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120 Circular Design Standards for Plastic Packaging – A Comprehensive Analysis

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Abstract

From the second half of the 20th century on, plastics started to gain relevance as a prime packaging material for both food and non-food products. Through packaging innovation, long shelf-life, great freedom of design, and high convenience in handling were achieved. However, the extensive use of plastic packaging paired with their typically short lifetime leads to increasing waste volumes. Often, these plastic wastes are incinerated, end up in landfills or leak into the environment rather than finding their way back into the economy via reuse or recycling. The problem of low circularity of plastics is increasingly being addressed by various circular design standards for plastic packaging from the corporate, non-governmental, and institutional sectors. According to the standards, plastic packaging designed for recycling is the key to overcome current barriers in the recycling value chains and to implement a Circular Economy (CE) of plastics. In contrast to a linear economy (take, make, dispose), a CE can be considered a more sustainable form of production as products shall be cycled in closed technical loops (reuse, repair, recycle) and/or in biological loops (composting, digestion), hence preventing the generation of waste. To fit into one of these loops, packaging must be designed in a way to be compatible with several closed material loops. For this paper, we analysed seven design standards such as the Designing for a Circular Economy, the Circular Packaging Design Guideline - Design Recommendations for Recyclable Packaging, or the Cradle to Cradle Certified Products Standard. We compared these standards by means of a qualitative content analysis. The analysis focuses on the type and number of packaging design elements addressed in each guideline as well as on potential conflicts between the design recommendations and the basic packaging functions defined in the literature. Further categories of evaluation were the elimination of certain formats, materials, and substances and the technical feasibility of the recommendations from a polymer engineering perspective. The individual analyses as well as the overall comparison revealed that most guidelines propose a similar packaging design. The topics of packaging design, technology, and input requirements for mechanical recycling are covered by almost every guideline. Thus, they seem to meet CE targets without seriously conflicting the basic packaging functions. However, the topics of polymers science and the toxicological profile of the output material from recycling processes remain mostly untouched in the standards. This leads to the conclusion that the currently available packaging design standards contribute to reducing the share of plastic packaging typically considered as non-recyclable at the end-of-life. However, for really closing the loop of plastic packaging by re-introducing recycled materials at the highest possible quality level into production, existing standards should incorporate more substantive specifications with regards to material science and toxicological profiles of substances and their effect on recycled material quality.

Keywords: Circular design, Circular economy, Design for recycling, Eco design, Plastic packaging

Introduction

In recent years plastics have attracted increasing attention especially because of improper disposal paired with their slow degradation in nature. While more and more plastic waste is entering the environment and thus endangering whole ecosystems, plastics are still an integral component in many products and industries. However, one type of plastic product is subject to serious criticism: packaging (Silpa Kaza et al., 2018, 1ff).

Packaging products account for around 40% of total plastics consumption which is the largest share and even twice as much as the second-largest share; building and construction (PlasticsEurope, 2017, p. 22). Worldwide, only 14% of plastic packaging waste is collected for recycling, the rest is incinerated (14%), ends up in landfill (40%) or leaks into the environment (32%) (WORLD ECONOMIC FORUM, 2016, p. 13). Today public and legal pressure force the plastics industry to set counteractions to the negative externalities of plastic packaging.

From a regulatory perspective, the European Commission (EC) is particularly ambitious in promoting plastics recycling. While some of the EC's efforts in this context are more general such as the target to bring 10 million tons of recycled plastics into new plastic products annually by 2025 (European Commission) or the substantially increased recycling target for plastic packaging wastes of 55% per weight by the end of 2030 (*Directive (eu) 2018/852 of 30 may 2018 amending directive 94/62/ec on* *packaging and packaging waste.* 2018), others are specifically impacting product design. As a matter of fact, the so-called Single-Use Plastics Directive (SUP) of the EC (European Commission 2019) not only foresees market restrictions and reduction targets for certain plastic products. In its article 6, it also imposes concrete product requirements. Caps and closures of plastic beverage bottles must remain attached to the bottles in future and beverage bottles made of PET have to contain at least 25% recycled content by 2025 (European Commission 2019). Moreover, the EC's Strategy on Plastics in a Circular Economy (European Commission, COM(2018) 28 final) contains the explicit statement that all plastic packaging placed on the EU market shall be reusable or easily recyclable by 2030. The EC's 2020 New Circular Economy Action Plan (European Commission 2020a) further strengthens this plan by demanding that recycling all (plastic) packaging put on the EU market shall be possible in an "economically viable way". In that sense, a particular focus is being put on the reduction of (over)packaging, the promotion of design for re-use and recyclability including restrictions on the use of certain packaging materials, and reduction of packaging materials complexity (European Commission 2020b, COM2020 98 final). Furthermore, a revised version of the Ecodesign Directive is envisioned to more comprehensively integrate diverse aspects of circularity for a wider range of products (European Commission 2020b).

This concerted regulatory pressure on the design of plastic packaging and products has stimulated quasi-voluntary commitments of members of the plastic packaging value chain such as the Ellen MacArthur Foundation's Global Commitment (Ellen MacArthur Foundation 2020) or private sector design guidelines. Several organizations published packaging development standards with the goal of a sustainable packaging future. These are mostly protocol-type models specifying voluntary design principles and evaluation-type models (interactive tools) (Koeijer et al. 2017, 446ff). These standards could support a transition towards a CE by specifying clear targets for packaging developers.

Packaging design standards face a difficult task. They must take into account proper cycling that safeguards high material quality and volumes over several life cycles (Koeijer et al., 2017) while still maintaining all necessary packaging functions. These functions set the boundary conditions for the transition from linear to circular. If the content of a guideline conflicts with the basic packaging functions, the practical relevance of the standards decreases. However, analyzing packaging design standards and their role for a transition towards a CE has been so far neglected (Koeijer et al., 2017). We address this gap by the following research questions: W*hich circular packaging design standards exist and where do they guide us? How do the packaging functions affect circular packaging design?*

Considering the specific functions and the short lifecycles of packaging, the recycling loop receives the most attention. Recycling in terms of a CE starts at the product design stage and has to take into account all related processes and value chain steps (Paletta et al., 2019). Recycling processes are often hampered by inseparable (polymer) composites, opaque materials, unnecessary use of additives, and the use of substances of concern (Paletta et al., 2019). Keeping plastic packaging in closed material loops can lead to the accumulation of hazardous chemicals in material streams (Aurisano et al., 2021; Groh et al., 2019; Zimmermann et al., 2019). Impurities, caused by both intentionally added substances (IAS) (monomers used to make the polymer, additives added to the polymer to impart a desired property or function, and other chemicals intentionally used during manufacturing such as solvents or processing aids), and non-intentionally added substances (NIAS) *(contaminations, reaction by-products, and breakdown products* (Groh et al., 2019)) can jeopardize proper recycling. To "fully close polymer loops, recovered plastic materials need to be recycled into new products at the same or similar quality levels as the original plastic product, that is, within applications comparable to the original products" (Eriksen et al., 2019). However, to date, knowledge on packaging composition is in general inaccessible for actors in the packaging value chain. This complicates circular packaging development and proper recycling (Kramm et al., 2020). Hansen and Schmitt (2021) provide an example of how a material transparent circular packaging development based on a requirement standard can work throughout the value chain. Along with these information barriers, several other barriers to packaging circularity exist. These stem from the political landscape (Bening et al., 2021), the plastic value chain (Paletta et al., 2019), the complex material science of polymers, and recycling technologies (Martens and Goldmann 2016, 271ff). Effective circular development standards will have to address all of these points.

Methods

The methodological approach is a qualitative and comparative analysis of recent packaging design standards with a focus on plastic packaging. The candidates were selected based on a set of criteria. To become part of the review, a standard must first, directly address plastic packaging; second, be directed towards a CE; third, focus on design elements of plastic packaging; forth, be based on the publisher's research; fifth, be available in English or German; and sixth, be published in or after 2015 (ensure up-to-date information)

We identified seven standards to fulfill our criteria for review (CEFLEX, 2020; Cradle to Cradle Products Innovation Institute, 2019; Ellen MacArthur et al., 2017; EverMinds - Borealis AG, 2019; FH Campus Wien, 2020; RecyClass, 2019; WRAP et al., 2018). Most of them are guideline standards but also one certifiable requirement standard

(Cradle to Cradle Certified) and interactive tools passed the qualification. A list of final candidates with their publishing institution and their date of publication can be found in Table 1.

Table 1 Overview of analysed circular design standards

Title of Standard	Publisher	Type of Standard	Latest Update
Polyolefin Packaging Design – 10 Codes of Conduct for Design for Recyclability	Borealis AG	Guideline Standard	2019
Circular Packaging Design Guideline - Design Recommendations for Recyclable Packaging	FH Campus Wien	Guideline Standard	2020
Rigid Plastic Packaging - Design Tips for Recycling	WRAP	Guideline Standard	2018
Design for Recycling Guidelines by RecyClass	RecyClass	Guideline Standard	2020
Designing for a Circular Economy – Recyclability of Polyolefin-based flexible Packaging	CEFLEX	Guideline Standard	2020
The New Plastics Economy – Catalyzing Action	Ellen MacArthur Foundation	Guideline Standard	2017
Cradle to Cradle Certified Product Standard	Cradle to Cradle Products Innovation Institute	Requirement Standard	2021

To review and compare the standards, an analysis grid was developed focusing on design elements that set a circularly designed package apart from a conventional one, and on the conflicts with the basic functions of packaging, which occur because of the recommended changes in packaging design. The analysis grid can be understood as a set of checkpoints to drive the reviews and comparisons of the standards. It enables compact delivery of the generated findings and ensures comparability in terms of content and scope.

In the first step of the analysis, we identified the circular packaging design elements from the conventional packaging design literature (e.g. Geueke et al., 2018, p. 493). We compared these design elements with those the circular packaging design standards propose for redesigning a package. These elements are the choice of the main material such as PE (polyethylene), PP (polypropylene), or PET (polyethylene terephthalate), additional substances for the material formulation such as stabilizers, plasticizers, or any kind of coloring agent, additional layers or coatings such as EVOH (ethylene vinyl alcohol) barrier layers, the size and shape of the product, the material density, product decoration (e.g. labels, sleeves or direct printing), and product features like closure systems. So, we not only got "true or false" statements that show whether a design element is considered by a guideline or not but also descriptive models of the ideally cyclable package according to the respective guideline.

Second, we analyzed the standards with regard to the basic functions of packaging. The packaging functions are containment, protection, preservation, information & merchandizing, facilitating convenient handling, being economically friendly, and environmental responsibility (e.g. Coles et al., 2003, pp. 8–9; Emblem & Emblem, 2012, 24ff; Lindh et al., 2016, 230ff). All of them might be affected by changes in product design. Despite the need for higher cycling rates, it must be ensured that the products do not lose their purpose and functionality at the cost of circularity. Today, even so-called conventional packages are already highly efficient engineering products providing a maximum of functionality with a minimum of resource consumption. Consequently, we pointed out the links between the standards and the packaging functions. We especially concentrated on conflicts between the functions and the design recommendations. Conflicts between the recommended design changes and the functionality of packaging decrease the practical relevance of the standards and thus hinder the transformation to a more circular economy. Pointing out these conflicts in design changes might help packaging designers and authors of future standards to solve certain conflicts by providing better alternatives.

Third, we visualized the relations between the design elements and packaging functions. Therefore, we developed a grid, see table 2, that shows which design elements cause what conflict.

After reviewing the standards individually for design elements and packaging functions, we compared them to each other and performed overall evaluations. Those enabled us to highlight the strengths and weaknesses of the standards and to deduce recommendations for further development.

Results and Discussion

Our analysis led to the following results.

Design Elements

Summary of recommended design elements

Main-Material: The analysis has shown that the average recommended packaging design includes a significant reduction in the variety of used packaging materials, however, plastics per se are not affected by that claim directly. The standards treat all polymer grades (PE, PP, PVC etc.) as individual materials. Among them are some polymers that should be replaced by other polymers but the substitution of polymers with non-polymeric materials never was recommended by any guideline. Some polymers even are treated as the number one choice for many products if they fulfill two barrier conditions. First, the packaging system must be realized as a mono-material structure. Second, the chosen polymer should be one of the following: PE, PP, or PET.

Additives: A major influence on the recyclability of plastics is caused by additives. It appears that most authors know little about polymer additivation. For example, “reducing additivities to a minimum” is a frequently read recommendation. In fact, correct additivation is strongly polymer- and application-specific and sometimes the reduction of additives causes a decrease in recyclability instead of an increase. This is especially the case for stabilizing additives in polyolefins. Polyolefins tend to undergo radical degradation during service life and (re)processing, which can be prevented through correct and enough additivities.

A special kind of additives are pigment-based or liquid-based coloring agents. While the material color does not necessarily have an influence on the packaging functions, it can negatively affect sortability and always causes a price reduction of the resulting recyclate which cannot be deliberately colored anymore. Especially carbon black is a barrier to recycling since it strongly absorbs electromagnetic radiation and thus cannot be sorted through NIR (near infrared).

Layers and coatings: To improve the preservation ability of packages, they are often equipped with barrier layers or barrier coatings. Many barrier materials are not stable as mono material structures because they are very cost intensive, unable to fulfill other requirements than barrier functions (e.g., load carrying capacity) or are sensitive to environmental influences like humidity. So, they are usually sandwiched between layers of the main material. Since this makes a 100% sorting rate impossible, barrier layers are addressed by all the candidates. They usually recommend the transition from polymeric, metallic, or paper barrier layers to plasma coatings. Barrier layers are much thicker than plasma coatings and consequently, the disturbing effect of plasma coatings on the recycling process is minor.

Size and shape of the product: These aspects are cycling relevant since some automated sorting facilities are not able the handle all sizes of input waste. Especially very small formats are problematic since sensor-based sorting techniques require the pieces of waste to be at least some centimeters long. But packages can also be too large to be handled by sorting machines. Thus, some standards recommend an upper volume limit of five liters for plastic packaging. Concerning the shape, many standards recommend a packaging design which enables full drainability.

Density: The density of polymers can be easily adjusted through certain processing principles or fillers. Density modification becomes problematic when sorting facilities use swim sink separators to separate polyolefins from other polymers or contaminants. So, most standards feature a section on material density. While some of them recommend preventing all density-changing activities, others specify their recommendations by allowing lowering the density of polyolefins and rising the density of other plastics.

Decoration: Labels, sleeves, and direct printing are used for packaging communication. Of course, here the potential for disturbing the recyclability is huge since it includes various product parts and colors. The average recommendation of the standards is to minimize the size of all forms of decoration, to use washable inks, and to use labels and sleeves made of the same material as the main body.

Other features: many packages have practical features like reclosable closure systems, ziplines, dosing systems, etc. In this case, the standards either recommend manufacturing all parts of the main body material or using parts with a significant difference in density that is easily decomposable at the same time.

Comparisons and evaluations of design elements:

Basing on the individual analysis of the standards, we compared the content of the standards with to draw overarching conclusions. The findings of the individual evaluation charts were entered in a calculation tool and graphically edited. Individual, as well as all-encompassing strengths and weaknesses of the candidates were revealed this way.

The number of addressed design elements corresponds to the conclusiveness of the standards. In detail, our analysis grid includes 14 different design elements. Figure *1* shows how many of them are addressed by which guideline. It appears that all but two of the candidates address at least eleven elements. The *Circular Packaging Design Guideline* by FH Campus Wien and *Designing for a Circular Economy* by Ceflex stand out as they are the only standards addressing all design elements of the analysis grid. Nevertheless, two candidates lie far behind the others. These are *The New Plastics Economy* and the *Cradle to Cradle Certified Product Standard*. Both candidates stand out as they have a style which is significantly different from the others. They are not pure packaging design standards. *The New Plastics Economy* is about a whole transformation of the economic system of packaging. Packaging design is only one of many topics that are subject to the framework. The *Cradle to Cradle Certified Product Standard* is a certifiable requirement-standard that applies to all product groups – the first with the explicit aim to foster a transition to a CE through product innovation. Its new version 4.0 contains a specific section with specifications for packaging (C2CPII, 2021) The broader focus of these two standards are assumed to be the reason for the weak focus on design elements.

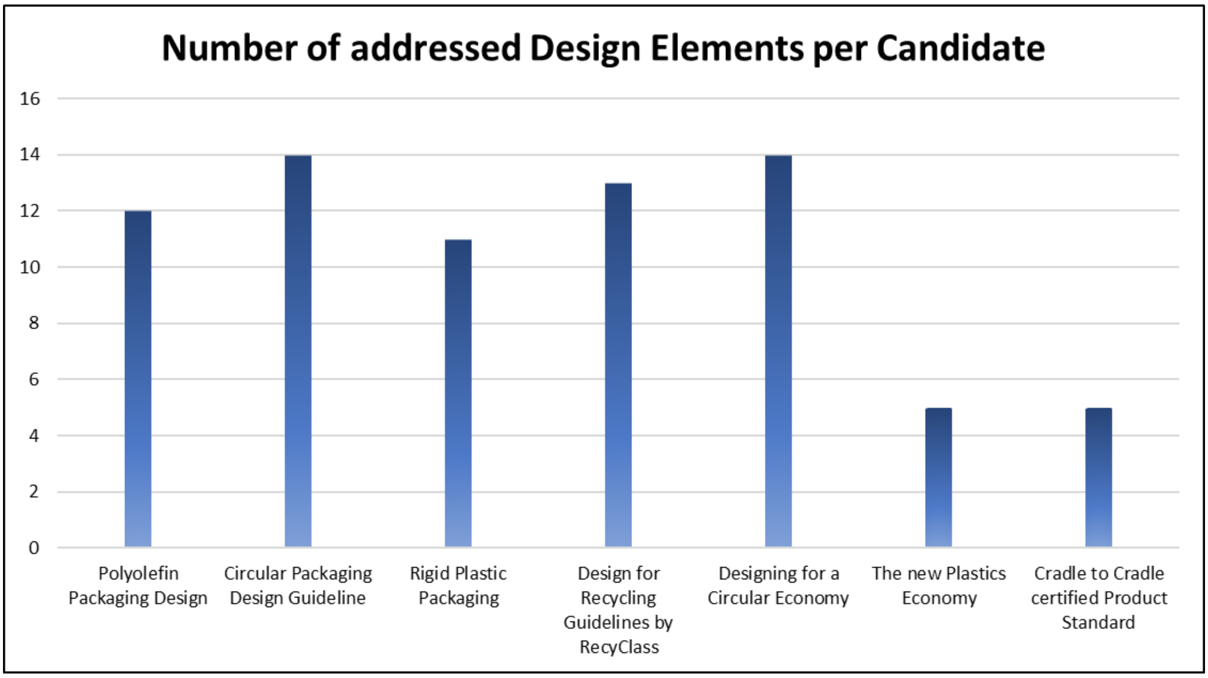

Figure 1: Number of addressed design elements per standard

Figure 2 shows how often the 14 design elements were addressed in total by all standards. It shows which design elements the packaging industry is generally aware of, and which elements still need to be made known. The choice of the main-body material stands out as it is the only design element addressed by all candidates. On the other hand, stabilizing additives are addressed three times and recommendations that go beyond product design are addressed only twice. General weaknesses can be identified in the field of full drainability of the package and its format design too.

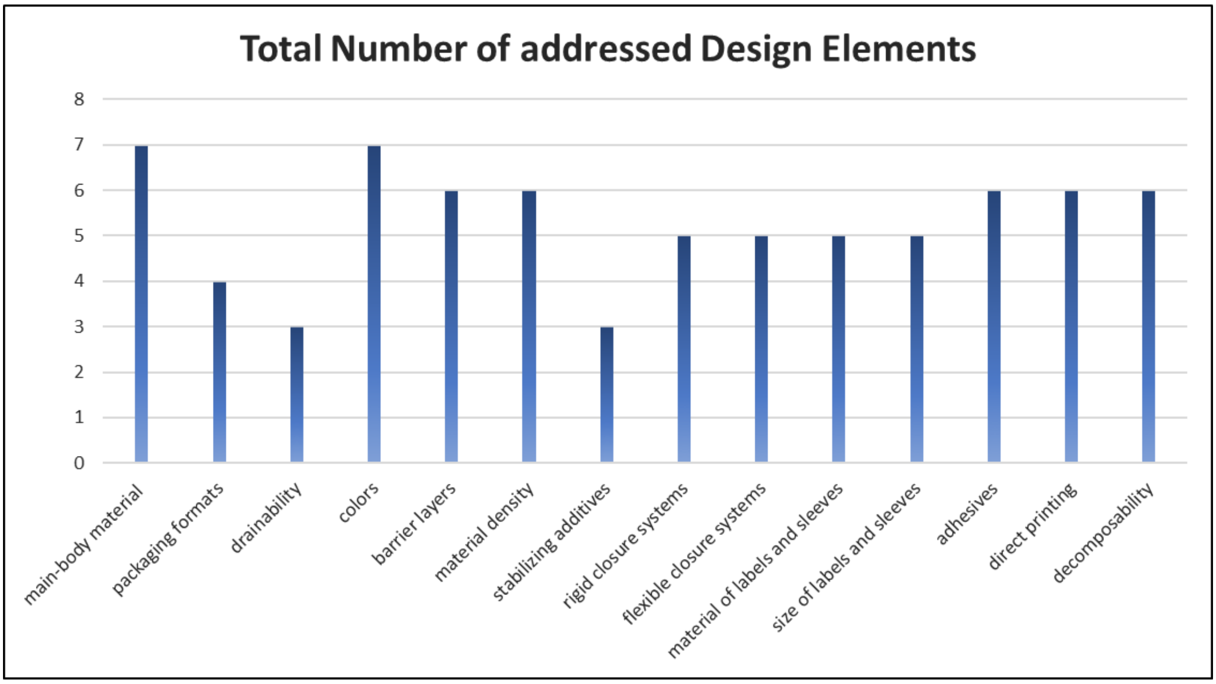

Figure 2: Total number of addressed design elements

Packaging Functions

Summary of packaging functions

Containment: as mentioned before, the standards offer recommendations concerning the size and shape of the products. Since creating sellable units is part of the function containment there is conflict potential. According to the recommended limitations, it would not be possible anymore to pack small products like bonbons individually or to sell beverages in units of more than 5 liters.

Protection: we did not find any recommendation within the standards conflicting with the function of mechanical protection.

Preservation: The analysis showed that keeping the preservation function will be an extensive part of the transition from linear to circular packaging design since this function faces many conflicts. First, there is the recommendation of avoiding well-established barrier materials such as aluminum or EVOH. Second, the standards recommend avoiding well-established sealing materials like PVC. Both recommendations conflict with a proper barrier against gases and humidity. Third, the standards recommend using clear packages. Since many products such as milk or meat require protection against (UV) light, this claim is problematic. Alternative light protection using full-size printings or labels is not recommended because of the claim for proper sortability. Fourth, at least one guideline recommends scaling up compostable packaging materials. Packages are usually designed to prevent interactions between the good and the environment and thus degradable plastics are badly suited to preserve goods unless they are highly modified with stabilizers.

Information and merchandizing: This function conflicts with the claim for reducing all forms of decoration. At least some standards mention washable inks or labels made of main body material as cycling compatible alternatives.

Facilitating convenient handling: This function generally conflicts with recommendations that shorten the shelf life like eliminating barrier layers, and with recommendations that require a more challenging waste sorting at home. An example is the recommendation of scaling up compostable packages.

Being economically friendly: Alternative solutions that cost more than conventional solutions will always have difficulties competing on the market. So, recommended changes in product design that cause a significant increase in cost are in conflict with this function. Again, this is for example the recommendation of scaling up compostable packages.

Comparisons and evaluations of packaging functions

The number of conflicts with the basic packaging functions corresponds to the practical relevance of the guideline. Conflicting with some of the functions is not the problem per se. The analysis even shows that most candidates propose recommendations that are in conflict with some of the basic functions. But as long as the standards also offer a feasible solution to the conflict, the practical relevance is maintained. Figure 3 shows how many conflicts each candidate faces (blue bars) and how many conflicts remain unresolved (red bars). It can be seen that most conflicts are resolved through alternative recommendations in the respective guideline. All but one of the standards have none or a very low number of remaining conflicts. The only guideline with more remaining conflicts is *The New Plastics Economy*. This guideline offers a high number of approaches but on cost of conclusive and meaningful description. It can be concluded that as a design-aid, it is rather unsuited.

Figure 4 shows the total number of conflicts with each packaging function. It represents the critical aspects of redesigning plastic packaging. Most conflicts are linked to the function of preservation. *Preservation* even faces more than twice as many conflicts as *information and merchandising*, which is the function with the second most conflicts. It can be concluded that the conventional way of preserving products is not suited for a recyclable packaging design. Enabling a recyclable way of *preservation* (offer a barrier against gases, humidity, and radiation) is a central challenge of redesigning plastic packaging. On the other hand, the function of *protection* (prevent product loss due to mechanical stress) does not cause any issues with a recyclable packaging design. Attention must also be paid to *information and merchandising*. Since reducing the information on packages would perhaps not be accepted by brand owners, recyclable alternative ways of packaging communication must be established.

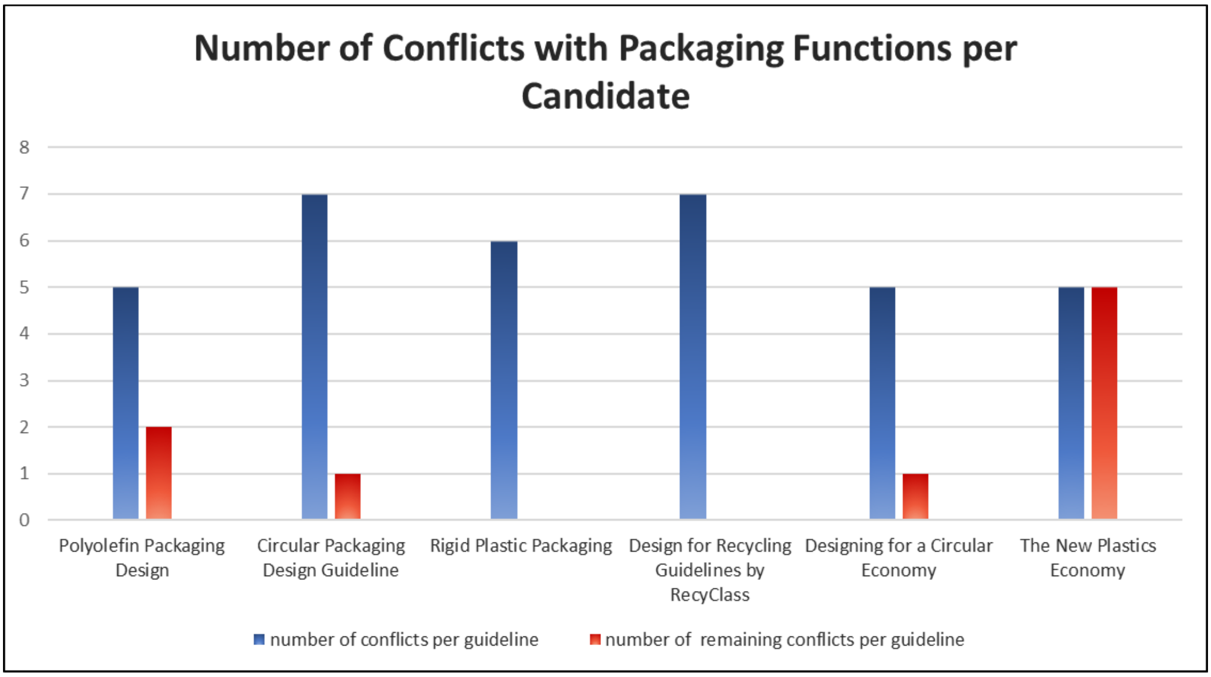

Figure 3: Number of conflicts with packaging Functions per standard

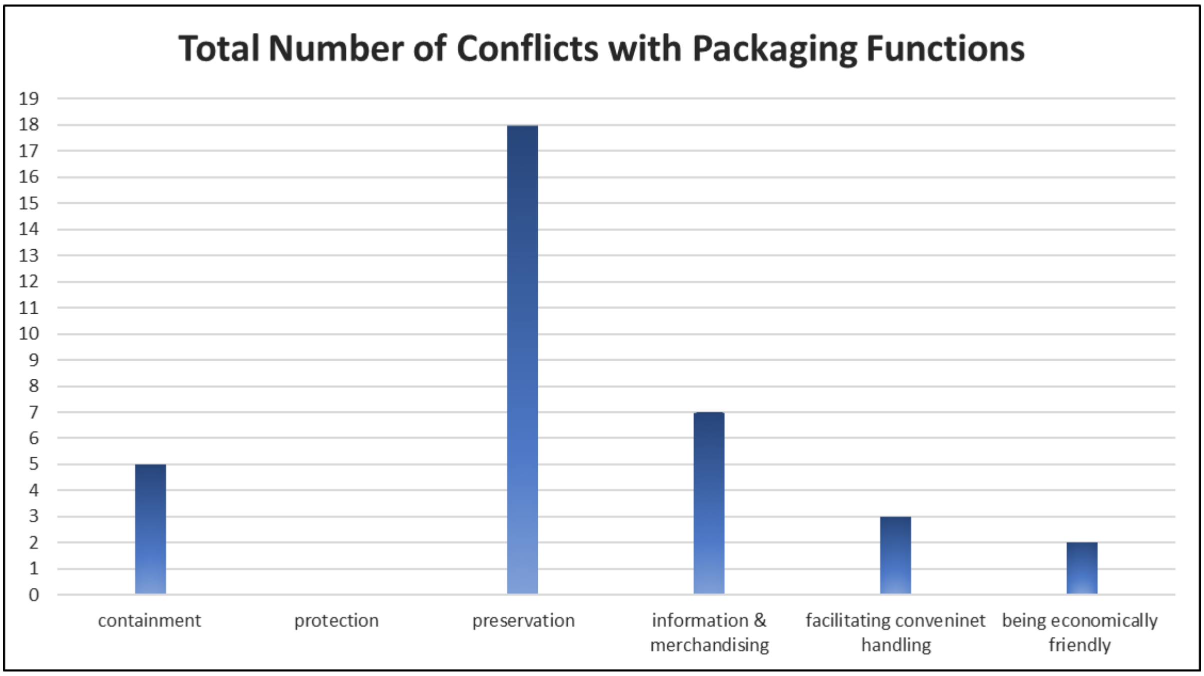

Figure 4: Total number of conflicts with packaging functions

Relations between design elements and packaging functions

After having analyzed the content of the standards for their recommendations regarding design elements and packaging functions, Table 2 summarizes our findings on the relations between both aspects. The column of protection is empty because no conflicts were found with this function in any of the reviewed standards (see figure 4).

Table 2 Relations between design elements and packaging functions

	Main material	***additives***	***Layers and coatings***	***Size and shape***	***Material density***	***decoration***	***Product features***
Containment				*Limitations in the freedom of creating sellable units*			*Limitations in the way of enclosing due to the avoidance of well-established sealing materials like PVC*
Protection							
Preservation		*Limitations in preventing quality losses due to radiation because of the avoidance of coloring agents*	*Limitations in preventing quality losses due to gases, humidity, and radiation because of the avoidance of established barrier layers like EVOH, PA or aluminum*			*Limitations in preventing quality losses due to radiation because of the avoidance of non-translucent coatings*	*Limitations in preventing quality losses due to gases, humidity because of the avoidance of well-established sealing materials*
Information and merchandizing						*Limitation in packaging communication due to minimization of labels sleeves and direct printing*	
Facilitating convenient handling	*Limitations in convenient storage because of the claim for degradable materials that have rather poor barrier properties*	*Difficult to get high quality recycled due to the avoidance of stabilizers*	*Limitation in convenient storage because of the avoidance of established barrier layers*				*Limitations in convenient use due to the avoidance of small parts like opening zippers*
Being economically friendly	*Limitations because of the claim for more expensive materials like degradable polymers*	*Limitations because of material losses due to too less stabilization*	*Limitations because of product losses because of too week barrier properties*				

Strengths and weaknesses of the standards

The circular packaging design as it is recommended by the standards is intended to bring along ecological and economic benefits. But is the knowledge from the standards enough to get the plastic issue under control? The general answer to this question is: No. Besides the human cooperation along the value chain of packaging, the impact of the standards is also limited by the recycling-capability of polymers. Studies with various types of polymers show that continuous cycling of polymers is linked to various technicalities. This is due to degradation mechanisms in polymers. Degradation means that at least one of the following effects occurs: change in molecular weight due to chain scission or crosslinking, or formation of oxygenated and unsaturated compounds. The degradation effects are triggered by mechanical-, thermal-, thermo-oxidative and photochemical stresses and lead to changes in material properties and process conditions. The stresses mainly occur at the reprocessing stage during shredding, washing, and extrusion.

The degradation mechanisms lead to several changes in the polymer behavior. A study, that addresses the effects of degradation was for example conducted by Jin et al., (2012). They showed the effects of extensive recycling on the properties of PE. With an increasing number of cycles, the mean molecular weight decreases for PE. This indicates chain scission because the shorter the average chain length, the lower the mean molecular mass. The molecular weight affects many other polymer properties such as viscosity. However, it is important to mention that the behavior of PE does not represents other polymers too. In fact, all polymers respond differently to recycling. While some tend to undergo chain scission due to heat and shear, other tend to crosslink instead.

However, the study of Jin et al. (2012) is idealized because it does not consider the use phase of the samples. The cycles of the study include shredding, melting, and regranulation while aspects that are linked to recycling such as mixing of polymer fractions, contaminations through waste or organic substances, aging during the use phase, or washing were neglected. So, the study shows the influences of reprocessing and not recycling. Moreover, it uses one defined material grade and thus neglects the effect of mixing differently modified PE grades.

To sum up, it can be said that sticking to the standards is not enough to close the loop on plastic packaging. Deeper competencies in polymer science are required to keep the product quality under control and to supply the industry with innovative approaches. Since it is difficult to prevent degradation, mixing, and contamination, a pragmatic suggestion from a recycler's point of view would be coping with these effects using special design from recycling principles (Ragaert et al., 2018, 528ff). An often-discussed attempt is sandwiching the recycled content between virgin surface layers to maintain the surface quality while simultaneously utilizing a significant amount of recycled material in the core. The feasibility of sandwiching contaminated PP between virgin material in transport boxes was already reviewed by Gall et al (Gall et al., 2021, 1ff). They concluded that not all product properties suffer under the use of recycled content and that the potential of this technique lies in design approaches, that include fracture mechanical methods. So, the feasibility and the limitations of design from recycling principles can be explored for potential applications.

The standards reviewed in this paper, help to organize the waste treatments and to establish a clear base for further developments, which of course is a key element in closing the loop on plastic packaging but not the only one. The consequent addition to the design for recycling-approach of the standards would be a design from recycling approach.

References to substances of concern within the standards

Material-toxicity can be described as a measure of a material's ability to harm living organisms. Establishing material-health, as the C2C standard terms it, means going for a saver product chemistry and thus reducing the harmful effects of the material. As such, material-health is the central element of C2C Design. Material toxicity or health must be discussed for plastics because various plastic products are suspected to contain substances of concern and researchers have already proven their presence and toxicological effects. For example, (Zimmermann et al., 2019, 11467ff) tried to benchmark the toxicological effects of several polymers used in consumer products like packaging using in-vitro-bioassays and nontarget high-resolution mass spectrometry. They detected baseline toxic effects in almost 3/4 of their probes. These toxicological effects can be endocrine disruption, steroidogenesis, neurotoxic, genotoxic, or oxidative stress etc. (Beach et al., 2013, 1613ff). But it appears that substances of concern are an uncommon topic among the analysed standards. In fact, in most of the standards, is the toxicological profile of substances not mentioned at all. At least some standards refer to regulatory standards like EuPIA (European Printing Ink Association 2020) or REACH (European Commission 2006). The guideline from Ceflex recommends eliminating the substances of very high concern according to REACH, the standards from RecyClass and FH Campus Wien recommend eliminating toxic printing inks according to EuPIA and the standard from the Ellen MacArthur Foundation generally recommends eliminating substances of concern. An exceptional case is the Cradle to Cradle Certified Product Standard. This standard is the only guideline in the analysis referring to a restricted substances list that was developed by the Cradle to Cradle Certified Products Innovation Institute itself. Apart from this framework, the topic of material toxicity is a general weakness of the analysed standards. With its focus on its purposive choice of materials and substances C2C can be regarded a specification of circularity. It must be discussed whether the topic of substances of concern is underestimated by the other standards or whether there are other reasons for the absence of the topic.

The strategy of Ceflex allows a prediction of a possible future scenario for plastics coming closer to the C2C concept. Ceflex perceives its current campaign for establishing a cyclable packaging design as the first phase of their two-phase transition strategy. Phase two shall be about improving the cycling strategies and getting rid of substances of concern in materials. Ceflex separated the phases because they need knowledge from testing programs that have just been started for the second phase.

Conclusions

This paper analysed current circular packaging design standards for their conclusiveness and practical relevance. The focus was on design elements, conflicts with the packaging functions, reductions and eliminations of formats, materials, and substances, and the technical feasibility of the recommendations. The analysis and comparisons showed that most of the candidates reach a high level of conclusiveness as they address a high number of relevant design elements. The preservation function turned out to face the most conflicts with the recommendations of the standards. It can be concluded that keeping the preservation function requires explicit attention to the redesigning of plastic packaging for a CE. Toxins in existing packaging basic materials is a minor topic of the standards. It is difficult to say whether the standards underestimate the importance of the topic or whether they lack knowledge because of the difficulties when accessing and assessing information on material toxicity. In any case, just following the standards is not enough to completely close the loop on plastic packaging. Polymers are complex materials whose performance depends on many influences. During processing, in particular, polymers are exposed to high shear stress and a high temperature. Both factors lead to degradation and negatively affect the polymer's property portfolio even if the package follows all design-recommendations of the standards. Of course, the standards help to control and organize the handling of waste, but to close the loop, further material and processing innovations in the field of plastic recycling are necessary. After these analyses and comparisons of packaging standards, the next step should be a collection and homogenization of the design-recommendations. This would result in a more conclusive and reliable packaging guideline. The key here is to connect design *for* recycling and design *from* recycling in a genuine design for circularity. Future guideline- and requirement standards might rather set focus on specific use cases of packaging such as guidelines for foils or beverage packages to provide unerring guidance. The to date voluntary standards could also be a valuable base for developing mandatory standardization on basic materials and additivation.

Not only knowledge should be harmonized, but also the waste treatment systems. Waste treatment systems are still different in many countries and consequently, the applicability of packaging design standards is locally limited. With a homogenous waste treatment system, giving recommendations that are internationally valid and at the same time precisely formulated would be much easier. Creating incentives for packagers to keep to the recommendations of the standards might also be helpful. The C2C Products Innovation Institute demonstrates that this incentive can be a product certificate for example. Also, governmental directives or the popularity of the standards among the consumers can be an incentive.

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