circularity.ID Open Data Standard, https://circularity.id/open-data-standard.html

[263] UNECE (n.d.), Project Traceability for Sustainable Garment and Footware, https://unece.org/trade/traceability-sustainable-garment-and-footwear

[264] Textile Exchange (2020), Material Processes Product Classification, https://textileexchange.org/documents/materials-processes-products-classification/

[265] Global Textile Scheme GmbH (2020), GTL Language von Global Textile Scheme, GTL Language: https://www.globaltextilescheme.org/

[266] GS1 (o.J.), 6.35 Web Vocabulary, https://www.gs1.org/gs1-web-vocabulary

[267] Textile Exchange (2022), The RCS and GRS are designed to boost the use of recycled materials, https://textileexchange.org/standards/recycled-claim-standard-global-recycled-standard/

[268] Greenpeace e. V. (2018), https://www.greenpeace.de/sites/default/files/publications/e01211-greenpeace-cheemie-einkaufsratgeber-textil-siegel-2018.pdf

[269] REGULATION (EU) 2017/745 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 5 April 2017 on medical devices, amending Directive 2001/83/EC, Regulation (EC) No 178/2002 and Regulation (EC) No 1223/2009 and repealing Council Directives 90/385/EEC and 93/42/EEC, EUR-Lex – 32017R0745 – EN – EUR-Lex (europa.eu)

[270] Paris Agreement – UN Framework Convention on Climate Change, https://eur-lex.europa.eu/content/paris-agreement/paris-agreement.html?locale=en

[271] REGULATION (EU) 2020/852 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088, https://eur-lex.europa.eu/eli/reg/2020/852/oj?locale=en

[272] REGULATION (EU) No 305/2011 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 9 March 2011 laying down harmonised conditions for the marketing of construction products and repealing Council Directive 89/106/EEC, EUR-Lex – 32011R0305 – EN – EUR-Lex (europa.eu)

[273] ISO 20887:2020-01 Sustainability in buildings and civil engineering works – Design for disassembly and adaptability – Principles, requirements and guidance, https://www.beuth.de/de/norm/iso-20887/320395771

[274] DIN EN 10020:2000-07, Definition and classification of grades of steel, https://www.beuth.de/de/norm/din-en-10020/27404233

[275] Beton-Festigkeitsklasse nach Eurocode 2, Eurocode 2: Betonbau (eurocode-online.de)

[276] Graf, J., Birk, S., Poteschkin, V., & Braun, Y. (2022), Kreislaufeffektive Bauwende – Auf dem Weg zu einer neuen Tektonik. Bautechnik, https://doi.org/10.1002/BATE.202100111

[277] VDI 2243:2002-07, Recycling-oriented product development https://www.vdi.de/richtlinien/details/vdi-2243-recyclingorientierte-produktentwicklung

[278] Funktional und komfortabel – Informationsportal Nachhaltiges Bauen https://www.nachhaltigesbauen.de/

[279] Bundesministerium für Wohnen, Stadtentwicklung und Bauwesen (o.J.), Bewertungssystem – Bewertungssystem Nachhaltiges Bauen (BNB), https://bnb-nachhaltigesbauen.de

[280] DIN EN 1991-1-1:2010-12 Eurocode 1: Actions on structures – Part 1-1: General actions – Densities, self-weight, imposed loads for buildings, https://www.beuth.de/de/norm/din-en-1991-1-1/134234392

[281] ISO 167391:2018, Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries – Part 1: Data schema, https://www.iso.org/standard/70303.html

[282] buildingSMART (o.J.), Building smart, https://www.buildingsmart.de/

[283] DIN EN 15978:2012-10 Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method (n. d.), https://www.beuth.de/de/norm-entwurf/din-en-15978-1/337039423

[284] DIN EN 15804:2022-03 Sustainability of construction works – Environmental product declarations – Core rules for the product category of construction products, https://www.beuth.de/de/norm/din-en-15804/344735627

[285] Institut Bauen und Umwelt e. V. (2020), EDP, Institut Bauen und Umwelt e.V. | Das Detail im Fokus.Das Ganze im Blick. (ibu-epd.com)

[286] BMWK (2022), BMWK startet Diskussionsprozess zu flächendeckender kommunaler Wärmeplanung, https://www.bmwk.de/Redaktion/DE/Artikel/Energie/diskussionspapier-kommunale-waermeplanung.html

[287] Feifel, S., Walk, W., Wursthorn, S., & Schebek, L. (2009), Ö̈kobilanzierung 2009 Ansä̈tze und Weiterentwicklungen zur Operationalisierung von Nachhaltigkeit; Tagungsband Ö̈kobilanz-Werkstatt 2009; Campus Weihenstephan, Freising, 5. bis 7. Oktober 2009. Karlsruher Institut für Technologie (KIT) KIT Scientific Publishing, https://www.itas.kit.edu/pub/v/2009/walk09a.pdf

[288] RecyClass. (o.J.), https://recyclass.eu/

[289] Green Delta (2022), Product Environmental Footprint (PEF), https://www.openlca.org/project/pef/

[290] European Commission. (n.d.), Life cycle costing – GPP – Environment, https://ec.europa.eu/environment/gpp/lcc.htm

[291] ISO 14051:2011-09 Environmental management – Material flow cost accounting – General framework, https://www.beuth.de/de/norm/iso-14051/146156682

[292] Federal Ministry of Labour and Social Affairs (BMAS) (n.d.), CSR – Corporate Sustainability Reporting Directive (CSRD), https://www.csr-in-deutschland.de/DE/CSR-Allgemein/CSR-Politik/CSR-in-der-EU/Corporate-Sustainability-Reporting-Directive/corporate-sustainability-reporting-directive-art.html

[293] Federal Ministry of Education and Research (2022), Programmaufbau von Horizont 2020 – Horizont 2020, https://www.horizont2020.de/einstieg-programmaufbau.htm

[294] EU Commission (n.d.), Ecodesign for sustainable products, https://ec.europa.eu/info/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/sustainable-products/ecodesign-sustainable-products_en

[295] Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL concerning batteries and waste batteries, repealing Directive 2006/66/EC and amending Regulation (EU) No 2019/1020, COM/2020/798 final, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52020PC0798

[296] DGNB (o.J.), Gebäuderessourcenpass, https://www.dgnb.de/de/themen/gebaeuderessourcenpass/index.php

[297] R-Cycle Initiative (o.J.), R-Cycle Pilotprojekte, https://www.r-cycle.org/pilotprojekte/

[298] New Legislative Framework – CE Directives.eu. (n.d.), https://www.ce-richtlinien.eu/ce-richtlinien/new-legislative-framework/

[299] ISO/IEC 15459 (all parts), Information technology — Automatic identification and data capture techniques – Unique identification

[300] Circular Economy Initiative (n.d.), Batteriepass (Battery Pass), https://www.circular-economy-initiative.de/battery-pass-de

[301] DIGITALEUROPE (2022), Digital Product Passport (CIRPASS), https://www.digitaleurope.org/digital-product-passport/

[302] EDICOM (o.J.), EDI-Standards, https://edicomgroup.de/learning-center/edi/standards

[303] GS1 (o.J.), ECR – Electronic Product Code (EPC), https://www.ecr.digital/book/gs1-standards/electronic-product-code-epc/

[304] IEC 61360- IEC/SC 3D – Common Data Dictionary (CDD – V2.0015.0004). https://cdd.iec.ch/cdd/iec61360/iec61360.nsf

[305] Council Decision (EU) 2020/1829 of 24 November 2020 on the submission, on behalf of the European Union, of proposals to amend Annex IV and certain entries in Annexes II and IX to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal for consideration at the fifteenth meeting of the Conference of the Parties, and on the position to be adopted on behalf of the European Union at that meeting as regards proposals by other Parties to that Convention to amend Annex IV and certain entries in Annexes II, VIII and IX to that Convention https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=OJ:L:2020:409:FULL&from=EN

[306] European Commission. (2020), Changing how we produce and consume: New Circular Economy Action Plan shows the way to a climate-neutral, competitive economy of empowered consumers, https://ec.europa.eu/commission/presscorner/detail/en/ip_20_420

[307] IK Industrievereinigung Kunststoffverpackungen e. V. (o.J.), ÜBERBLICK ZUM ECO DESIGN LEITFADEN. Retrieved September 30, 2022 from https://ecodesign-packaging.org/leitfaden/management-ueberblick/

[308] AVAW, (o.J.), ReWaste F, https://www.avaw-unileoben.at/de/forschung-projekte-rewaste_f/

[309] Papiertechnische Stiftung (PTS) (o.J.), Neue PTS Methode PTS-RH 025:2022 zur Analyse der wässrigen Phase bei der Faserstoffwiedergewinnung, https://www.ptspaper.de/de/aktuelles/detailseite/pts-rh-0252022-for-the-analysis-of-the-aqueous-phase-in-fibre-recovery-processes/

[310] 4ever green alliance (2022), GUIDANCE ON THE IMPROVED COLLECTION AND SORTING OF FIBRE-BASED PACKAGING FOR RECYCLING. https://4evergreenforum.eu/wp-content/uploads/4evergreens-Guidance-on-the-Improved-Collection-and-Sorting-of-Fibre-based-Packaging-for-Recycling.pdf

[311] 4ever green alliance (2021), guidelines and protocol, https://4evergreenforum.eu/about/guidelinesandprotocol/

[312] Dr. Maier, R.-D., & Dr. Schiller, M. (2016), Handbuch Kunststoff Additive. In Handbuch Kunststoff Additive (4. Auflage, Vol. 4). Carl Hanser Verlag GmbH & Co. KG, https://doi.org/10.3139/9783446432918

[313] Calisto Friant, M., Vermeulen, W. J.V. & Salomone, R. (2020), A typology of circular economy discourses: Navigating the diverse visions of a contested paradigm. Resources, Conservation and Recycling, 161, 1–19, https://doi.org/10.1016/j.resconrec.

[314] Johan Schot/W. Edward Steinmueller (2018), Three frames for innovation policy: R&D, systems of innovation and transformative change, Research Policy –1567, https://doi.org/10.1016/j.respol.; Expertenkommission Forschung und Innovation (EFI) (Hrsg.) (2021): Gutachten zu Forschung, Innovation und technologischer Leistungsfähigkeit Deutschlands 2021, EFI, Berlin.

[315] DIN EN IEC 62902, VDE 0510902, Secondary cells and batteries – Marking symbols for identification of their chemistry (IEC 62902:2019), https://www.beuth.de/de/erweiterte-suche/272754!search?alx.searchType=complex&alx.search.autoSuggest=false&searchAreaId=1&query=62902&facets%5B276612%5D=&hitsPerPage=10

[316] IK Industrievereinigung Kunststoffverpackungen e.V. (o.J.), Design For Recycling, https://ecodesign-packaging.org/en/guidelines/strategies/design-for-recycling/

[317] DIN EN 45558:2019-10, General method to declare the use of critical raw materials in energy-related products, https://www.beuth.de/de/norm/din-en-45558/309791380

[318] DIN EN 45552:2020-05, General method for the assessment of the durability of energy-related products, https://www.beuth.de/de/norm/din-en-45552/316877675

[319] DIN EN 45556:2020-03, General method for assessing the proportion of reused components in energy-related products, https://www.beuth.de/de/norm/din-en-45556/317433757

[320] DIN EN 45555:2020-04, General methods for assessing the recyclability and recoverability of energy-related products, https://www.beuth.de/de/norm/din-en-45555/311516381

[321] DIN EN IEC 62485-5; VDE 0510-485-5:2021-12, Safety requirements for secondary batteries and battery installations – Part 5: Safe operation of stationary lithium ion batteries (IEC 62485-5:2020), https://www.vde-verlag.de/normen/0500212/din-en-iec-62485-5-vde-0510-485-5-2021-12.html

[322] DIN EN IEC 60086-4; VDE 0509-4:2020-07, Primary batteries – Part 4: Safety of lithium batteries (IEC 60086-4:2019), https://www.vde-verlag.de/normen/0500173/din-en-iec-60086-4-vde-0509-4-2020-07.html

[323] DIN EN 62620; VDE 0510-35:2015-09, Secondary cells and batteries containing alkaline or other non-acid electrolytes – Secondary lithium cells and batteries for use in industrial applications (IEC 62620:2014), https://www.vde-verlag.de/normen/0500056/din-en-62620-vde-0510-35-2015-09.html

[324] DIN EN 60086-1:2016-07, Primary batteries – Part 1: General (IEC 60086-1:2015), https://www.beuth.de/de/norm/din-en-60086-1/251340357

[325] IEC 60079-0:2017, Explosive atmospheres — Part 0: Equipment — General requirements, https://www.vde-verlag.de/iec-normen/225215/iec-60079-0-2017.html

[326] DIN EN ISO 9092:2019-08, Nonwovens – Vocabulary (ISO 9092:2019), https://www.beuth.de/de/norm/din-en-iso-9092/300001545

[327] DIN 60900-1:1988-07, Yarns; technological classification, https://www.beuth.de/de/norm/din-60900-1/1389771

[328] DIN 30692-2:2012-07, Diaphragms for gas distribution and installation – Part 2: Requirements and test of reinforced diaphragm material, https://www.beuth.de/de/norm/din-30692-2/150436903

[329] DIN 61101-1:1979-01, Weaves; general terms, basic weaves, https://www.beuth.de/de/norm/din-61101-1/766498

[330] DIN EN ISO 6938:2015-01, Textilien — Textiles – Natural fibres – Generic names and definitions, https://www.beuth.de/de/norm/din-en-iso-6938/225357042

[331] DIN EN 12562:1999-10, Textiles – Para-aramid multifilament yarns – Test methods, https://www.beuth.de/de/norm/din-en-12562/8541504

[332] DIN CEN ISO/TR 11827:2019-04 (DIN SPEC 4869:2019-04), Textiles – Composition testing – Identification of fibres, https://www.beuth.de/de/technische-regel/din-cen-iso-tr-11827/287580578

[333] DIN EN ISO 2076:2022-02, Textiles – Man-made fibres – Generic names https://www.beuth.de/de/norm/din-en-iso-2076/343339011

[334] DIN EN ISO 11074:2015-11, Soil quality – Vocabulary (ISO 11074:2015); Trilingual version https://www.beuth.de/de/norm/din-en-iso-11074/221924667

[335] DIN EN ISO 472:2013-06, Plastics – Vocabulary (ISO 472:2013); Trilingual version, https://www.beuth.de/de/norm/din-en-iso-472/127272445

[336] DIN EN ISO 17422:2019-11, Plastics – Environmental aspects – General guidelines for their inclusion in standards (ISO 17422:2018), https://www.beuth.de/de/norm/din-en-iso-17422/309798963

[337] DIN EN 17615:2022-12, Plastics – Environmental Aspects – Vocabulary, https://www.beuth.de/de/norm/din-en-17615/348914344

[338] DIN EN 45554:2020-10, General methods for the assessment of the ability to repair, reuse and upgrade energy-related products, https://www.beuth.de/de/norm/din-en-45554/327255150

[339] DIN EN 62569-1:2018-06, Generic specification of information on products by properties – Part 1: Principles and method (IEC 62569-1:2017), https://www.beuth.de/de/norm/din-en-62569-1/283805971

[340] Fraunhofer-Institut für Optronik, Systemtechnik und Bildauswertung IOSB. Digitaler Zwilling – das Schlüsselkonzept für Industrie 4.0 [online], [Retrieved on 2022-11-09]. Available at:https://www.iosb.fraunhofer.de/de/geschaeftsfelder/automatisierung-digitalisierung/anwendungsfelder/digitaler-zwilling.html

[341] DIN EN 45557:2020-09, General method for assessing the proportion of recycled material content in energy-related products, DIN EN 45557 – 2020-09 – Beuth.de

[342] Suhendro, B. (2014), Toward Green Concrete for Better Sustainable Environment, in: Procedia Engineering 95, Seite 305-320, https://doi.org/10.1016/j.proeng.2014.12.190

[343] Agustí-Juan, I., Habert, G. (2017), Environmental design guidelines for digital fabrication, in: Journal of Cleaner, Production 142, Seite 2780-2791, https://doi.org/10.1016/j.jclepro.2016.10.190

[344] Wallbaum, H. (2008), Beton – ein nachhaltiger Baustoff? 14. Holcim Betontagung, Zürich

Index of figures

DIN e. V.
Am DIN-Platz
Burggrafenstraße 6
10787 Berlin
Tel.: +49 30 2601-0
Email: presse@din.de
Website: www.din.de

DKE German Commission for Electrical, Electronic & Information Technologies
Merianstraße 28
63069 Offenbach am Main
Tel.: +49 69 6308-0
Email: dke@vde.com
Website: www.dke.de

VDI – The Association of German Engineers
VDI-Platz 1
40468 Düsseldorf
Tel.: +49 211 6214-0
Email: vdi@vdi.de
Website: www.vdi.de

January 2023